This extensive review was prepared by Dr Samit Kallianpur under the guidance of Prof Beena Rani Goel.

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REVIEW OF LITERATURE

The problems in the management of root perforations were discussed as early as 1893, when **Evans** found that root perforations “below the line of the edge of the alveolar process” were associated with rare chances of successful healing.

<u>Smale and Colyer (1893]</u> : stated that perforations occurred due to the misdirection of the dental burs, and that the instruments used during the removal of pulpal contents caused these defects.

<u>Guilford (1901)</u>: suggested that moist POP could be used, for sealing pulp chamber perforations, and zinc phosphate cement was recommended by him, over this, so that the POP could be kept in its place.

<u>Peeso (1903):</u> described the treatment modalities of perforations and stated that these defects had to be filled. He gave the following options…

a) ***Apical perforations:*** "fill as is", and if symptoms persist, then resection of the root would be the treatment of choice. That is, the tooth would have to be treated in a manner akin to that of an apical abscess.

b) ***Middle perforations*:** a softened gutta-percha cone could be plugged into the perforation after gauging the dimensions of the defect with a gutta-percha cone. Copper amalgam could also be used, for this purpose, and then, to seal the defect “taking care not to extrude the material into the periradicular tissues”.

c) ***Coronal perforations*:** these could be treated in a manner similar to the defects occurring in the mid-root region. For furcation areas, a tin or a platinum sheet could be used as a barrier, to cover the defect.

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Prior to 1965, several studies done on experimental animal models in Germany, by pioneers like **Euler (1925)**, **Kubler (1934)**, **Ruchenstein (1941)** and **Kaufmann (1944)** provided the guidelines for the contemporary management of perforations, during that era.

Several authors and investigators studied the effects of, and gave further support, towards the management of perforations. Some excerpts of their methodology, of management of perforations are presented herein…

Head (1904) : advocated the use of gutta-percha, platinum sheets as well as lead discs for the repair of root perforations.

Spaulding (1912) : claimed to have 36 years of experience in the treatment of root perforations! He stated that unless his treatment with the metal - lead, was used, middle and apical third of root perforations would be "almost fatal".

Upto 1972, studies done by authors, and researchers alike, [Grossman in 1957; Ingle in 1961; Nicholls in 1962; Taatz and Stiefel from 1965-1972; Lantz and Persson in 1965, 1967, and 1970; Weiselberg in 1969; Seltzer and associates in 1970; and Stromberg and associates in 1972] evaluated the periodontal response to root perforations from the furcation, upto the apex, in experimental animal models as well as in human subjects.

These studies formed the guidelines of root perforation management, during that period.

Over the next decade, studies done by Harris [1975, 1976], Sinai [1977], Oswald [1979], Tidmarsh [1979], Moreinis [1979], Holland and associates [1979], Wood and Salamat [1979], Delvanis and Goerig [1981], Lysell [1981], Martin and associates [1982], Jew and associates [1982], El Deeb and associates [1982], Trope and Tronstad [1985], Petersson and associates [1985], Oynick and Oynick [1985] Aguirre and associates [1986], Beavers and associates [1986], Benenati and associates [1986], Bramante and Berbert [1987], Biggs and associates [1988], served as guidelines, for the clinical management of perforation repairs.

These studies contributed much, towards the comprehension of the various parameters that could affect the outcome of a perforated tooth. More light was shed on the prognostic factors, and their ramifications on perforation management were better understood. The animal studies provided a broader view of the histologic aspect of root perforations, and the results obtained from these studies, have since been considered to be the strictest criteria in assessing the "success" or "failure" of perforation repairs, in that, true healing of the periradicular tissues could be gauged. Thence, histologic studies using the experimental animal models, became an integral part of the management of perforations.

Some excerpts--

Grossman (1957) : recommended the use of gutta-percha cones in order to plug the canals, and then fill the furcation perforation with amalgam. This procedure would prevent the amalgam particles from blocking the canals.

Nicholls (1962) : emphasized the fact that for a successful treatment of root perforations, irritation to the supporting periodontal structures must be either prevented, or eliminated, as the response of the periodontium, would ultimately determine the success or failure in the management of perforations. He advocated the immediate closure of such defects, if good results were to be expected. Grossman, Cohen and Burns had also agreed that time was an important determinant in the prognosis of perforations.

Taatz and Stiefel (1965) : suggested that small perforations of the pulp chamber could be treated with a calcium hydroxide cement, and then amalgam could be condensed over it. A well-condensed gutta-percha filling, on the other hand, could be used as an alternative, according to the authors.

Lantz and Persson (1965,1967,1970) : conducted experimental studies in dog teeth, and studied them clinically, radiographically and histologically. They created experimental perforations and instituted 5 modes of treatment, and found that histologically,

a) Perforations and canals filled immediately with chloroform rosin, and gutta-percha [under aseptic conditions) resulted in a favourable healing of the periodontal tissues.

b) When the perforation entrances were sealed with zinc phosphate, and then, chloroform-rosin and gutta-percha were used at varying time intervals, to seal the defect, favourable healing occurred.

c) The control perforations, which were left open to saliva, were associated with severe periodontal breakdown.

d) Zinc phosphate cement when used alone aseptically, also resulted in destruction of the periodontium.

e) When the defects were contaminated with saliva, and then sealed with chloroform-rosin and gutta-percha, a delayed but favourable healing occurred.

f) Perforations sealed with amalgam caused more irritation than gutta-percha, in every case.

Their radiographic study revealed that

a) Zinc phosphate cement was always associated with destruction of the supporting structures.

b) Defects sealed with gutta-percha were conducive to repair.

The investigators also showed that if the defect site was surgically exposed, and the over-extruded material was removed, then good healing resulted.

c) Perforations close to the bone margin [crest] were associated with irreversible bone loss.

Auslander and Weinberg (1969) : suggested that amalgam, soldered against a carefully burnished indium foil matrix, would "solidify into a single piece", without any detectable junction. They also added that if the defect is large, the over-extrusion of amalgam into the peri-radicular tissues could be prevented, by inserting this matrix.

The method was thus...

a) Dry the canal with alcohol and cotton pellets.

b) An indium strip, could be chosen, the size of which, had to be larger than the defect [so that its margins would be on the pulp chamber].

c) Reamers of suitable sizes could be placed, to maintain the full diameter of the canals.

d) The amalgam could then be condensed against the "resistant" indium matrix.

e) The reamers could be removed after the material had set, and the excess of the amalgam could be flushed out, to prevent blockage of the canals.

f) Now, the integrity of the pulp chamber "has been re-established with a leak-proof filling", according to the authors.

g) The authors also reported of no cases of irritation, or harmful effects, and stated that the tissues had "responded, and tolerated well", their technique of perforation repair.

Seltzer and associates (1970) : in their in vivo histological study on monkeys, found that the repair of perforations, depended on the location of the perforation and the time that had elapsed before sealing the defect.

The canals were filled with ZnOE and the controls comprised of perforated teeth that were left open to the oral environment. The investigators reported that the periodontium always showed damage, due to the perforations. The reaction varied from mild, to severe depending on how quickly the perforation was sealed, periodontal pockets were found in some cases, whereas chronic inflammation was always present. Sometimes acute inflammatory cells were seen and these indicated that the periodontal destruction was being continued.

Bhaskar and Rapparport (1971) : in their in vivo histological study in dogs, found that sealed perforations generally resulted in less inflammation. This was observed even after delayed closure of the wounds.

Stromberg, Hasselgran, and Bergstedt (1972) : followed 24 perforations cases repaired with gutta-percha and resin-chloroform, for a period of 1-8 years. They deemed 18 perforations as successful, and also added that coronal- third root perforations were least likely to heal. The basic reason for the poor prognosis associated with crestal perforations was the proliferation of the epithelial cell rests of Malassez along the entire periodontal ligament space. This hindered further bone deposition and prevented the healing and regeneration of tissues.

Harris (1975-76) : reported a clinical and a radiographic evaluation of 159 patients, in whom root perforations were filled with Cavit.

He claimed that around 90% of the cases were successful. The period of follow-up ranged from 6 months, to 10 years. He concluded that Cavit, was an adequate material, to seal perforation defects.

Weine (1976) : stated that surgical repair of a perforation defect, could be tried by raising a flap to the site of the perforation, and enlarging the area with a small preparation, in order to fill a temporary or a permanent material.

He also stated that in dilacerated roots, the chance of creating a false canal, tangential to the main canal, was always there.

Sinai (1977) : gave importance to factors like the location of the perforation ,the time elapsed from it's occurrence, to closure, the possibility of sealing the defect, and the accessibility to the main canal-all of which could affect the prognosis of a perforated tooth. He stated that in his experience, middle- third, and apically situated perforations were “less serious” than those which occurred in the coronal third of the canal, like perforations of the floor of the pulp chamber, and furcal perforations. The trauma of the perforation and the inflammation would rapidly produce an un-correctable periodontal lesion, with the development of a communication between the gingival sulcus and the pulp canal space. The location of the perforation, in relation to the gingival sulcus would produce inflammatory changes, and breakdown of the periodontium would occur. This could extend to the gingival sulcus, producing a deep, nonmanageable periodontal defect. The inflammatory changes could “probably” subside, if the defect could be treated before the periodontal breakdown occurred. He stated that perforations in these areas should be sealed immediately after locating the canals, and isolating the area. Further irritation, should be avoided, for quick healing.

The factor of time was associated with microbial contamination, in that the longer the defect remained open, the more prone it was, to pathogen ingress. In case of apical perforations, sealing of the defect could be done later, provided the area was protected from contamination. Moreover, the coronal seal, in between appointments would have to be maintained intact “under any circumstances”, until a seal could be achieved. Else, periodontal breakdown would occur.

If a perforation, say, in the coronal third of the tooth occurred during locating the main canals, a change in the anatomy of the tooth would increase the difficulty of locating the canal. If the main canal couldn't be located and treated endodontically, the apical end of the canal would have to be sealed directly using a surgical approach. The defect must then be sealed, for repair to occur.

If a perforation occurred in the vicinity of the apex, and if the apical end of the canal could be negotiated, it would be possible to fill the defect as well as the apical end. If this was not possible, the apical end could be left unfilled, and a surgical approach to either remove, or seal the unfilled canal portion could be considered if healing failed to occur.

Sealing of the defect, if not done, either due to its large size or due to inaccessibility owing to anatomic aberrations would render the prognosis questionable.

He gave 6 approaches to tackle the problem of perforations:

a) ***Perforations sealed along with routine endodontic therapy*:** This could be done by pressure, so that the obturating material could extrude into the main canal, as well as the perforation. This method could be employed in apically - situated perforations.

b) ***Perforations sealed as an additional canal***- diagonally extending perforations which reached the root walls, creating a "canal-like" effect, could be treated as an additional root canal in that tooth. Cleaning and treating this "second canal" in a routine manner could then be accomplished.

c) ***Perforations sealed with amalgam via the chamber*** – perforations that occurred during locating canals could be treated by creating a retentive preparation in the pulp chamber floor, in the region of the defect after protecting the patency of the canal orifices with paper points. Amalgam could be gently packed in the area, taking care to avoid extrusion of the material into the periodontal membrane. An indium foil could be used as a barrier, in large defects. This, apparently, would give a "good seal".

d) ***Perforations sealed using a surgical approach*** – In cases, where the defects were extensive, or wherein the apical end of a canal could not be negotiated, this option could be considered. Or, if a perforation occurred during post-space preparation, and a coronal approach was not possible, then the post could be prepared and cemented short of the defect. The area could then be surgically exposed, and the defect could be filled with amalgam. This approach could be used only in cases where other treatment modalities weren't possible.

e) ***Perforations repaired by stimulation of calcification***- Calcium hydroxide, in a paste form could be used in a cleansed, but dried canal. The procedure would have to be continued till the desired calcification occurred.

f) ***Apicoectomy, root amputation, or hemisection***- If the last few mm's of a perforation near the apex could not be treated by sealing, apicoectomy could be done, upto a point coronal to the perforation and the unfilled canal. In multi-rooted teeth and especially in surgically inaccessible areas, like the lingual surface of the mesio-buccal root of the upper molars or the distal surface of the mesial root of lower molars, root amputation or a hemisection could be done.

Sinai concluded that in most instances, satisfactory healing would occur, if a perforation could be treated.

Moreinis (1979) : emphasized on the preventive aspects of perforations and advocated a thorough pre-operative evaluation of good quality radiographs taken at different angles prior to gaining access. He stated that a bur placed on a prescribed area of the tooth, need not always lead into the pulp chamber [Ettinger 1968]. That a 3-dimensional perception was imperative in understanding the internal morphology of the tooth, was stressed upon by the author.

Angled radiographs could reveal the degree of cervical constriction, coronal asymmetries and disparities between long axes of the roots and the crowns. Furthermore, the presence of additional canals could be detected by exposing two angled radiographs - one with the central beam perpendicular to the facial aspect of the tooth, and the other, with a mesial or distal angulation of 15 degrees from the perpendicular.

In the posterior teeth, palpation of the bony eminences could determine the root position, and a bitewing radiograph could provide information regarding any crown malformations, or the degree of tipping, if present. He also stated that coronal landmarks like the buccal grooves on the molars could give clues to the direction of the roots.

An explorer could be used to provide information regarding the furcal anatomy, or an endodontic explorer could be used inter-proximally, and held flatly along the root surface both mesially and distally to guage the external anatomy of the root. He advocated taking the midpoint of the incisal edge or the cusp tips in canines or premolars, as an orientation point provided that uneven distribution of the coronal bulk or uneven wear of the cusp tip was not present. Else, misdirection of the bur could lead to a perforation.

A long- shank bur, would be helpful in such instances said the author.

He also stated that the crown and the root, anatomically had their own axes, and that these, may not coincide. In upper molars, the furcation between the 2 buccal roots was more prone to perforations, than the furcation between the mesiobuccal and the palatal roots. The dentist could locate the palatal orifice, prior to extending the access opening in a buccal direction. In the lower molars, the lingual aspect of the furcation was more prone to perforation, than the buccal aspect. Here, the bur would have to be directed towards the distal canal, which, in general, was the largest. The extension could then be done, in a mesial direction.

He further added that the bur must be lined up mesio-distally while viewing the tooth perpendicularly from the facial aspect. If severe cervical constrictions, tooth rotation, or absence of the crown were evident, the root-position and the dimension could be delineated by wedging toothpicks, interproximally- mesially, as well as distally.

In malposed teeth, the rubber dam could be placed after locating the pulp chamber. Frequent checks on the progress of the procedure, with x-rays taken from various angles would be helpful. The initial entry of the bur should always be directed towards the area of the greatest bulk of the crown, or toward the largest canal, or both, in multi-rooted teeth, was emphasised, by the author.

The author concluded that a thorough knowledge of the internal anatomy would be of the utmost importance, to attain success in endodontics.

Meister and co-workers (1979) **:** presented 5 cases in which perforations into the furcations of lower molars resulted in the loss of alveolar bone.

One patient was a 45- year old woman, in whom a furcation perforation had occured in the lower second molar, in the mesiolingual canal, during instrumentation. The tooth was not filled immediately, but it was sealed, and the patient was recalled at a later date. She had severe pain, which subsided after 2 days of medications. Instrumentation was resumed, and 6 weeks after the initial perforation, the canals were obturated with gutta-percha. A x-ray revealed material-extrusion into the furca. The patient was asymptomatic during this period. A sinus tract developed, and exudate was elicited, when the tissue was palpated. Probing revealed a defect on the buccal aspect, into the furcation area. Periodontal surgery was done, and at this time, a 7-mm pocket was evident on probing. The area was curetted after exposing the defect and the excess gutta-percha was removed. The flap was replaced, and 7 months later, re-evaluation revealed the presence of the defect. There were no symptoms, however. The tooth, at this time, was extracted and on examination, the defect had remained the same, and the investigators found that osseous filling had not occurred.

Another case was of a 52-year old man in whom endodontic treatment had resulted in a perforation into the furca, with gutta-percha extending into the defect, as well as an over-filled distal root. The alveolar bone was normal, in the furcal region. A 1 year recall x-ray revealed loss of the furcal bone, upto the apices of the roots! Gutta-percha placed into the defect on the buccal aspect went upto the apices of both the roots. Periodic swelling and purulence, were the only complaints. A vertical fracture was suspected, and surgery was scheduled. After flap elevation, the defect was curetted, and the bone loss was seen. Vertical fracture was not seen, but a perforation of the furcal wall was evident in the distal root. Excess gutta-percha into the furca was removed, and the flap was replaced. Three months later, the defect had not ossified, and hence, the tooth was extracted.

The third case was of a 47 year-old patient, recalled for his 6-month appointment. At the time of obturation, of the lower molar, a x-ray revealed bone loss in the furcal area, with gutta-percha extending into this area. There was severe bleeding during instrumentation of the mesiolingual canal. The canals were obturated after 3 months! A 6-month x-ray showed more bone loss in the furcal region. As the tooth was asymptomatic, no treatment was instituted. 1 year later, the recall x-ray revealed more bone loss. The patient had no complaint, but there was some drainage from the area.

A flap was reflected, on the buccal as well as the lingual aspects, as both these areas had probable defects into the furca. Curettage was performed, and the excess gutta-percha was removed. Bone contouring was done. Apart from the perforation of the mesio-lingual canal, a vertical fracture was also evident, of the onlay, into the furca. Amalgam extended through the fracture line.and the osseous defects were seen on the buccal as well as the lingual aspects. The flap was apically repositioned. The tooth was thus saved and the furcal area was open, to aid in proper cleansing of the area.

In the fourth case, a 27-year old woman, who had undergone endodontic treatment of a lower molar was recalled after 2 months for the placement of a post in the distal canal. A full cast crown was cemented, and 3 months later, the buccal tissue in the area swelled intermittently with minimal pain. The adjacent soft tissues were tender on palpation. Gutta-percha cone was inserted into the sinus tract that had formed, and it showed a defect at the mesial aspect of the distal root. Bone loss was seen in the furcal area. A flap was reflected, and the area was curetted, which showed bone loss on the mesial aspect of the distal root. A root perforation was evident. This was attributed to either the instrumentation, or the placement of the post [size 140].

The defect was cleaned, and the area was packed with $Ca[OH]_2$ and $BaSO_4$ paste, “with the hope” that osteogenesis might be stimulated. A 3- month recall revealed that the defect was probable, and gutta-percha was placed into the defect. There was no sign of bone regeneration! The patient preferred to retain the tooth, and didn’t want additional treatment at the time.

In the 5th case, a 27-year old patient had a perforated mesio-buccal canal, and the tooth was not filled at that time. The canals were obturated at a later date, and gutta-percha was forced into the furca. At a 6-month recall, a radiolucency was seen at the furcal area, and a 10 mm defect was probable. There was no complaint, but drainage was evident.

After raising a flap, the bone defect was seen in the furcation area. Most of the buccal plate was present, and so, the defect was curetted and the excess gutta-percha was removed. The flap was repositioned, and a re-evaluation was done after 3 months. The patient had no complaints, but a defect of 8 mm was probable. The gutta-percha was removed, from the mesio-buccal canal and the defect was filled with $Ca[OH]_2$ and $BaSO_4$.

3 months later, a re-evaluation check showed that exudate was still oozing from the defect which was still present, upon probing. Though the patient was asymptomatic, the tooth was extracted.

The authors concluded that perforations in the lower molars could result in alveolar bone loss, and that these areas were difficult to treat. The prognosis, according to them, was “questionable at best”, with conventional surgical techniques. They speculated that if the teeth had been filled immediately, at the time of the perforation, the bony defects might not have occurred that readily. Moreover, if Ca[OH]2 therapy had been instituted, bone loss might not have occurred.

Another consideration could have been packing gelfoam into the perforation, and building a matrix so that amalgam or gutta-percha could be packed into the canal, without it’s extrusion into the alveolar bone. Moreover, since all the cases were relatively asymptomatic, this could pose problems during diagnosis of the periodontal defect.

Oswald (1979) **:** stated that the long-term relationship of a perforation of the apical foramen to post-treatment healing was related to the overfilling of the repair materials. The size of the defect, the amount of the material extruded, the type of the materials used, and the feasibility of surgical repair- all these factors compromised the chances of healing. The larger the size of the defect, the more prone it would be, to exposure of tissue fluids, sealer wash-out, and leaching out of the residual canal debris. The amount of filling material that's pushed out, also affected healing, as none of the materials used, were "truly biocompatible", and the likelihood of significant inflammatory changes would be enhanced. Moreover some of the materials were better tolerated than other materials, by the tissues. Rigid materials could be removed intact, non-surgically, whereas pastes, sealers and thermoplasticized gutta-percha would be impossible to retrieve intact, if pushed beyond the apex. The feasibility of surgical repair was considered to be the final determinant of the prognosis. There would also be instances, in which surgical approach would not be possible due to anatomic considerations or other factors. Once an apical perforation was recognized, the author suggested its confirmation, with x-rays. If the file overextended, the discrepancy could be measured, and a new working length could be established ¾ mm from where the foramen was now expected to be.

A stop could be set on the next larger instrument, and reaming, upto the corrected working length could be done.

If this new length would be correct, then the dentine would be amenable to cutting, within the root structure. A larger file, when used, should not go apically, when pushed, according to the author. If the second instrument stops, then a larger file could be used with a reaming motion, till dentine was no longer being cut. The next step would be to revert to the smaller size file, to check for the maintenance of the stop. If the stop remained, then instrumentation could be completed. On the other hand, if the instrument goes past the working length, the length would have to be shortened by ½ mm. If an x-ray revealed that the file was at the working length, but no "stop"could be felt, ½ to ¾ mm had to be subtracted from the present working length and instrumentation with a larger file would have to be done, to this corrected length.

When the file no longer cut dentine, apical pressure would have to be applied, to confirm the presence of the stop. If the stop had been retained, then the apical canal would have to be reamed with a larger instrument. The smaller size instrument could then be inserted into the canal to see if the stop remained. If this didn't happen, an additional ½ to ¾ mm would have to be subtracted from the length of the instrument.

On the other hand, dentin filings could be packed close to the foramen, as long as the canal was clean.

The extent of the defect had to be gauged, prior to obturation with the same size of the file that had been used to determine the original foramen. Stops would have to be set on the larger instruments, beginning from the size that had been used to detect the perforation.

The first file could then be placed into the canal at the working length, and moderate pressure had to be applied, to check whether the file went past the working length.

This would determine the size to which the foramen had been enlarged.

To prevent overfilling of gutta-percha from the foramen, the canal walls had to be tapered, after which the foramen would be packed with dentin chips, prior to filling gutta-percha. Parallel walls of the canals, increased the chances of over-filling. In such cases, the canal preparation would have to be flared, to get some mechanical advantage. The apical 3 to 4 mm could be tapered, by “stepping back”. Following this, the mid-root and the coronal portions of the canal could be flared with H-files.

Though flaring improved material control, it did not totally preclude material extrusion, even if the foramen remained open to a No. 25 or a larger file.

The dentin chips would provide a “solid plug” in the apical segment and gutta-percha could then, be condensed without resulting in an over-fill.

The author found that dentine chips were well tolerated, and allowed for the deposition of cementum in some cases. However, there was no evidence that this phenomenon occured in non-vital teeth, according to him. Small foramen sizes, with divergent walls, could be plugged with 0.5 to 1 mm of dentine. In canals with relatively parallel walls, 2 to 3 mm of dentin plugs would suffice. The amount of dentine required would be determined by clinical judgment and testing of the dentin plugs, in different cases. After sufficient coronal filing, to ensure that clean dentin has been cut, a final irrigation would be done, and the plug could then be formed.

Peripheral filing of the coronal and the middle thirds of the canal with No.50 to 70 H-files would flare the canal, as well as provide the dentin chips, for the apical stop. The loose dentin could then be pushed into the canal, with a small plugger. This procedure would have to be continued, till resistance was met when a K-file that would bind at the working length would be placed approximately 1 mm from the original working length. A light tamping motion could be used, to condense the dentin chips.

The adequacy of the plug would have to be tested with a No.25 file, by tapping the plug with moderate pressure to check for any soft spots. The plug would have to be solid, and should not move, when tested with the No.25 file. Obturation could now, be done, after taking an x-ray with an instrument seated to the plug in order to gauge the level to which the gutta-percha had to be filled.

The importance of forming the plug immediately prior to obturation lay in the fact that in certain cases, delaying of the obturation resulted in partial washing off, of the plug. The obturation could be done with chemically or thermally softened gutta-percha, in which the size of the cone had an apical diameter that would be 2 to 3 sizes larger than the largest instrument used, to shape the canal. The cone would have to resist withdrawal at a point from 2 to 3 mm coronal to the plug. The trial cones would have to be trimmed, till this criterion was met with.

The sealer could then be mixed, and the apical 3 to 4 mm of the cone could dipped in chloroform, and gently introduced into the canal, and then removed, to examine the tip to ensure molding of the apical 3 to 4 mm of the cone.

The sealer could then be applied to the canal walls, and the cone could be re-seated with cotton pliers. Additional accessory cones could be then added, and a x-ray taken, to confirm the fit. Condensation could then be done.

Root perforations : In these cases, the prognosis depended on the un-instrumented and unfilled portion of the original canal apical to the defect. Generally, the instruments penetrated the canal at an oblique angle, and the defects would be oval shaped. A frequent problem with these defects was overfilling, or the lack of a good seal around the defect. This would cause an inflammatory response and percolation around the deficient filling and a persistent lesion would develop at the site of the defect.

Since intra-coronal approaches were "generally ineffective" according to the author, sealing the defect as well as the apical portion of the canal. Surgical accessibility determined the ultimate prognosis of these defects, the adequacy of obturation of the apical segment, the relationship of the defect to the crestal bone, and the epithelial attachment.

As alloys were used to repair most of these defects, visibility and a dry field were mandatory. Hence, perforations on the facial aspect could be more easily managed than those that occured in the lingual aspect, like in the lower molars. In such cases, amputation of the root, coronal to the defect would have to be done. If the defect would be close to the crestal bone, surgical access would require much of the bone to be eliminated. The trauma and the placement of the repair material close to the epithelial attachment "commonly resulted in the formation of a chronic periodontal defect" that extended to the apical margin of the repair material!

Functional demands of the tooth would also have to be considered, prior to undertaking surgery. For instance, a furcal perforation in a lower molar that was to be used as an abutment for a fixed appliance could not be repaired with surgical means with an alloy. Extraction, or hemisection, with a new bridge design would be prudent, in such situations. The similar condition in an intact arch, however, could be managed by amputation of the perforated root and then contouring the crown.

Hence, the decision for a surgical approach would have to be based on astute consideration of the periodontal condition, the ease of repair, and the projected functional demands.

For a successful repair of a perforation, the canal segment apical to the defect had to be clean and well obturated. The repair of the defect must not lead to a chronic deterioration of the surrounding tissues, according to the author.

Mid-root perforations could be repaired with a surgical approach after placing a silver point or a file in the canal, to act as a matrix, against which the alloy could be condensed, and also to prevent the alloy from entering into the canal while the repair was being undertaken.

After sealing the defect, the obturator would be removed, and then, the canal enlargement, and obturation could be done in one visit.

Another method of repairing mid-root perforations which were not surgically accessible, was by long-term Ca[OH]2 therapy.

Cervical perforations had to be repaired without preventing re-establishment of the epithelial attachment. These perforations were the most difficult to manage, due to the occurrence of periodontal breakdown. Perforations just apical to the intact epithelial attachment posed a delicate problem, as attempts at surgical repair would “most certainly” result in attachment loss. The author suggested Ca(OH)2, as it was the “best alternative available” at the time.

If the defect involved the attachment, the ideal means of repair would be the externalization of the defect, so that re-attachment could occur further apical on the root. An apically repositioned flap, after bone contouring and root repair, would move the attachment zone apical to the margin of the repair. Another option was orthodontic extrusion for supereruption, of the tooth till the defect would be coronal, to the attachment.

These methods were generally applicable to single-rooted teeth, and furcation perforations could not be managed thus. Short-term results could only be expected in such cases. Furthermore, if loss of alveolar bone had occurred, then a matrix, which would be needed to condense the repair material, would be absent!

Holland and associates (1979): instrumented the root canals of dog premolars, and created apical perforations in them, by enlarging the foramen up to a size 40, or a size no. 80 file.

The investigators then filled the apically perforated canals with calcium hydroxide, up to the foramen. 90 days later, the animals were sacrificed, and a histoanalysis was performed.

The investigators reported that their data revealed more favourable results in terms of tissue responses, when the canals were instrumented upto a size no.80 instrument.

Holland and associates (1979) : negotiated the root canals of dog premolars, and overfilled them, after intentional perforations were created. After 30 days, half of the teeth were re-filled upto the apical limit. The root canals which were left open to salivary contamination, served as controls.

After 90 days, the histoanalysis showed that more favourable results had occurred in the canals that were re-filled.

The investigators concluded that overfilling of the canals, with Ca[OH]2 elicited its resorption, and that the peri-apical connective tissue had proliferated into the canals.

Abou-Rass and associates (1980) : stated that the "anti-curvature" filing method, would maintain the original integrity of the canal walls, especially at their thinner portions [the "danger zones"] and thereby would reduce the possibility of root perforations, like stripping of the lateral walls. They also added that a good digital control over the endodontic instrument could be achieved. This method, of selective dentinal removal, that is, at the expense of the mesial root-dentin made the preparation of curved canals much easier, according to the investigators.

Abou-Rass and associates(1982) : in their *invitro* study, on 150 extracted molars, divided the teeth into 6 groups, of 25 teeth each. They prepared the canals up to a size no.30 file, and then used the nos. 2, 3, and 4 peeso drills, to produce a post-space in the canals. After each size of the drill, the canal thickness was measured at 2 places- the mid-portion of the canal [at a level 4mm from the canal orifice], and the apical portion of the canal [7mm from the orifice].

The mean thickness of all walls was determined, for each tooth, and the drill size was noted.

The investigators reported that –

a) the incidence of perforations and strippings of the root, was greater, on the distal aspect of the mesial roots, in lower molars, or,

b) On the proximal walls of the buccal roots of the upper molars.

Martin and associates (1982) : reviewed the management of perforations and presented 3 case reports of Ca[OH]2 therapy and stated that in the past, perforations were managed usually by extraction. The recent advances, in non-surgical management of perforation "showed promise" during the period, according to the authors.

They described the basic techniques of Ca[OH]2 therpy, for root perforations as-

a) The pulp chamber would be accessed, and the tooth would then be thoroughly instrumented, and irrigated with NaOCl.

b) If the patient had any acute inflammation, the problem would have to be resolved, prior to the starting of Ca[OH]2 therapy.

c) The defect could be sealed with cavit, and in the next recall, when the patient would be asymptomatic, the therapy is begun.

d) The thick paste of calcium hydroxide or barium sulphate could be mixed, either with CMPC, distilled water, metacresylacetate, or saline.

e) A file or a "jiffy tube" could be used to introduce the cement into the canal, and then obliterate the canal, and the perforation.

f) An amalgam carrier, could also be used, to place dry powder of Ca(OH)2 into the pulp chamber. Endodontic pluggers could then be used, to condense the material into the root canal space and the defect.

g) The procedure would be carried out without anesthesia, so that the patient would be aware of the condensation of the material.

h) The tooth is then sealed with a permanent restorative material.

i) In the anterior teeth, silicate cement, and in the posteriors, amalgam over IRM would be given. This could also keep an intact coronal seal between appointments.

j) Follow-up at 2 to 3 month- intervals could be advocated, to evaluate the condition clinically and radiographically, and thus, monitor the case.

k) As fluid exchanges took place at the perforation site, the paste would resorb, and hence it had to be replaced at periodic intervals.

l) Six months to 1 year later, the hard barrier could be felt. Since perforations healed in an irregular manner, gutta-percha filling technique could be used, in order to get a good adaptation.

m) In the 3 cases the authors reported, 2 lower incisor- perforations in one patient, which, at the 2- year recall period showed a radiographic and a clinical success.

n) Two pre-molars and one molar with the pulp chamber floor perforated were also presented, and all the cases showed healing radiographically, at 2- year follow-ups.

The authors concluded that –

1) Pulp chamber floor perforations in molars offered an increased prognosis when treated aseptically and immediately.
2) Perforations in the apical regions of the roots had a good prognosis, when the defects did not create any problems in keeping, the apical 2 mm of the canal unfilled.
3) Lingually located perforations had a poor prognosis.
4) Recent advances, in the use of calcium hydroxide, for the repair of perforations showed promise.

Weine (1982) : stated that the cases that were currently managed, would, in the past decade, have been considered "hopeless".

He said that in his experience, treatment of perforations with Ca(OH)2, had given poor results. He advocated immediate closure of the defect, and also added that though some defects remained normal, after treatment, for years together, but some cases had "suddenly developed" serious periodontal problems.

He preferred retaining perforated teeth that were surrounded by healthy, sound, bone!

Stress was also placed, on the later, occlusal rehabilitation, and the author cautioned against the usage of a perforated tooth, although treated, as an abutment or a bridge.

<u>Treatment of furcation perforations by packing the chamber</u> : according to the author, a defect created during the location or search of canals, could be easily treated by immediate closure of the defect , through the intracoronal approach, and this apparently had a good prognosis, provided the periodontal health and status of the patient was healthy or not compromised.

When a perforation is detected, and confirmed under atleast 2 x-rays, then a search for the missing canal could be done, and if the canal still remained elusive, then extration of the tooth or amputation of the involved root would be necessary.

In such cases or situations, the repair of the defect as such, was not indicated.

When the true canal is located, then all the canals are enlarged atleast to file no.25, upto the working length.

With an inverted cone bur, the coronal aspect of the perforation could be widened, to provide a retentive groove or a “lock”, for the sealing material.

Maintaining the canal patency with silver points, and then filling the perforation with a thick mix of ZnOE, could be done, by gentle but firm packing of the cement.

A larger portion of the material could be packed over it.

After the cement sets, the Ag points could be removed, and the canals could be enlarged slightly, to ensure patency.

Jew and associates (1982) : investigated the histologic response of the periodontium, to non- surgical repair of endodontic perforations which were sealed with cavit.

They used 36 teeth from 6 dogs for this *in-vivo* animal study.

The canals were first obturated, and some gutta-percha was seared off with hot pluggers, so that an apical plug of 3-4 mm was left in the canal, which maintained the apical seal.

The investigators then created experimental perforations in 31 teeth, for the test group, while 17 unfilled canals served as controls.

Pre-treatment x-rays were taken, for all the specimens.

The lateral perforations were created from the proximal aspect of the ligament, through to the adjacent periodontium.

This was done so that the defects could be visualized radiographically as well as histologically.

The perforations were sealed with cavit, and condensed with pluggers. Over extrusion of the repair material was not controlled in order to simulate a clinical situation.

A cotton pellet was placed into the pulp chambers of the control teeth. The access cavities were then sealed with a temporary crement and amalgam. Post-op x-rays were then taken.

The dogs were sacrificed after 1, 5, 30, 60, and 120 days and the histoanalysis was performed after a clinical, and a radiologic check.

The investigators reported that in the pre-operative period, the oral health of the dogs was normal, but post-op, the condition worsened.

Their histologic analysis confirmed this finding. Several teeth showed pockets, which confirmed too, histologically.

It was very difficult to prevent over-filling of the material, despite the best efforts of the operator!

The investigators concluded that :

a) Progressive destruction of periodontal tissues took place in the perforations near the oral sulcus.

b) Cavit, when used, to seal non-coronal perforations, would result in the fibrous encapsulation type of repair.

c) Any perforation, whether sealed, or unsealed, close to the gingival sulcus caused the proliferation of the oral sulcular epithelium, and negated thechances of repair.

d) Perforations located away from the sulcus, even when left un-filled, showed the most favourable response in terms of healing.

e) The root and cementum always resorbed, unless successful filling of the perforation was not obtained.

f) Cavit produced a mild, to a moderate inflammatory potential.

The investigators added that the coronal third perforations, which were unfilled, were associated with acute inflammatory reaction and the periodontal ligament was degenerated. Apically, fibroblastic activity and disorganization of the ligament cells was seen.

The alveolar bone adjacent to the defects had undergone vertical resorption. Besides this, the roots had undergone resorption at different points on the root surface, with few signs of repair.

Later, a communication between the gingival sulcus, and the defect, was seen and chronic inflammation was prevalent. Attachment loss had definitely occurred.

The alveolar bone was resorbed, and the replacement of it, was in the form of an irregular connective tissue stroma, which was loose.

At a later stage, severe destruction of the bone, along with epithelial proliferation was seen, and this had gone down to the apex of the root. The histologic picture was that seen in an abscess.

Cavit was associated with an acute inflammatory reaction. The periodontal ligament, near the material was intact, at the mid-root region. But, the collagen fibres were dis-organized and de-polymerized. The coronal portion, when perforated, showed the most intense inflammation, with hyalinization of the periodontal ligament, and severe disruption.

The authors also emphasized the fact that immediately sealing the defect, would give the most favourable prognosis [Grossman 1957;Lange (1958); Stromberg (1972), Sinai 1977; Frank (1974); Lantz and Persson 1965, 1967, 1970; Schwartz 1970; Bhaskar and Rappaport 1971; Seltzer and associates 1970; Grossman 1974].

Sorensen and Martinoff (1984) : stated that when a method of intra-coronal reinforcement is selected, say for instance, a post, hazards which could lead to the perforation of the tooth/root in the form of fractures. The authors attributed these outcomes to-

a) The induction of stresses in the root substance, while placement of the dowel.

b) The wedging action of tapered dowels, which could induce significant stresses internally, into the tooth.

c) Excessive removal of tooth substance, while preparing some room for the post.

d) The usage of self-threading pins, in endodontically treated teeth, could also result in perforations.

The authors added that using large diameter dowels, the strengths of which, greatly exceeded those of the roots, would decrease the prognosis, of clinical success, by ultimately causing a tooth fracture.

Aguirre and associates (1986) **:** determined whether the use of an indium foil matrix over amalgam would improve the healing response of the periodontal tissues, in the furcal areas., and compared it with the use of gutta-percha or amalgam alone, for the repair of iatrogenic perforations.

They studied 48 maxillary posterior teeth in 8 dogs for this in vivo experimental study. After the perforations were created in the furcal region they were immediately filled with the 3 test materials – Group 1 - amalgam, Group 2 - gutta-percha, Group 3 – indium foil.

All the coronal access openings were closed with amalgam. The dogs were sacrificed at 2 and 6 months respectively, and the tissues were prepared for histoanalysis.

Based on the clinical, radiographic and the histologic findings, the investigators reported that – a) amalgam and gutta-percha showed significantly better results than indium foil.

They concluded that the radiographic indiation of furcation involvement preceded the clinical evidence.

Prompt treatment of perforations close to the gingival sulcus did not necessarily prevent a periodontal communication from occurring.

The use of an indium foil caused a more unfavourable reaction than amalgam or gutta-percha.

The extent of inflammation diminished after 6 months to a mild degree in all the 3 groups. Gutta-percha showed the mildest degree of bone resorption at 2 months, and tended to be better than amalgam and indium foil.

Cemental and dentinal resorption were more frequently associated with the amalgam group, although in general, all the groups had this.

Their clinical results were similar to earlier studies, in that the sulcular epithelium migrated apical to the restorative material. When the perforation was close to the bony crest (Lantz and Persson 1970, Frank 1974, Sinai 1977, Jew et al. 1982, El Deeb et al. 1982).

Benenati and associates (1986) : presented the findings of a clinical study, using internally placed amalgam, or gutta-percha or amalgam, to repair iatrogenic perforations. They obtained 57 endodontic cases with perforated teeth, which had been treated with amalgam or gutta-percha. 52 teeth had furcation perforations, in the mid-root or the coronal third of the canals. Four teeth had perforations of the chamber floor, and 1 molar had a perforation in the apical- third of the root.

The teeth that had been repaired with amalgam, had their canals obturated by vertical condensation, with warm gutta-percha with sealer. The obturation was ended 2-3 mm apical to the defect. From that point onward, amalgam was vertically condensed, up to the canal orifice.

A wet mix of Durelon was placed over the amalgam repair, as a secondary seal.

In the teeth repaired with gutta-percha, the canals were obturated completely, including the site of the defect, with the same vertical condensation technique. Durelon was placed over these repairs, too.

All the patients were recalled at 3 and 6 months, for a clinical as well as a radiographic evaluation. Five cases that were initially determined to be failing were later treated surgically.

The investigators reported that –

a) The repairs done with gutta-percha had a 57.6% failure rate, and accounted for 73% of all failures.

b) 26% of amalgam failures were recorded.

c] 70% of all failures were involved with the extrusion of the repair materials, and 83%, among these were gutta-percha repairs.

The investigators concluded that the successes were more, than the number of failures with both the materials –amalgam and gutta-percha, even when the treatment was delayed by upto 60 days.

Amalgam was found to be superior to gutta-percha .

Gutta-percha repairs were most likely to fail, when the material extruded out of the tooth, and into the periradicular tissues.

The rate of success, according to the investigators, was not adversely affected by delay in treatment. All the 5 cases that had been surgically treated due to initial failure showed healing during the subsequent evaluations.

The investigators stated that there was no "comprehensive review of literature, dealing with root perforations", till then, and that there were neither any clinical studies, nor any studies which demonstrated predictable methods of repair, in adequate numbers.

The authors criticized Nicholls' classification, and said that his study on the treatment of perforations was based only on 29 clinical cases that had been repaired with ZnOE or amalgam.

They said that the teeth had not been differentiated, by the repair material, nor was any success rate presented by Nicholls!

They also added that Harris, who had evaluated 154 "successful" perforations that had been repaired by cavit, had not reported the percentage of cases that that needed surgery.

Moreover, he [Nicholls] had not considered a case to have failed, until after it had failed surgically. Neither the specified areas of the perforations, nor the location of the defects were included.

Stadler and associates (1986): studied the technical complications that could occur, during instrumentation of curved root canals, using either the filing, or the reaming motions.

They used 520 roots, with varying degrees of curvatures, and got them treated, by dental students under supervision.

The investigators found that treatment complications were associated mainly with severely curved canals [> 35°], or, in about 15% to 20% of molars.

The incidence of instrument fracture and lateral deviations from the original canal curvatures, were more frequent with the reaming method, whereas, over-filing and root perforations were dominant, in the group which used the filing technique.

They stated that if the files were used for canal enlargement, and the reamers are used for the final stages of the apical preparation, then the frequency of procedural accidents could be greatly reduced!

Bramante and Berbert (1987) : evaluated histopathologically, the effect of Ca(OH)2 with iodoform, and ZnOE, on the periradicular tissues of dogs, when used as repair materials for perforations.

They used 4 dogs, and 15 premolars were studied. After creating the experimental furcation perforations, the teeth were randomly divided into 2 test and 1 control group.

Grp 1- the perforations were dressed with an acqueous mix of Ca(OH)2 and iodoform.

Grp 2 – the perforations were repaired with ZnOE.

The dogs were euthanized after 90 days, and their teeth as well as the surrounding structures were prepared for histoanalysis.

The investigators reported that

a) the Ca(OH)2 and iodoform group had periodontal attachment destruction.

b) Areas of dentin and cemental resorption, presented a basophilic layer, indicative of hard tissue apposition, indicating that repair was underway.

c) An area of coagulation necrosis was seen, which extended uptothe bone or the periodontal ligament space.

d) Repair could also be seen in the resorbed areas of the bone next to the defect.

e) Cemental hyperplasia, as well as incomplete hard tissue barriers were seen, which allowed for the ingrowth of granulation tissues.

f) Ankylosis was observed in a few cases.

The most important aspect, that is, the sealing off, of the defect had not taken place.

In the ZnOE dressed perforations, a necrotic area was seen, under which severe neutrophilic infiltration was seen, and this led later, to an abscess formation.

Severe resporption of the supporting bone, almost upto the alveolar crest was seen.

No repair of the dentin or cementum had occurred.

Bone regeneration was not completed, and opened areas with bone resorption still persisted, in most of the cases.

The root perforations had not sealed, and even when it occurred, it was in the form of a bow-shaped barrier projecting towards the bone, and away, from the perforation!

The investigators stated that materials like gutta-percha, $Ca(OH)2$, $CaPO4$, and ZnOE had been suggested for the repair of perforations, and that these studies were based on clinical, rather than histoloogical observations.

In conclusion, the investigators stated that $Ca(OH)2$ and iodoform showed necrosis at the perforation site, and different levels of cemental hyperplasia.

ZnOE caused severe inflammation and abscess formation, along with the resorption of the alveolar crest.

The perforations near the gingival margins were more prone to epithelial proliferation.

Grossman (1988) : advocated the use of calcium hydroxide paste whenever possible for the treatment of perforations. The canals must first be located and their patency must be maintained by the insertion of files so that the orifices will not get blocked during the repair attempts. The files are removed only after the filling material sets.

Perforations must be treated by condensing a gutta-percha seal "that will not leak" and will not hinder the periradicular tissue repair.

Calcium hydroxide paste used over a period of several months was considered impractical by the author. Instead Dycal or Life (calcium hydroxide paste) could be packed into the perforation and allow to set. Amalgam could be then gently packed over the calcium hydroxide with a plugger.

The seal must be wiped with a cotton pellet to ensure adequate marginal adaptation. After setting of the amalgam, the free particles of the material should be washed away with an anasthetic solution.

For perforations in the anterior region the author advocated a similar technique, but if the perforation was in the middle third of the canal and the calcium hydroxide therapy had failed to induce a calcific barrier, then a file or a GP cone could be placed after accessing the root canal. A flap could then be reflected and the defect could accessed by the cutting of bone.

The perforation could be packed with amalgam against the instrument that is placed within the canal. The flap is then sutured and the root canal treatment is done in the routine manner.

If a palatally placed defect was present then a surgical access from the palate could be considered.

If the apical third of the canal was perforated and a periapical rarefaction was present, then a periradicular surgical procedure should be considered as an alternative. If the defect is close to the root apex, then the tooth could be treated routinely and monitored for healing. If it failed to heal and a surgical approach was not feasible, then the last means of saving the tooth would be intentional reimplantation.

Seltzer (1988) : stated that perforations often lead to failure of treatment since the materials that are used to seal the defects are "inherently irritating". Systemic factors also played an important role in determining success or failure of treatment. These factors, according to him are often overlooked.

The biologic aspects of the living tissues and the systemic factors that relate to the diagnosis and the treatment of diseases has to be understood, if optimal results are to be expected. He added that Cheraskin (1957) had categorized more than 200 systemic diseases, whose signs and symptoms are present in the oral cavity.

This possibility and the fact that disease = systemic substrate + local irritating factors, makes it more imperative to assess the medical and the dental history.

But, he emphasized that the presence of a systemic disease does not mean that it is a direct cause and effect relationship with the local lesion. Basically, since all the materials are irritants, cytotoxicity had to be expected.!

Biggs et al. (1988) : reported 4 cases of iatrogenic perforations with associated osseous lesions. They used different treatment methods which included surgical repair, non-surgical repair, and the combination of both.

The repair materials used by them were amalgam, gutta-percha and calciun hydroxide. The cases were recalled after 1 year and all were deemed to be successful, except the 1 that was repaired surgically.

Kvinnsland & associates (1989) : presented the etiology and location of 55 root perforations from a dental school clinic and related their outcome to the pretreatment conditions and the various procedures that were used to treat the perforations. The mean recall period was 3 years 5 months.

In this study, the maxillary teeth were found to be perforated 3 times more often, than the mandibular teeth (74.5% and 25.5% respectively). 47% of the perforations were due to endodontic treatment whereas 53% occurred during prosthodontic treatment. The buccal and the mesial root surfaces, as well as the mid-root areas, were found to be the most frequently perforated.

In 25% radiographic changes were directly related to the perforated areas. 28 perforations were repaired by orthograde fillings with gutta percha, and kloropercha N-O; 8 received a combination of the orthograde and the surgical repair. In only 3 cases a surgical approach was used. 4 cases received no treatment but, they were recalled and 12 perforations showed a size and a location, which were deemed hopeless for repair and were hence extracted.

5 failures of the primary orthograde treatment group later underwent surgical treatment, and were followed up for 3 years and 3 months.

The investigators concluded that the overall success rate in the primary treatment group of teeth was 56% while 36% became failures. 5 failures were retreated, and of these 4 became successful. The combined approach using the orthograde and the surgical repair of the perforations provided the most favourable outcome, with a 92% success.

The investigators also stressed on the importance of preventing this type of treatment complication. They stated that frequencies of root perforations during endodontic treatment or dowel preparation was about 3% [Bergenholtz et al. 1979, Kerekes & Tronstad 1979). They also added that only a few studies had dealth with long term results [Stromberg et al. 1972, Harris 1976). Since there was little consistency, concerning the treatment procedures and the criteria used for the evaluation of the treatment results it was difficult to compare the outcome of different studies. However, several investigators had reported favourable results after repairing root perforations.

According to these authors attempts to repair perforations exclusively with an orthograde technique were less predictable. The major problem with this approach was the inability to achieve a seal routinely in the canal and at the defect site without extruding considerable amounts of filling material into the adjacent periodontal structures. The mechanical trauma associated with the perforation compled with inadvertent tissue destruction may result from treatment procedures and could cause permanent periodontal defects. In this study 2 teeth with furcation perforations were successfully treated. However, the defects were not exposed to saliva, prior to treatment.

The authors also directed the use of a calcium hydroxide dressing in canals that were already exposed to saliva prior to the repair process, and thereby preventing the growth of granulation tissue [Beavers et al. 1986].

Andreasen, Rud & Munksgaard (1989) : examined the histological response of monkeys to a new roto end filling material – Gluma (dentin bonding agent) and a composite resin (Retroplast). They studied 2 monkeys, and infected the root canals of the canines and the incisors, and sealed the canals with a retrograde approach. 1 year later, the animals were sacrificed and the tissues were histoanalysed. The investigators reported –

2 out of 3 canines showed epithelial proliferation over the resected root surface, apparently originating from the incision, which had been placed very close to the level of the resection. In the third canine that was filled with composite containing tricalcium phosphate, there was not only the reformation of sharpey's fibers, but seen for the first time, was the regeneration of new cementum directly over the retrofilling material.

2 incisors were extracted, their apices were resected and a retrofill material was applied. The teeth were then reimplanted. In this way the epithelial interference could be avoided. After one year, both the teeth showed a narrow fibrous zone without inflammation opposite the filling material. The surprising finding that a composite could allow for the regeneration of the periodontal ligament and cemental deposition implied that a "new biologic material" was at hand. They added that experiments were currently in progress to characterise the necessary condition for cemental repair, upon composite when used as a retrograde filling material.

Foreman and Barnes (1990) : in their review of calcium hydroxide for perforation repair, stated that perforations of the root may be treated in a way similar to apical closure- a hard tissue barrier would accomplish this[Heithersay 1975, Zeigler and Serene1987].

That the success of perforation management lay in avoiding material extrusion through the defect, was also stressed upon by the authors [Bergenholtz and co-workers 1979; Stock 1987].

Cvek [1974 and 1981] had advocated CaOH for the treatment of horizontal root fractures. In such cases, it was difficult to retain the root filling within the coronal section of the root, as it would extrude into the fracture site. A dressing of CaOH left in place for 3-6 months could encourage soft tissue healing and possibly, abet mineralization at the fracture site. A barrier would then be formed, so that subsequently, a filling material could be condensed.

Hovland and Dumsha [1985] showed that there was no difference between the apical seals produced by CaOH- based materials, and those produced by Tubli-Seal.

Himel and co-workers [1985] had questioned the use of CaOH in treating root perforations, when they found that tricalcium phosphate provided a much better matrix against which an obturating material could be packed. Furthermore, lesser tissue destruction was associated with tricalcium phosphate.

The position of the defect, if in the coronal third, could lead to necrosis of the periodontal membrane after placement of CaOH [Beavers et al 1986].

They [Beavers et al] also emphasized the importance of an early dressing of the perforation with CaOH to prevent the ingrowth of granulation tissue, into the defect. This was attributed to the fact that fibroblasts of the periodontal membrane lacked the capacity to differentiate into odontoblasts, unlike the fibroblasts of the pulp.

Bone healing, along with the ingrowth of trabaculae into the perforation after 42 days, and reparative cemental deposition,as well as ankylosis was reported by these investigators.

Gordon and Alexander [1986] had investigated the rise in pH caused by the two Ca[OH]2-based sealers [Sealapex and CRCS], and they had found that it was not sufficient to produce beneficial biological changes.

Zmener and Cabrini [1987] found that when blood monocytes and lymphocytes came in contact with Ca[OH]2-based materials, adverse effects occurred. Zmenner [1987] also reported that the degree of leakage of Ca[OH]2-based sealers and Tubli-Seal was similar.

Kvinnsland and co-workers [1989] had also reported that the success rate for non-surgical treatment of perforated roots with CaOH was poorest in the cervical region. This was attributed to the proximity of the perforation to the epithelial attachment, leading to a permanent periodontal defect.

Sinai and co-workers [1989] in their study using the rat-model, had reported no significant differences between Ca[OH]2, and tricalcium phosphate when used for the repair of perforations. No bone formation was observed in the 30-day period of their investigation.

Pitt Ford and Rowe [1989] had reported that the Ca[OH]2 – based sealers were not different from the ZnOE-based sealers in terms of a successful outcome.

The basic setting mechanism of CaOH was by two methods-

a) The two-paste system in which the reaction between Ca and Zn ions with a salicylate chelating agent, is accelerated by water.
b) The single paste system wherein polymerization of a dimethacrylate occurs, by means of a light source.

One inherent problem in attempts in the listing of the proprietary setting- type materials according to their composition was the lack of consistency, in their formulation [Watts & Paterson 1987]. An example was Dycal, which had undergone considerable changes in the percentage composition of most of its constituents since it was introduced.

A problem with the manufacturing of the material was that it was difficult to establish a balance between the material-solubility and its therapeutic effect. The material had to be slightly soluble to exert it's therapeutic effect, but would not have to be very soluble, as it would tend to get washed away. The properties of setting-Ca[OH]2 materials were related to it's pH.

The ability of calcium hydroxide to dissolve necrotic material was reported by Hasselgren et al [1988]. Its action was similar to that of sodium hypochlorite, but it was less effective. However, its prolonged presence in the root canal, where it had a continuous therapeutic effect, had to largely compensate for this.

The pH was dependent on the levels of unbound calcium and hydroxyl ions that remained after the material had set, and it followed, that the egress of ions from the set material would lead to a reduction of its mass.

In conclusion, Foreman and Barnes stated that though Ca[OH]2 was not a panacea for all dental problems, the possibility of furthering it's applications in the future, was always there.

$Ca[OH]_2$ in its pure form, as well as in proprietary cements were of "particular value" in dentistry. The need for a lesser empirical, and a more scientific evaluation, of the mechanisms of it's effects and efficacy, was also addressed by the authors.

Sonat and co-workers (1990) : in their in-vivo study on dog teeth, compared the response of the peri-apical tissues, when the roots were filled with Sealapex or pure CaOH powder. They investigated the hard tissue formation after different periods of time – 7, 30, and 90 days.

They studied 56 root canals in 6 dogs, and after pulp extirpation the teeth were divided into 3 groups

a) Only gutta-percha.

b) Pure CaOH and gutta-percha.

c) Sealapex and gutta-percha.

The animals were euthanised at the specified time intervals and histo-analysis of the specimen was performed.

The investigators reported more pronounced hard tissue formation with Sealapex, than with CaOH or gutta-percha.

In the first group all sections showed a slight oedema and minimal inflammatory response at the apex. In some sections, pieces of gutta-percha were observed in the root canal space.

In the second group, some oedema, a few inflammatory cells and dilated vessels were present. Moderate inflammation was observed in some specimen. Continuity of the periodontal ligament was lost.

In the third group sealapex was observed in the root canal. There was slight inflammatory response of the periapical tissues. One case showed severe inflammation with an infiltration of lymphocytes and plasma cells.

At 30 days in the second group, a slight infiltration of inflammatory cells consisting predominantly of polymorphs and plasma cells, were seen.

In the third group the periapical tissues and adjoining bone were normal. Cementum and bone apposition and resorption were observed.

At 90 days, in the second group, areas of cementum formation were seen. There was ankylosis in one root. In one case there was over-filling, associated with an inflammatory reaction with a high frequency of macrophages.

In the third group healing was observed, and areas of cementum apposition were noticed, at the apex. The periodontal fibers were organised. Ankylosis was seen with one specimen. There was no inflammation observed in the specimen filled with Sealapex.

The investigators concluded that both Sealapex, and Ca[OH]2, encouraged peri-apical healing by cemental deposition, and that both the materials caused a chronic inflammatory reaction when the material extruded through the apex. Periapical healing was more pronounced with Sealapex, than in the other groups.

Dazey and Senia (1990) : compared the sealing ability of Tytin amalgam, Ketac-Silver, and Prisma VLC Dycal, in vitro. After access was gained, the roots of the extracted teeth were perforated laterally, and they were then repaired with the test materials. The teeth were then immersed in the dye, for 10 days. They were then sectioned, and the linear extent of dye penetration was measured. Their statistical analysis of the data revealed that the Prisma VLC Dycal group exhibited significantly less dye penetration than the other two groups. The investigators also reported that there was no difference found between the Tytin, and the Ketac-Silver groups in terms of sealability.

Pitt Ford and Roberts (1990) : examined the periapical tissue response when GIC was used as a retrograde filling material, when no other root- filling was present in the root canal system, and when root fillings were present.

They used 8 incisors from 4 monkeys for this in-vivo study. The pulps were extirpated and one canal in each pair was filled with laterally condensed gutta-percha immediately after canal preparation. The other canal was prepared, and left open to the oral environment. Apicectomies were done on both teeth in each pair, after 1 week and GIC retrograde fillings were placed. 5 months later, the animals were sacrificed and the tissues were prepared for histoanalysis. The investigators observed that all 4 teeth with out root canal fillings were associated with severe periapical inflammation, and bacteria were present in the interface between the root-end fillings and the dentine. The teeth with root canal fillings showed either minimal, or no periapical inflammation.

They added that adhesive retrograde root fillings were successful when the root canal was completely filled. But in the absence of a gutta-percha canal filling, they failed to provide a seal. The most likely reason for bonding failure was attributed to the action of microbes, and their metabolites, which could have destroyed the smear layer and the surface layer of the cement. The authors cited that if the root canals couldn't be accessed via an orthograde approach due to the presence of a post-restoration and cleaning the canal from the apical end wouldn't be possible, due to limitations in either the access, or bleeding tissues, or in the inability to use antiseptic solutions to irrigate the canals, the placement of a GIC retrograde filling would be additionally hindered by problems in handling the material and moisture contamination on the setting cement. In conclusion, the investigators stated that though GIC was biocompatible as a retrograde filling material, it had its limitations in handling properties, and it's bonding to dentin failed in the presence of infection.

Balla and co-workers (1991) : examined histologically, the tissue response, to experimental furcal perforations immediately treated with tricalcium phosphate and hydroxylapatite, and compared the results with those that were treated with amalgam and Life.

They selected 120 premolars in 6 monkeys, for their in-vivo study.

The perforations were created and each of the 4 repair materials was randomly assigned to one quadrant of either the upper, or the lower teeth and the defects were repaired. Amalgam was used to seal the pulp chambers and the access openings.

The animals were euthanised after 2, 4, and 6 months respectively, and a histoanalysis was performed.

They found that in the teeth repaired with tricalcium phosphate, the periodontal tissue reaction was severe, and the defects were prevalent with epithelial and chronic inflammatory cells at the 2-month period. Bone resorption was also reported. The inflammation reduced to a milder reaction, as the time period increased. No hard tissue deposition was seen.

One case of a very severe tissue response was seen at the 2-month period with hydroxylapatite, and this reduced along with the passage of time and a favourable response was observed. Bone tissue, however, did not form.

The tissue response associated with Life, was similar to that seen with hydroxylapatite- no hard tissue formed.

Amalgam was associated with a severe tissue response in one specimen, at the 2- month interval. The defect was lined with epithelium having inflammatory cells.

At 6 months, the perforation defects were filled with fibrous connective tissue and exhibited bone resorption with minimal inflammation.

The investigators concluded that complete healing of furcation perforations did not occur during the 6-month experimental period, when they were immediately treated with tricalcium phosphate, hydroxylapatite, amalgam and Life.

Insertion of fibrous connective tissue into any of the repair materials was not seen.

They also added that the layer of stratified squamous epithelium was not “healing”, which, in its true sense, would show repair with connective tissue attachment, and not epithelial adhesion to the root surface.

The authors reasoned that the biodegradable ceramic of tricalcium-phosphate and alloplastic hydroxylapatite had shown promising results in periodontal therapy, as they were bio-compatible [Getter and co-workers [1972], Levin and co-workers [1974], Kent and co-workers [1980], Rabalais and co-workers [1981], Martin and co-workers [1982], Frown and co-workers [1982], Moskow and Lubarr [1983], Himel and co-workers [1985], Roane and Benanati [1987].

The authors added that materials such as Cavit, phosphate cement, zinc oxide-eugenol, zinc oxide-eugenol and amalgam, calcium hydroxide, and gutta-percha and indium foil had been used to manage furcation perforations. So far, none of the materials had offered a predictable prognosis, for the repair of furcation perforations. Migration of gingival sulcular epithelium apical to the defect frequently created the most serious barrier to the healing of furcation perforations. The ultimate goal, according to these authors, of the treatment of perforations was to maintain or re-establish the damaged attachment apparatus. This was impossible to achieve, with the above mentioned materials.

Clinical studies had indicated that endodontic perforations could be successfully treated with conventional means [Jew et al 1982, Harris 1976, Martin et al 1982].

Histologic studies, on the other hand, demonstrated unfavourable tissue responses at the treatment site [Petersson et al 1985, El Deeb et al 1982, Bhaskar & Rappaport 1971, Lantz & Persson 1967].

Clinically "successful" fucation repairs could have perforation defects lined with epithelium, which could not necessarily be detected by pocket probing.

Petersson et al [1985] had shown the frequency of periodontal pocket formation increased with increased observation time in experimental root and furcation perforations.

Gutmann and Fava (1991) **:** demonstrated a case of 2 incisors, wherein radiographically, a favourable tissue response was observed with the use of Sealapex. This was seen even when the material extruded beyond the apex.

Dissolution of excess sealer in the periradicular tissues with subsequent osseous repair was reported. The dissolution was seen 4 months later, and a decrease in the radiolucency was also noted.

At a 12 month recall, there was a significant and a similar reduction in the size of the radiolucencies , and the patient was asymptomatic.

The authors inferred that the macrophage debridement process, and the possibility of residual sealer particles, apparently did not affect the course of the periradicular healing and bone repair. They also felt that a favourable response was based on multiple factors like canal cleanliness, the nature of the sealer and it's physiologic effects on the surrounding tissues, the seal of the canal system, and the host response.

In conclusion, the authors added that depending upon the nature of the sealer and cleanliness of the canals, either a productive or a destructive response would occur in the periodontal tissues.

Roth (1991) **:** investigated the use of various glass ionomer cements for retrograde root filling from the point of view of sealing qualities, ion release and ease of application. The sealing qualities of the material were tested by dye penetration and microscopic and SEM examination. Fluoride and silver ion release tests showed an initial loss of these two ions from the glass ionomer cement. A modified system for mixing and application was developed for the purpose. Dye penetration did not differ from that of controls using vertically condensed gutta-percha. He concluded that glass ionomer cement is possibly a clinical alternative for the sealing of retrograde cavities; however, the silver-reinforced materials may cause tissue irritation from release of silver ions and their corrosion products.

Gutmann (1992) **:** emphasized the fact that "sterilization" of root canals, was a myth [Shovelton 1964; Rowe and Binnie 1977; Bystrom and Sundqvist 1981; Martin 1987], and that all root canal fillings leak! He added that a thorough cleaning and shaping were of paramount importance, if success of treatment was to be expected. Moreover, bacterial contamination, which was considered to be the most common cause of failure in endodontics, was not the only reason - significant immunologic and inflammatory components [host factors] were also involved [Seltzer and Naidorf 1985; Bergenholtz 1990]. The biologic interaction of the living tissues was too complex to fathom, and at times, said the author, failure may occur even if a "proper" treatment had been meted.

A proper diagnosis along with thorough knowledge would have to be integrated into a repair-predictive, treatment–oriented approach, to case management. A diagnosis based on the treatment designed to ensure reasonable healing of the periradicular tissues, would result In a favourable outcome

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Multiple integrated factors were involved in the identification of the source of any problem.

He further gave the criteria for the assessment of success or failure, as indicated by the American Association of Endodontists [AAE] in 1987. These criteria, enabled the clinician to classify patients into any 1, of the 3 categories like...

A) <u>CLINICAL SUCCESS</u> :

a) No tenderness to percussion or palpation.

b) Normal tooth mobility.

c) No sinus tracts or integrated periodontal disease.

d) Tooth in function.

e) No signs of infection or swelling.

f) No evidence of subjective discomfort.

B) <u>CLINICAL FAILURE</u> :

a) Persistent subjective symptoms.

b) Reccurent sinus tract.

c) Predictable discomfort to percussion or palpation.

d) Evidence of irreparable tooth fracture.

e) Excessive tooth mobility, or periodontal breakdown.

f) Inability to function, on tooth.

C) <u>CLINICAL QUESTIONABLENESS</u> :

a) Sporadic, vague symptomologies, which often could not be reproducible.

b) Low-grade discomfort to percussion and palpation, or discomfort on chewing.

c) Superimposed sinusitis with a focus on the treated tooth.

D) <u>RADIOGRAPHIC SUCCESS</u> :

a) Normal or a slightly thickened periodontal ligament space [<1mm].

b) Elimination of previous rarefaction.

c) Normal lamina dura in relation to adjacent teeth.

d) No evidence of resorption.

e) A dense 3- dimensional obturation of visible canal space, within the confines of the root canal space extending to the cemento-dentinal junction [approx. 1mm from the anatomic apex].

E) <u>RADIOGRAPHIC FAILURE</u> :

a) Increased periodontal ligament space [> 1 mm/<2mm].

b) Stationary rarefaction, or evidence of slight repair.

c) Lack of lamina dura formation or a significant increase in osseous density in the periradicular tissues.

d) Presence of osseous rarefactions, where previously none existed.

e) A visible patent canal space, which was unfilled, or represented voids in obturation of the canal.

f) Excessive over-extension of the filling material with obvious voids in the apical third of the canal.

g) Active resorption coupled with other radiographic signs of failure.

F) <u>RADIOGRAPHIC QUESTIONABLENESS</u> :

a) Increased periodontal ligament space (>1mm/<2mm).

b) Stationary rarefaction, or evidence of slight repair.

c) Increased lamina dura in relation to adjacent teeth.

d) Evidence of resorption.

e) Voids in the density of the canal obturation, especially in the apical third of the canal.

f) Extension of the filling material beyond the anatomic apex.

Recall evaluation had to be done for a minimum of 4 years, especially in "questionable" cases.

G) <u>HISTOLOGIC SUCCESS</u> :

a) Absence of inflammation.

b) Regeneration of periodontal ligament fibres adjacent to, or inserting into healthy cementum.

c) Laying or repair of cementum, with new cementum into or across the apical foramen [rare].

d) Evident osseous repair with healthy osteoblasts surrounding the newly formed bone.

e) No resorption and previous areas of resorption which demonstrated cemental deposition.

H) <u>HISTOLOGIC FAILURE</u> :

a) Moderate to severe inflammatory infiltrate.

b) Lack of osseous repair.

c) Concomitant resorption, of the surrounding bone.

d) Active cemental resorption with no evidence of repair.

e) Presence of zones of necrotic or foreign tissue remnants.

f) Presence of granulation tissue and possible epithelial proliferation.

The author added that if the retention of the tooth, in an asymptomatic clinical function was the goal of endodontic therapy, according to Seltzer [1988], then several cases could be classified as "successful", based only on clinical criteria.

The concept of "adequate clinical function", which was apparently a more "realistic" term, according to Seltzer [as the retention of the tooth in function was the "ultimate goal" of endodontic therapy), was actually not so. If this was the case, then only the clinical criteria could, and probably did, satisfy the means of many patients as well as practitioners.

However, success or failure, according to Gutmann, must maintain a “middle-ground” in which clinical, radiographic as well as the histologic factors must be integrated, so that the ultimate disposition, and the implications on the tooth in concern, could be recognized and accepted by all concerned. The clinician must, however, determine what is in the best interest of the patient.

Lemon (1992) : presented some techniques to improve the long term prognosis for several types of perforations which would “reduce the need”, for surgical repair.

He described some microsurgical methods for the non - surgical management and repair of inaccessible strip perforations, using a fiberoptic imaging technology, which was being adapted for use, in dentistry.

The internal matrix concept, which was similar to G.V. Black’s Class II cavity preparation, was used by Lemon.

The rationale was that a matrix was needed, to control the material and thus prevent overfilling or the extrusion of the repair material into the periradicular tissues.

Requirements of an internal matrix :

a) It must be biocompatible, since it cannot be removed after placement.
b) It must be sterile, or be easily sterilized.

c) It must be easy to manipulate within the root canal system.

d) It must stimulate bone formation [DFDB, and CPC's like tricalcium phosphate and HA].

The author preferred HA, due to it's handling characteristics. Commercially available as a 40 - 60 mesh size, it could be used for accessible perforations, which were more than 2 mm in diameter. For a smaller defect, the mesh could be milled, to a smaller size.

The author stated that several materials met the criteria for sealing the defect, like amalgam, cavit, ZnOE, gutta-percha and sealer. But none of these materials could overcome contamination with hemorrhage, as well as overfilling or underfilling.

<u>Technique for placement of the matrix</u> :

a) **Tooth preparation**- since a perforation usually would occur prior to obturation, the defect had to be sealed first, so that cleaning and shaping procedures wouldn't be compromised. Moreover, sodium hypochlorite couldn't be used and bleeding would contaminate the root canal filling materials.

After attaining hemostasis, files or silver cones or gutta-percha points could be placed in the canals, to maintain their patency.

b) The HA particles had to be wet lightly with saline, and blotted – the particles would "clump together", and would allow for easy transportation.

c) The Prima Endogun could be used as the carrier device for maximum control of the matrix material. This device had a curved, or a straight tip, for this purpose.

d) The particles of HA could be deposited into the perforation, and condensed into the periodontal defect with pluggers. This would also stop bleeding.

e) The process had to be repeated until the defect was completely filled with HA.

f) Excess material would then be removed with an excavator, to the level of the periodontal ligament.

g) Saline irrigation and drying followed, for good visualization of the area.

h) A bur could be used, to prepare the perforation site to receive the material.

i) Since overfilling or underfilling could be prevented, the technique sensitivity of the repair material would be "reduced", according to the author. Amalgam or GIC were recommended as repair materials, over the HA matrix.

Indications :

1) Accessible perforations, below the crestal bone approximately 1 mm or larger.

2) Large perforations in the middle or the apical third of roots with straight canals.

Contraindications :

1) Inaccessible defects to matrix placement, like strip perforations

2) Perforations on the external root surface at or above the level of crestal bone.

Evaluation :

1) Generally, post-op symptoms would be mild and limited to gingival soreness and bite sensitivity.

2) Analgesics and/or antibiotics could be prescribed.

3) The occlusion could be relieved

4) A monthly recall could be scheduled.

5) Only gentle perobing had to be done during the initial weeks of the recall period.

6) If a sinus tract formed in the attached gingiva, then the prognosis would be more favourable than a communication through the furcation.

7) If no pocket developed, then the treatment could be deemed as a “success”.

8) If a pocket had been present then it's closure or it's reduction in depth, would indicate success.

9) If bone formed within 3 – 6 months, the procedure could be deemed as a success.

Drawbacks :

a) The internal matrix cannot be used in all cases. The defect would have to be directly accessible.

b) Radiographic evaluation of bone fill was difficult, as the radio-opacities of HA and bone, were similar.

c) The procedure required a special device for the placement of the matrix material- utilizing the "fiber-optic imaging technology".

The author added that currently, research was solving the problems of visibility, accessibility, maintainence of canal patency, and the problem of the placement of the repair material.

A small fiber-optic probe [0.69mm] that could be inserted into the root canal system to allow for the visualization of the internal canal anatomy, including the perforation, was being developed. This would enable the operator to view the procedure, on a colour monitor.

A syringe delivery system was also developed, for delivering a much smaller particle size [50 μm) of HA. This could be used in conjunction with the imaging system [as conventional instruments were too large). The smaller particles, would be easier to wash out with saline. However, maintaining canal patency was still a "tricky aspect", needing an innovative approach, according to the author.

He concluded that microsurgical techniques were being developed and researched, which would allow for the non-surgical repair of inaccessible perforations, thereby declining tooth mortality.

Bakland [1992) : stated that pulp chamber floor perforations had to be sealed as early as possible. He advocated the use of a material with minimal irritation. For furcal perforations, amalgam or cavit, was suggested by the author as repair materials.

The method was thus –

A] Attach a little ball of cavit to the large end of a paper point.

B] The point could then be used as a plugger. The preparation had to be dry, prior to the placement of cavit.

C] Alternatively, a small ball of amalgam could be placed with a paper point. A small depression at the end of the point to hold the amalgam would have to be made. The point would not push the amalgam out of the defect. The material could then be tampped with the end of the paper point.

D] If bleeding had to be arrested cavit could be used as a barrier to control it.

E] Amalgam would then be placed on top of the cavit. Coronal perforations, according to the author, were usually inaccessible and extrusion of material in that area was quite common. For a continuous, diffuse perforation $Ca[OH]_2$ could be applied in the canal to arrest the bleeding as well as to dry the canal. A large access opening was advocated, to enable the operator to visualize what was being done.

A small apical perforation could be repaired with sealer and gutta-percha, as done in any routine endodontic treatment.

Perforations in the apical half of the tooth provided the best prognosis. However, these defects were often impossible to negotiate. Moreover, re-entering the original canal after laterally perforating it was difficult. Gutta-percha and sealer “work well” in sealing the apical area, according to the author.

On the other hand, dentin powder, $Ca[OH]_2$, or HA powder could be used, as repair materials. The dentin powder could be made by running a Gates-Glidden bur, in the coronal portion of the canals. Gutta-percha pluggers could then be used, to pack the powder into the defect. All the three materials "worked well" according to the author, in creating a physical barrier against which gutta-percha could be packed.

A $Ca[OH]_2$ intracanal treatment for 6 months, would stimulate a fibrous repair and could usually retain condensed warm gutta-percha. This, according to him, was a useful technique for larger lesions. Surgical repair of perforations could be done, in case a post was present. But, cautioned the author, amalgam placement would have to be avoided if a cast gold post was present, or else galvanic corrosion could occur.

IRM, or EBA cement could be used as a retrograde filling material, in cases wherein metal was present, within the canal.

These materials however, dissolved with time and hence, ultimately no repair would be permanent, as “all the presently available materials will either washout, dissolve or corrode over a span of time”.

Amalgam repairs would generally be rough, but unless symptoms developed, it would be better not to surgically smoothen the restoration, as more problems could be created, than being solved.

A communiation between the sulcus and the lesion had to be surgically corrected, as otherwise the prognosis would be hopeless.

The author concluded that perforations were “facts of life” in endodontic treatment and although there were ways to minimize the chances of their occurrence, procedural mishaps per se, were generally unavoidable. If a perforation occurred, “do your best to repair the situation”.

<u>Frank & associates [1992]</u> : felt that although surgically placed amalgam fillings were successful on a short-term basis[1-2 years], the long-term prognosis may not be as favourable. To test this hypothesis, as many patients as could be contacted, who had been

treated by the authors, prior to 1981[10 years, or earlier], were recalled and evaluated. Excluded from this study, were cases for which failure could be attributed to any reason, other than failure from the amalgam retrofill. Hence, all the cases included had to demonstrate periapical healing prior to ultimate breakdown.

The patients were asked to return to the authors' respective offices, and 1 or more radiographs were taken. A thorough soft tissue evaluation was also performed. If a patient could not be contacted directly, the referring, or a subsequent dentist was contacted, and a radiograph which was atleast 10 years old post-op, was requested from the dentist, for substantiation and the prevailing condition of the tooth was reported. In cases wherein the teeth had been extracted, the reason for the extraction was obtained, along with the pertinent x-ray. Other patients were evaluated in a similar manner, when they had returned for endodontic treatment on another tooth.

Success was based on the presence of tooth comfort, function, the absence of any clinical symptoms, as well as the absence of any radiographic pathosis. Fibrous scars, were also deemed to be successful.

On this basis, 60 of the 104 teeth [57.7%] were considered to be successful and 44 teeth were deemed as failures [42.3%].

The failures were categorized by the authors, either in terms of tenderness of the tooth, the formation of a chronic sinus tract, the development of a periapical radiolucency, or by tooth mobility.

The authors concluded that the long-term success of the amalgam retrograde filling procedure was approximately 60%, [from 104 teeth, of 96 patients] averaging 15.1 years after surgery. Three teeth were associated with a fibrous scar, while 44 teeth [42.3%] were deemed unsuccessful, averaging 11.9 years years after surgery.

Many failed cases were re-treated with materials other than amalgam placed apically, and a few of these teeth indicated that healing was underway.

The authors felt that this percentage could have been increased by variations in of some of the procedures involved, in the apically placed fillings. Moreover, as 42.3% of failures had to include atleast 1 x-ray which demonstrated complete healing, prior to breakdown, the authors stated that all of the cases included in the present study would have been considered to be successful at one time or another, by several observers.

So, clinicians who relied on short-term success rates as indicated by the initial healing of radiographic lesions, could have been wrong, in their assumption that no other problems would occur after the initial "successful" treatment.

The authors criticized the report that had been described by Grung et al, who had quoted a 65.2 % success rate with "retrograde fillings." Though the follow up period of these investigators had extended from 2 to 8 years post-op, the average period came upto around 2.3 years only. Recalls, in most of the cases had been stopped after 1 year, if healing was evident.

The authors of the present study stated that provided their investigation was accurate, some of the cases done by Grung et al would surely breakdown later

They added that alternative materials had to be considered, to replace amalgam, as the filling material of choice. Re-treatment via the orthograde approach had to be given the first priority, and this would hold true, even if surgery was anticipated as curettage, or apicectomy could be performed into a well-filled canine.

The authors speculated whether the failures were due to amalgam, as the apically placed material or whether similar results could be obtained, if alternative materials were used.

Alhadainy and Himel (1993) : compared the sealing ability of LC-GIC and LC-CaOH, versus chemically cured GIC and CaOH, when placed in furcal perforations in vitro.

They used 70 extracted molars out of which 60 were used in the experimental groups. After creating the perforations, the teeth were randomly divided into 4 groups, of 15 teeth each.

Grp 1 - 15 defects were sealed with LC-GIC, and obturation of the canals, was performed.

Grp 2 - 15 defects were repaired with LC- CaOH, and the canals were obturated.

Grp 3 - 15 defects were with chemically cured GIC.

Grp 4 - 15 defects were repaired with chemically cured CaOH.

All the defects were repaired with a stereomicroscope (x10), and the access cavities were sealed with LC-composite resin.

Moist cotton pellets were placed passively between the roots in the furcal areas, and all the pulp chambers and access preparations were filled with LC- composite resin.

The teeth then spent 10 days in 2% erythromycin B dye, at room temperature. They were then sectioned parallel to the long axis, and examined under a stereomicroscope(x40) for the evaluation of leakage(blinded).

Their statistical analysis of the data revealed that LC materials allowed statistically significant less dye leakage, than the chemically cured materials. Controlling the extent of the material extrusion was difficult and each material showed 9 teeth with overextrusion of material. Dycal (chemically cured) showed under-extension in 11 defects. This extrusion adversely affected the leakage, and it would also hamper healing, if used in-vivo.

The investigators concluded that the light-cured materials provided a better seal than the chemically cured materials and that they could show promising results in the treatment of furcation perforations. The flow of the material was an important factor that controlled the extrusion of the repair material. The repair material must have enough flow to obturate the defect and seal the apical end of the perforations.

The flow of the material is an important factor that controls extrusion. The material must have enough flow to obturate and seal the apical end of the perforation.

If a technique for treating these defects of pulp chamber floor were perfected, many teeth could be saved. There is no ideal means of repairing perforations. Cohen & Burns (1980) found that in the non surgical repair of perforations, the defects acted like "Bottomless pits" and the material control was a major difficulty.

ZnPO4, GIC, Indium foil and amalgam, amalgam without surgery, cavit, gutta-percha, CaOH, tricalcium phosphate, teflon disks, dentin chips and HA have been used to repair perforations but all these materials were associated with varying degrees of success.

There was no in-vitro study which compared the leakage of the filling materials used to repair furcation perforations.

The prognosis, according to the authors depended on the size and location of the defect, length of time that the defect was open to the environment and the amount of periodontal ligament irritation.

The choice of the repair material was important, as the prognosis is affected by material biocompatibility and its ability to provide a hermetic seal.

Pecora and Andreana (1993) : recommended the use of the dental operating microscope(DOM) in endodontic surgery, as it enhanced and facilitated each phase of the procedure. They performed 50 apicoectomies, with or without retrograde fillings. For clinical evaluation, cases treated with the DOM were compared with cases treated without it. Their post- operative evaluation revealed a reduced incidence of symptoms in the cases treated with the DOM.

The authors also stated that the usage of the DOM had been suggested by Baumann (1977), Apotheker and Jako (1981), Apotheker (1981), Hume and Greaves (1983), Linares (1989). In Endodontics, the use of the DOM had been reported by Baumann (1975) , Selden (1986, 1989), Bellizzi and Loushine (1990).

In conclusion, the authors added that the usage of the DOM lead to changes in surgical procedures and improved the performance of the procedure and most likely, the success rates of endodontic therapy.

Lee and co-workers (1993) : compared the sealing ability of MT aggregate with that of amalgam and IRM, inexperimentally induced lateral perforations in vitro. They used 50 extracted molars, and after creating the perforations from the mesial canal orifices, extending towards the mesial surface of the root with a bur. the defect was then enlarged with a no. 80 file. The teeth were placed in a saline-soaked oasis,to simulate a clinical scenario wherein over/underfilling couldn't be observed. They were then randomly divided into 3 test groups as -

a) 15 defects sealed with amalgam.

b) 15 defects sealed with IRM.

c) 15 defects filled with MTA.

Gentle force was applied to condense the filling materials. All groups had their access cavities sealed with the respective materials. MTA was mixed to a putty consistency and placed with a messing gun. It was then condensed with a small cotton pellet.

After placing the repair materials, the teeth were kept for 4 weeks in the oasis model.

The sites of the perforations were then stained with methylene blue for 48 hours, sectioned, and examined under a dissection microscope.

They reported that MTA leaked significantly less than IRM or amalgam. Moreover MTA showed the least over-filling tendency whereas IRM showed the least underfilling tendency. They inferred that moisture present in the perforation sites decreased the sealability of amalgam, IRM and EBA. Eugenol could also irritate vital tissues. MTA, because of it's hydrophillic characteristics, caused no problems in it's usage, in a moist environment. In a pilot study, when MTA was placed in retrograde cavities contaminated with human blood, it was found that blood did not affect the seal between the cement and the dentin walls. The absence of extrusion, with MTA was attributed to a less condensation force. Only one sample showed extrusion of MTA, but there was no dye penetration associated with it.

The investigators concluded that over/under-filling of MTA did not affect it's sealability.

The moisture present in the perforation site reduced the sealability of amalgam, IRM and EBA. Eugenol can also irritate tissues.

Because of its hydrophillic characteristic of MTA, the moisture acts as an activator of the chemical reaction and poses no problem with its use in a moist environment. In a pilot experiment, MTA placed in retrograde cavities contaminated with human blood did not affect the seal between the material and the dentin walls.

Lussi and co-workers (1993) : developed a machine which allowed cleansing of the root canals automatically without conventional motorized or hand instruments.

They used 79 extracted molars and 52 teeth were prepared with the machine, using NaOCl (1, 2 or 3%).

In the control group of 27 teeth, the step-back method of canal preparation was performed. The teeth were then prepared histologically, and examined by light microscopy. The investigators reported that overall, the treatment with NaOCl resulted in similar or better cleanliness when comparing machine and hand instrumentation.

In curved canals, the apical third was also significantly cleaner when the machine was used.

In conclusion, they stated that it's possible to clean a root canal system by "non-instrumentation technology (NIT)", as well as by conventional hand instrumentation.

Torabinejad and co-workers (1993) : used the tandem scanning reflected light microscope(TSM) and rhodamine B fluorescent dye(as a tracer), to determine and compare the sealability of MTA, amalgam and super EBA as root end filling materials. The investigators used 30 extracted single-rooted teeth for this in vitro study, and after cleaning and shaping, the teeth were obturated with gutta-percha and sealer. The apical 3 mm were resected, and the teeth were randomly divided into 3 groups. The root fillings with the 3 test materials were placed after retrograde preparations were made. The teeth then spent 24 hours in 100% humidity. The roots were then exposed to acqueous solution of rhodamine-B fluorescent dye for 1 day. They were then longitudinally sectioned, and the extent of dye penetration was measured with a confocal microscope. The dye penetration was guaged with the TSM with and a green filter. A video camera and a monitor were adjuncts of the TSM.

They reported that voids and gaps between the filling material and the canal walls was seen in teeth restored with amalgam and super EBA. Dye had penetrated the entire extent of the cavity filled with amalgam.

MTA was associated with excellent sealing ability, and showed no dye penetration in majority of the samples, while amalgam had the least adaptability. Amalgam leaked significantly more than super EBA($p<0.0006$), while super EBA leaked significantly more than MTA($p<0.0007$). Some samples of EBA showed dye penetration through the junction between the cement and the dentin walls, and also got impregnated into the material itself.

The investigators concluded that if a filling material wouldn't allow penetration of small molecules (of dye), then it had the potential to prevent larger substances like bacteria and their by-products. They also added that amalgam had several drawbacks like initial leakage, secondary corrosion, mercury and tin contamination, moisture sensitivity, need for an undercut in the cavity preparation, "scatter" and tissue-staining. IRM and EBA were moisture sensitive, irritating to vital tissues, soluble, and difficult to handle.

Testori & Co-workers (1993) : performed a clinical statistical study on 36 cases of vertical root fractures in an attempt to better define the clinical and radiographic features and identify the etiology. Vertical root fractures in endodontically treated teeth are one of the most difficult problems to diagnose and treat. In case there are no symptoms the diagnosis is further complicated. Many a time, a combination of signs and symptoms may imply the presence of a root fracture. The clinical and radiographic findings depend on the location and extent of the fracture. Usually the treatment in such cases is extraction. In multi-rooted teeth hemisection may be done, but the long-term prognosis is jeopardized if the tooth is used as an abutment. Only a few cases have shown satisfactory therapeutic measures but without long-term follow up.

The causes of vertical fractures are 1) wedging effect of posts (Wechler et al. 1978). 2)the expansion of the posts from corrosion (Rud and Omnell 1970). 3)excessive force during obturation (Holcomb et al. 1981). 4)loss of dentin while cleaning and shaping and during post preparation (Meister et al. 1980). 5)some investigators have found the dehydration of the root structure after endo treatment to be the cause (Helfer et al. 1970).

The authors stated that vertical root fractures most frequently occurred between 45-60 year age group. The average time elapsed between the endo treatment and the diagnosis of the fracture was found to be 10 years.

Most common evidences and symptoms were mild pain (50%) in the area of the fractured tooth, often with a swelling (53%) and a fistula (42%) along with a deep pocket in just one area of the attachment surrounding the tooth (78% of cases).

The sign most often revealed in a radiograph was a radiolucent periradicular band (72% of cases).

Premolars (56%) and molars had greater number of fractures. 83.3% of the fractures occurred in posterior teeth. The authors stated that the anatomic factors played an important role as smaller the mesiodistal diameter of the root, greater is the incidence of fracture.

The mesiobuccal roots of upper molars, the mesial root of lower molars and premolars had these characteristics.

Gher et al. (1987) in their clinical study of 100 fractured teeth, found 67% to be molars. Tamse (1988) also confirmed this observation.

Trope et al. (1985) studied 64 upper centrals and showed that preparation of the post space weakens the root. Hence posts must be used only if necessary, to retain the core and not for reinforcement.

The authors concluded that in this study, insertion of posts beyond the mid-1/3rd of the root did not increase the risk of fractures. The length of the root obturated was the only parameter taken into consideration and other co-relations were not studied.

Nyman & Lindhe (1979) in a longitudinal study of 299 patients with 332 fixed prosthetic reconstructions found vertical fractures occurred in root filled teeth with posts, and those serving as terminal abutments for free-end segments.

This study showed that there were many factors included and the high % of retentive systems associated with vertical fractures suggested that natural retention like slots, boxes and so fourth must be used during reconstruction of a tooth.

Preserving root structure at the level of the coronal third of the canal during endo treatment is of the utmost importance. Endo treated teeth must not be used as abutments for partial removable prostheses with extra coronal precision attachments and reconstructed with intra radicular retentive systems. This would increase the risk of fracture.

<u>Moloney and co-workers (1993)</u> : evaluated the sealability of amalgam, EBA and silver GIC, in the repair of lateral root perforations. They used 35 extracted teeth for this in-vivo study. The teeth were root filled with AH-26, and gutta-percha and were perforated at the apical third. Repairs were done with the 3 materials, and the roots were implanted subcutaneously in rats, for 5 days to attain a surgical environment.

After the retrieval, the roots were placed in 20 micro Ci/ml of calcium-45 for 7 days. They were then rinsed, sectioned and autoradiographs of the repaired defects were made. These were then projected onto a screen and the extent of penetration of the radioisotope was measured. Their statistical analysis of the data revealed that EBA provided a better seal than amalgam or silver GIC.

De Cleen (1993) : stated that the use of posts should be avoided whenever possible. When preparation of post space is required, immediate removal of gutta-percha using heated instruments and small Gates drills would be apt. He emphasized that posts are indicated only if the remaining tooth structure does not have enough bulk and/or undercuts to provide the necessary retention for the core. This was the main function of a post. Lab research had shown that the root dentin of a root – treated tooth had a slightly less moisture content [Helfer and associates (1972)] which would not affect the hardness of dentin [Lewinstein and associates (1981)].

Posts, in fact do not re-inforce the tooth but rather, weaken it. Roots with posts were not stronger than intact roots [Bravin (1976); Trabert and associates (1978); Guzy and Nicholls (1979)].

The author concluded that atleast 3 mm of well condensed root canal filling left in the canal would preclude the disruption of the apical seal.

Soluti and co-workers (1993) : compared the sealability of a mineral trioxide aggregate(MTA) with that of amalgam or IRM for the repair of root perforations. 50 extracted molars were used for this in vitro study. The teeth were placed in a saline soaked “oasis” to cover the defects and simulate a clinical condition.

The materials were placed into the perforations (15 teeth per material) and the teeth were kept in 100% humidity for 4 weeks. The perforation sites were then stained with methylene blue for 48 hours, sectioned, and examined under a dissecting microscope. Linear dye penetration was measured and the statistical analysis revealed that MTA had a significantly less leakage than IRM or amalgam. The MT aggregate also showed the least overfilling tendency, while IRM showed the least underfilling tendency.

<u>Williams and Gutmann (1993)</u> : assessed the healing of periradicular tissues to Diaket and Diaket with tricalcium phosphate, as root end filling materials in vivo.

The fillings were placed in a blind fashion and the root ends were burnished with 10% citric acid for 2 minutes. After 30 and 60 days respectively, the animals were euthanised and their jaws were resected and prepared for light-microscopic evaluation, for the degree of inflammation, connective tissue response, periodontal ligament formation/apposition.

The sections of the 30- day specimen revealed variable inflammation, encapsulation of the root end filling material and the initiation of functionally oriented periodontal ligament fibres. The 60-day specimen showed a similar, albeit advanced healing. For all the factors evaluated, only the degree of cemental deposition at 60 days, in the diaket-tricalcium phosphate specimen showed any significant difference.

The investigators concluded that healing of the periradicular tissues was comparable, in the presence of both materials at 60 days.

Hartwell and England (1993) : conducted a longitudinal study to evaluate histologically, the healing of perforation defects in molars of monkeys, after repairing them with de-calcified freeze dried bone(DFDB).

Furcal perforations were created in 18 teeth, in 3 rhesus monkeys and 15 teeth were filled with DFDB. After 6 months, the gingival tissues were clinically healthy with normal sulcular probing depths. One tooth showed furcal bone loss radiographically. The histological picture revealed a layer of epithelium immediately beneath the perforation site and deep to this, was fibrous connective tissue and bone. Chronic inflammation was present in 2 of the 15 DFDB samples.

No new bone formation was observed in any of the samples.

The investigators concluded that both positive and negative findings were associated with DFDB as a perforation repair material.

The **positive** findings were –

a) Excellent clinical, and radiographic findings at 6 months.

b) DFDB mixed well with blood and the particles would "weld together" into a solid mass to fill the defect.

c) It provided a good barrier.

d) There was no inflammation in 13, of the 15 samples.

The **negative** findings were –

a) No bone was formed, in any of the specimens.

b) Epithelium was present in all 15 specimens!

The investigators concluded that DFDB was biocompatible, relatively non-toxic, easy to obtain, relatively inexpensive, completely degradable and that it provided an excellent barrier. They speculated that if the osteogenic potential could be studied and the presence of epithelial tissue could be eliminated, DFDB seemed to have good potential for usage as a perforation repair material.

TCP seems to have demonstrated the best results yet, but Sinai et al. 1989 stated that it was not the ideal repair material.

Himel (1985) had found necrosis of the bone in 12.5% of dog's teeth treated with TCP.

The authors stated that materials like amalgam, gutta-percha, dentin chips, AH-26 root canal sealer, CaOH, cavit, tri-calcium phosphate and HA did not fulfill the criteria of an ideal repair material which should –

a) induce osteogenesis and cementogenesis,

b) be biocompatible,

c) be non-toxic,

d) Be non-carcinogenic.

e) Be easily obtainable

f) Be convenient to use

g) Be completely degraded during the repair process to allow for its replacement by new healthy bone.

h) Act as a barrier or a matrix against which an obturating material or restorative material could be placed.

Neilsen & co-workers (1993) : examined the tissue injuring and bacteriological properties of an experimental chelate cement HN. ZnOE cement was chosen as the reference, as accepted root filling cements have significant amounts of ZnOE. They tested the in-vitro and in-vivo toxicity of HN. 35 rats were used and ZnOE and HN were injected under the neck skin. 1,2,5,7,15,30 & 45 days later 3 rats of HN and 2 rats of ZnOE were killed, and samples were prepared for histo analysis. For the in-vitro cultures, human buccal fibroblasts were used. For the antibacterial tests, ZnOE cements were placed in celluloid molds. Each group of specimen were stored under water in plastic containers for 8 days. 3 strains of bacteria were used to test antimicrobial action. The histoanalysis revealed that both the cements gave rise to tissue injury. But the injury was more severe in ZnOE samples than in the HN samples.

The in-vitro toxicity showed no significant differences between the two cements.

Both the cements had an antimicrobial action in freshly mixed and present condition. They were comparable against the three bacterial strains.

The investigators concluded that the ISO standard for approval of root canal sealing materials late down a series of demands for a sufficient root filling. But, they do not include highly important tests for sealability, setting expansion, adhesion to dentin, resistance to destructive chemical forces when in-situ, tissue injury and the antibacterial activity.

Alpaslan and associates (1994) : histopatholocally compared the behaviour of coral with that of HA/collagen / glycosaminoglycans [HA/C/GAG] implants and evaluated the tissue reaction and bone formation after sub-periosteal implantation.

They used 18 guinea pigs, and 9 were implanted with coral, while the other 9 animals got HA/C/GAG implants.

A 20 mm incision was made on the cranium , and a sub-periosteal pocket was created in each animal prior to the implantation., and the wounds were closed with nylon sutures.

The animals were sacrificed in groups of 3, at 3o, 60, and 90 days respectively.

The implants, along with the bone and the adjacent soft tissues were histoanalyzed with polarized light and light microscopy.

The investigators reported that –

In the 30-day specimens, all the sections from the coral group revealed new bone formation along the periosteum. Osteoblasts were seen in large numbers. Focal "woven bone" pattern was visible between the fine lamellar areas, when observed under polarized light. The coral, had completely resorbed. All the HA/C/GAG samples were surrounded by foreign-body type multi-nucleated giant cells, around HA particles and the collagen samples. Bone resorption was seen, under the implant material, and there was no new bone formation.

In the 60-daysamples, the coral group specimens showed that the new bone that had formed, was thinner than before. Lamellar bone pattern was increased, when seen under the polarized light. In the HA/C/GAG group, the HA particles were surrounded by multinucleated giant cells. Collagen fibres were not seen. Bone resorption was seen adjacent to the HA particles. Though no new bone had not formed, a thin layer of new sub-periosteal bone was seen in some samples that were devoid of the implant material.

In the 90-day samples, the coral group samples were associated with new lamellar bone. The woven bone was confined to a focal area, when seen under the polarized light. The ratio of resorption and replacement of the implant material with the newly formed bone wasnot equal to the smaller amounts of new bone formation.

The investigators concluded that the combination of collagen and GAG, with particulate HA did not interfere with tissue healing, and bone formation. The combination of HA with C/GAG was easier to handle. Coral, had resorbed completely resorbed and was replaced with new bone. Both these materials could be used in situations wherein contour augmentation was desired.

They added that in the last decade, a number of biocompatible materials had been used widely in clinical practice, for the repair of osseous defects and augmentation procedures. HA, which was a calcium phosphate compound had received the “most attention” due to its biocompatibility , its physical and chemical properties [Jarcho (1981, 1986); DeGroot (1996)].

The problems associated with HA blocks, in the management of augmentation procedures, led to its introduction in a particulate form. Even this, apparently had its drawbacks in terms of migration of the particles and the maintenence of the material over the desired confines of the alveolar ridge . In order to overcome this negative aspect of HA, it was combined with GAG and collagen , to get a solid form implant[Hatcher and Matukas (1986); Wittkampf (1988); Nagase et al (1989)].

Coral, is basically a CaCo3 (99%), and bio-inert. Its physical architecture is similar to bone, and resoption takes place, of this material, unlike HA [Issahakian et al (1987); Levet et al (1988)].

This seemed to be a satisfactory bone graft substitute, in animal studies [Ouhayoun et al (1989)], as well as in clinical applications[Brasnu and associates (1988); Roux and associates(1988) ; Lekovic and associates (1992)].

Chong and associates (1994) : assessed the antibacterial activity of all the potential retrograde root-filling materials and compared this property with that of amalgam, using the agar diffusion inhibitory test.

The materials tested were—ZnOE (Kalzinol) ; ZnOE (IRM) ; EBA cement(Stailine, Super-EBA-regular set; Zinc –free amalgam (Tytin capsules); and finally, L-C GIC(Vitrebond).

The bacteria used in the study were-a) *S. milleri* (NCTC 10707).

b*) E. faecalis* (NCTC775).

Forty standardized pellets of each material were made. The fresh as well as the 1-week set materials were placed on blood agar plates inoculated with the bacteria.

At intervals of 3, 7, and 10 days the presence and the diameter of the zones of inhibition were recorded.

The statistical analysis of their data revealed that the diameters of the zones of inhibition increased with time, for all the materials. This was irrespective of their physical constitution-

a) The fresh, as well as the set materials showed the same toxicity.

b) Kalzinol, IRM, and EBA cement were more bactericidal when aged, rather than in the freshly mixed state.

c) Vitrebond was more active in the fresh state. The material was found to have the most pronounced bactericidal effect, compared to the other materials. Though the diameter of the inhibition zone reduced with time, this was seen only with this material.

The anti- bacterial property were graded as :

Vitrebond > [IRM= EBA] > amalgam

The investigators concluded that Vitrebond was the most effective antibacterial material, followed by Kalzinol. The antibacterial property of this material remained the most active, though the amount of the material, had reduced due to ageing.

IRM and EBA were more active when aged, than in the freshly mixed state.

Amalgam had no inhibitory affect at all, in both the freshly mixed as well as the set-state, regardless of the period of exposure.

Duggins and associates (1994) : described a case in which techniques of endodontic retrograde filling and GTR were used in combination, to treat a strip perforation of the mesiofacial root of the upper left 1st molar, in a 40-year old patient. The other canals were prepared and obturated, and a temporary restoration was given.

1 month later, at a recall, the patient was asymptomatic, but surgical intervention was decided upon.

After a full thickness buccal flap was reflected, it showed a 3mm defect near the apex of the root. The fenestration was enlarged to gain adequate access to the furcal perforation, which was located on the distal surface of the mesio-buccal root. The marginal bone on the facial aspect of the 1st molar was preserved.

An apicectomy was done, and the MB root received a root-end filling with IRM. The perforation was thoroughly debrided and prepared under magnification [x2]. The roots were treated with tetracycline, for 3 minutes, with a cotton pellet and the defect was filled with DFDB [human cadaver bone].

The access fenestration was covered with a barrier membrane- Gore-Tex [Oval No.6] [Nyman and associates 1982; Gottlow and associates 1984], in such a way that there was an overlap of 2-3 mm at the bone margins. The flap was then replaced and sutured with Gore-Tex sutures, in order to maintain the flap precisely in its place over the bony defect. An IOPA was taken, and an oral prophylaxis regimen was prescribed, along with doxycycline, for 10 days.

One week later, during the suture removal, uneventful healing was observed. Recall visits were scheduled on a weekly basis, and a x-ray was taken, 6 months post-op.

A recall at 7 months showed that a 100% bone fill had occurred. This was seen during the surgical re-entry procedure, to remove the membrane.

After 15 months, a 3-unit gold fixed partial denture was fabricated and seated, and another x-ray was taken, to assess the healing.

The authors stated that the most common treatment for perforations, was probably extraction. Although this could not be avoided in several cases usually, other modalities of treatment could be employed for successfully treating the perforation, and retaining the tooth.

One option was periodontal crown lengthening, to remove the bone and the soft tissues to a level up to which the defect could be sealed in a conventional manner, or, it could be covered by the margin of a fabricated crown.

Root amputation and hemisection, could also be done, but many factors like the anatomy of the root, the bone thickness, the periodontal condition etc, would have to be contemplated prior to a surgical intervention. If a communication between the defect and the gingival sulcus had already formed, then the prognosis would be hopeless.

The authors also added that the method they had used in the present case, was the “first of its kind”, wherein a combined technique was utilized to repair recent perforations, since an endodontic retro-fill and the obturation of the defect with IRM, and GTR with DFDB. This was a “heroic” technique, according to the authors, and was undertaken, to retain a tooth.

Although other conventional methods that were less complicated, or cheap, could be utilized, these would not help if the perforated tooth had to be used as a “key” abutment, for the subsequent fabrication of an appliance. This technique would also be beneficial in maintaining an intact, un-restored quadrant of teeth to avoid placing a fixed partial denture, and to preserve tooth structure on the adjacent teeth.

The authors added that this technique was being further investigated, for the repairing of recent perforations, under a surgical microscope [x2 to x10] and, with new microsurgical instrumentation. More conservative procedures could be performed, and accurate instrumentation of the perforation area would be possible.

Moreover, 2 other patients who underwent the same procedure, were showing signs of adequate healing that was underway, as the barrier membrane was yet in place, at the time.

The drawback of this method, was that there was no way of predicting what type of healing was actually occurring, since it had been used only in human subjects, and animal studies would have to be undertaken, to gauge the healing procedure, which could be the regeneration of the periodontal ligament fibers, alveolar bone, and cementum [new attachment apparatus]. The authors speculated that new bone may have formed, and may have been associated with fibrous capsules around the root, or ankylosis could have occured.

Owadally and associates (1994) : evaluated the effect of the addition of 10% and 20% HAP, on the anti-bacterial activity of IRM , and compared these properties to those of amalgam, which was a commonly used root-end filling material.

They used the agar distribution inhibitory test, for the purpose. Forty standardized pellets of each material were produced (20 fresh, and 20 aged for a week in saline).

S. milleri and *E faecalis* were cultured in blood agar, and the fresh and the aged samples were placed into the plates.

The presence of zones of inhibition, and their diameters were studied, at intervals of 3, 7, and 10 days.

The statistical analysis of the data revealed that there was no significant difference between the in the response of the 2 bacteria tested.

However, there were statistically significant differences in the diameters of the zones of inhibition related to the different materials, the exposure period, and the ageing of the materials.

With the increase in the time period, all the tested materials showed increased zones of inhibition when either fresh, or aged.

IRM and both of the HAP modified forms produced large zones of inhibition, whereas amalgam did not show any inhibitory activity- in either the fresh, the aged, and nor during an increased exposure time.

The cytotoxicity was measured using the Millipore filter method. Ten pellets of each material were produced, and aged in sterile water for 3 days. Ten filters were included as controls.

The investigators found that amalgam always produced a consistent cytotoxic score of 1 [mild cytotoxicity], with a zone of reduced staining intensity, or an unstained zone, 7mm wide. This was statistically different than the test materials.

The investigators concluded that the antibacterial activity and the cytotoxicity could be put down as-

[IRM=IRM+10% HAP=IRM+20%HAP] > amalgam.

The authors added that though ZnOE based products were used as root-end filling materials, the presence of eugenol in the cement, was a negative aspect, as the material would be in close contact with the periapical tissues [Owadally and associates 1993].

The addition of HAP to IRM had been suggested, in order to improve its biocompatibility.

A dye-leakage study had shown that there was no difference between the sealability of IRM, and HAP-modified IRM. They were found to be better than amalgam, though.

In conclusion, the authors stated that IRM showed the most pronounced antibacterial activity against both the bacteria, and that it was the most cytotoxic amongst the materials tested. There was no difference in this property when IRM was added or modified with 10 or 20% HAP.

Holland and associates (1994) : observed if the status of the root canals may influence the healing process after experimental periodontal surgical injury in dog teeth.

They used 40 teeth, from 4 dogs, and the roots were divided into 4 groups according to the root canal status as

Grp 1 – Root canal with vital pulp.

Grp 2 - Root canal with out pulp, and open to the oral environment.

Grp 3 - Root canal infected, and filled with ZnOE.

Grp 4- Root canal infected and filled with Ca[OH]2.

The treatment was done in 3 sessions. Apart from the 1st group, the other roots were subjected to an access preparation and pulpectomy.

The entrances to the pulp chambers were left open to the environment for 30 days.

In the 2nd session, the root canals of groups 3 and 4 were prepared, and dry cotton pellets were placed into the pulp chambers, and the openings were sealed with ZnOE cement. After a week, the canals were filled with ZnOE or Ca[OH]2 paste.

The access cavities to the pulp chambers were sealed with ZnOE and amalgam.

In this same 3rd session, after surgical exposure of the roots, a standard cavity was prepared in the mid- portion of the roots, by removing cementum and some dentine.

The cavities were then cut with a bur, and the soft tissues were sutured and allowed to heal.

Six months later, the animals were sacrificed, and the segments of their jaws, each having one tooth, were prepared for histoanalysis.

The investigators measured the thickness of the newly formed cementum, the periodontal ligament, and the dentin between the cavity floor and the pulp.

Statistical analysis of their data revealed that in group 1, all the specimen showed newly formed dentin, next to the area associated with the dentinal tubules involved with the cavity preparation. No inflammatory cells were observed in the dental pulp.

Small areas of dentin resorption were seen in the cavity walls. These were covered by newly formed cementum.

The thickness of the dentin remaining in the cavity floor was 37[+ or – 70] μm, on average. Bone tissue had grown in the cavity space. The thickness of the periodontal ligament next to the cavity floor was 113[+ or – 13] μm.

Inflammatory cells were absent, and the periodontal fibres were inserted in the newly formed bone cementum.

In the 2nd group, the dentin remaining in the floor of the cavities was 100 [±39]μm. Areas of hard tissue resorption were seen in the floor and the walls of the cavities, as well as in the cementum next to the cavities. New eosinophillic cementum was seen, which covered all the walls and the floor of the cavities. The thickness of the cementum was 86[±31]μm. This was significantly higher than that seen in group1. The periodontal ligament was free of inflammatory cells and the ligament fibers, were found to be inserted into the newly formed cementum and bone.

Group 3 – In all specimens new formed bone tissue had grown into the bony defect. The average thickness of the periodontal ligament was 150[±18]μm. A mild chronic inflammatory reaction was seen and there was exudate between the periodontal connective tissue and the cavity floor. Few lymphocytes and macrophages were observed in five specimens. The cavity floor showed a smooth surface and the dentinal resorption was rarely seen. Cemental resorption was also seen in some cases. The cavity floors had an average thickness of 459[±78]μm. New cementum was not observed in half of the specimens. In the other 5 cases an eosinophilic newly formed cementum was covering only a part of the walls and the cavity floor. Periodontal fibers had inserted into the hard tissues only in these places, while in the other areas the fibers were parallel to the floor and walls of the cavity. The thickness of the cementum was 5[±9]μm. This was better attached to the dentin in areas of previous resorption. The smooth areas exhibited a space between both the dentin and the newly formed cementum.

Group 4 – Similar to the group 3, a few areas of resorption of the floor and walls of the cavities was seen. The average thickness of the dentin in the floor was 453[±54]μm. The walls and the floors of the bony cavities were covered with eosinophilic cementum, in all specimen.

The average thickness of this was 2[±9]μm and the cementum was better attached to the dentin in areas which were resorbed. The ligament was free of inflammatory cells and its fibers were inserted into the hard tissues. The ligament thickness was 146[±11]μm.

The investigators concluded that the status of the root canals influenced the healing process of the experimental periodontal lesions in the root canals filled with calcium hydroxide, and the best results were obtained in the group in which Ca[OH]2 was used.

When the root canals were left open to the oral environment, resorption of the dentin in the cavities was the most frequently seen. However, this did not prevent the repair process – only slowed it down.

The investigators inferred that the thickness of the cementum deposited on the cavity floor was dependent on the states of the root canal. Canals open to the oral environment, showed the largest amount of newly formed cementum. The absence of, or the minute deposition of cementum observed in the group in which the canals had been filled with ZnOE, compared with the calcium hydroxide group suggested that the material had a special characteristics. In the group filled with ZnOE, oedema and a mild chronic inflammatory reaction between the supporting structures and the floor of the cavity were observed. The cytotoxic effect of eugenol was well known, when applied directly to either soft tissues or to cells in culture media. Free eugenol, according to the authors, could be the toxic component.

Torabinejad and associates (1994) : compared the amount of dye leakage in the presence or the absence of blood, in root-end cavities filled with Super-EBA, IRM, and MTA.

They used 90 extracted teeth for this in-vitro study. The apical foramen of each tooth was enlarged to file size no. 40, and coronal and mid-root flaring was also done. The canals were obturated with laterally condensed gutta-percha, and sealer, and the access openings were sealed with Cavit.

The apical 2-3mm of each root was resected at 90° to the long axes of the roots.

After the root-end preparations were made, the roots were randomly placed into the following-

80 roots were divided into 4 groups, and 10 roots served as controls.

The 4 materials tested were amalgam, IRM, Super-EBA and MTA.

They were divided into the 4 experimental groups [20 teeth/group], and 10 samples from each group were inserted in the presence of blood in the root-end, and 10 teeth were root-filled without blood contamination at the root-end.

A constant supply of fresh blood was ensured, during the root-end filling, with the help of a catheter.

The root-end cavities were filled with blood before placement of the root-end filling materials in half of the roots assigned to each filling material.

Immediately after the fillings were placed the roots were immersed in 1% methylene - blue dye, for 3 days.

The roots were grooved on the buccal and the lingual surfaces down to the gutta-percha. They were then split into 2 sections and the root-end fills were removed, to enable the examiners to 3-dimensionally assess the dye penetration.

The dye penetration was measured linearly to its furthest extent within the root-end cavity with a stereomicroscope (x10).

The length of each root-end cavity preparation was also measured.

The statistical analysis of their data revealed that –

Dye leakage occurred in varying degrees, between the dentinal walls and the materials, in amalgam, IRM, and Super-EBA samples.

In comparison, MTA leaked significantly less than the other materials whether in the presence, or in the absence of blood.

The investigators concluded that in the present study, the presence or the absence of blood affected the leakage of the filling materials- IRM, Super-EBA, and amalgam.

In the case of MTA, blood did not interfere in its sealing ability. Amalgam too, was not as adversely affected as IRM and Super-EBA in the presence of blood.

IRM as well as Super-EBA leaked more than amalgam, in this study.

The reason for comparing the sealing ability of the materials in the presence or absence of blood was important in that these circumstances are usually unavoidable clinically, in the periradicular tissues, wherein moisture and blood can adversely affect the physical and the chemical properties of the other materials.

Attaining a totally dry surgical site was not feasible, even when L.A with an increased concentration of adrenalin was used, or if materials like bone wax, chemical or electric cautery was done.

The authors added that “no study had intentionally left the root-end preparations filled with blood to gauge the apical seal under these more relevant clinical situations”.

The non zinc-containing amalgam used in the present study had the advantage of the absence of setting expansion when in contact with moisture. Hence, the usage of Zn-free amalgam could produce better results than with the Zn-containing amalgams. However, the non-Zn containing amalgams tend to have more porosity and diminished physical properties when compared with the Zn- containing amalgam.

IRM and Super-EBA had the disadvantage of solubility, in the presence of moisture. Moreover, moisture dramatically decreases the setting reaction time of these cements, and hence they may set prior to their placement, in the root-end preparations, and may not seal the dentinal walls. Additional material, if needed, would also pose a problem in such cases, as the increments of the cements would not be cohesive.

The ideal characteristics of the root-end filling material, according to these authors were the same, as those required of the orthograde filling materials.

It should

a) adhere to the preparation walls of the cavity and seal the root canal system.

b) Be non-toxic.

c) Be well tolerated by the periradicular tissues.

d) Promote healing.

e) Be easy to handle.

f) Be radiopaque.

g) Be dimensionally stable.

h) Be non-absorbable.

i) Be unaffected by moisture.

j) Not corrode.

k) Not be electro-chemically active.

l) Not stain the periradicular tissues.

<u>Wang and associates (1994)</u> : studied the histopathologic affects of Yunnan Baiyao (YNBY), amalgam, HA, and (CaOH)2, as repair materials for perforations.

They used 40 dogs, in this *in vivo* animal study. Experimental perforations were created they were sealed with the test materials. Teeth those were opened to the oral environment, served as controls.

Twenty teeth were taken, from each dog, and each group comprised of 4 teeth, as the test groups.

The animals were sacrificed after 1, 4, 8, and 12 weeks respectively and the tissues were prepared for histoanalysis , under an optical microscope

The investigators reported that –

a) in the initial period, (1-4 weeks) :inflammatory infiltration was present in every group. But the reaction to YNBY was significantly milder than the other materials.

b) Pyogenic foci were present, in the HA and the Ca(OH)2 groups.

c) At 8th and the 12th week – the inflammatory reaction of each test group had significantly reduced. Epithelial metaplasia and cicatration was found in the vicinity of the perforation area.

d) Dentin, cementum, and alveolar bone were resorbed in majority of the samples.

e) In the later stage, cementogesis and osteogenesis was seen in the region of the perforation wound that was repaired with YNBY.

The investigators concluded that promotion of blood circulation, hemostasis, and the anti-phlogistic actions of the material YNBY might promote the repair of cementum and alveolar bone.

Andreasen and Pittford (1994) : Developed an in-vivo model which could screen the current and potential new filling materials before their clinical trials. They used the experimental animal model (monkeys) for this in-vivo study. The teeth were extracted and an extra-oral technique was followed to make a root end cavity and thereby minimize experimental deviations. In order to expose the filling materials to the effects of bacterial contamination, the canals were exposed to saliva prior to placement of the filling and replantation. The periapical healing was recorded radiographically at 8 weeks. The root end preparation was done in such a way that the crowns of the teeth were held by forceps, and 2mm of the apices were resected. A retrograde cavity was drilled and a file contaminated with saliva was placed into the root canal. One group of 8 teeth served as infected controls. In the other teeth the root ends were filled with one of the following materials – amalgam, non-$\gamma 2$ amalgam, GIC, calcium hydroxide liner, AH26, EBA, IRM, IRM+human chips, Kalzinol, cavit, G-P fillings with zinc oxide eugenol, IRM, Kerr sealer, Kloropercha.

The materials were randomly allocated to the teeth except for those filled with amalgam. The fillings were done within 15-20 minutes. The molars were then replanted and left unsplinted for 8 weeks.

The animals were sacrificed and jaw sections from the canine to the 3rd molar were removed and placed on an IOPA. The film was placed in a projector after processing, so that about X5 magnification was obtained. The tracing was made of the outline of the apical part of the roots on paper. The outline of the lamina dura (PDL) space was also traced from the most survical enlargement of the lamina dura. The measurement was done with a planimeter.

The PDL space around the apices of normal untreated teeth was measured to yield values for ideal healing (8 teeth were used). Duplicate registrations were performed on 10 randomly selected roots after 7 days to determine the reproducibility of the drawing and measuring procedures.

The statistical analysis of their data revealed that the number of roots filled with each material and the mean root end PDL radiolucencies were measured. The mean area of the PDL of normal apices was 11.3 units while that of the infected controls was 49.5 units.

Amalgam, whether conventional or corrosion resistant, did not lead to root end healing. There was no difference in the size of the radiolucency compared with non-obturated infected controls.

GIC did reduce the size of the radiolucency compared with the controls.

The calcium hydroxide liner was associated with similar findings, as of the infected controls.

The AH26 without gutta-percha did not reduce the size of the radiolucency. Zinc oxide eugenol cements like EBA, IRM and Kalzinol, IRM+dentin powder reduced the radiolucency significantly. Plain ZnOE did not reduce the size of the lucency.

Cavit, retrograde gutta-percha and plain ZnOE sealer or IRM produced a significant reduction in the root end radiolucencies.

The authors stated that ZnOE cements showed the best periapical healing in this study. The presence of radiolucencies in connection with amalgam filled teeth was of concern since it has been the most widely used retrograde filling material.

The better healing with GIC as observed by bone formation in the part of the socket formerly occupied by the root apex was in agreement with the bone healing seen in histologic studies (Zetterqvist et al. 1987, Callis & Santini 1987, Pitfort & Roberts 1990), where the canal space was not left empty. However, in infected canals the healing was confined to the surrounding bone as inflammation was present against the filling at the root end. The group of materials which allowed consistent periapical healing were ZnOE cements.

The investigators concluded that this study supported the use of ZnOE cements as potential retrograde filling materials. But, the solubility of these materials was a main disadvantage (Weine 1982). These modified materials like, EBA and IRM have a reduced solubility due to the addition of various components. They have also been proved clinically successful as root end filling materials (Dorn and Gartner 1990).

A combination of gutta-percha with IRM or plain ZnOE achieved the best results in this study, in that the reduction of the radiolucencies was not dissimilar from the normal apices.

The authors concluded that this experimental model could be a satisfactory screening method for potential root end filling materials. They added that the materials must be histologically examined to assess the results and compare the different methods.

<u>Torabinejad and co-workers (1995)</u> : evaluated the cytotoxicity of 4 root-end filling materials, using the agar overlay and radiochromium methods. The materials tested were amalgam, super-EBA, IRM, and MTA.

The statistical analysis of the data from the agar overlay technique revealed that freshly mixed amalgam and set amalgam were significantly less toxic than the rest of the materials. Fresh, as well as the set MTA ranked second, when tested with this method.

Similar statistical tests revealed a significant statistical difference between the toxicity of freshly mixed, and the set materials after 24 hours of incubation with radiochromium-labeled mouse L929 cells. The investigators found that the degree of cytotoxicity of fresh and the set materials was thus- MTA was least toxic, followed by amalgam, super-EBA, and finally, IRM, which exhibited the most toxicity.

They also added that since the filling materials are in contact with the periradicular tissues, They must possess a good sealing ability, and be biocompatible.

The authors contemplated that the difference between the cytotoxicity of the fresh and the set MTA could be due to the presence of leachable and toxic components in this material. Yet, the toxic effect of MTA was significantly lesser than super-EBA and IRM..

The investigators concluded that MTA appeared to be a potential root-end filling material.

Numerous materials had been advocated, for root-end filling, like gutta-percha, ZnOE, cavit, composite resin, gold foil, and GIC. To date, no material has been found, which fulfills all, or atleast most of the "ideal" properties.

<u>Biggs and associates (1995)</u> : evaluated the condition of in-vitro retrograde fillings of amalgam, GIC, and EBA cements after 10 years of storage in physiologic saline. The authors assessed the durability of amalgam and alternate materials that had been subjected to conditions that simulate the periapical environment. Sixty one extracted incisors were divided into 6 groups of 10 teeth each, with 1 tooth as control.

Half of the teeth were resected with a high- speed bur and half, with a low speed bur. They were prepared for retrograde fillings, and EBA and GIC were placed in 10 teeth each, of the high and low speed groups. Zinc containing amalgam was placed in 10 teeth of the high-speed group, and zinc-free amalgam was placed in 10 teeth in the slow speed group.

The teeth were then stored in saline for 10 years! After this period, the apical portions were photographed at x30 magnification, and evaluated by the authors for marginal discrepencies , root crazing, staining, voids, and roughness.

The investigators reported that overall, EBA cement and amalgam sealed better than GIC in every category, except root crazing.

They concluded that perhaps, as some studies suggested, EBA may replace amalgam as the retrofill material of choice. Failure of endodontic surgery including retrofills had been attributed to the poor marginal adaptation, metabolic intolerance to the materials and their break-down products, and mechanical failure of the material due to solubility and corrosion.

The authors stated that long term studies evaluating amalgam suggest that the breakdown products of the material may contribute to the high failure rate of surgically treated endodontic cases. Studies suggesting the use of EBA or GIC, to be more suitable as compared to amalgam [Frank et al (1992)], Dorn and Gartner (1990); Inoue et al (1991)], are promising, but further evaluation must be done.

Goon and Lundergan (1995) **:** reported a case of a long-standing undetected perforation of the furcation of a lower molar, n a 27 year old patient. There was osseous breakdown, loss of attachment, and a chronic draining periodontal pocket about 6mm deep was also present. A radiograph revealed large threaded posts in the mesial and the distal canals, as well as an inadequate endodontic treatment. There were independent lucent lesions at the apex of the mesial root, as well as in the furcation, and a perforation was suspected.. Endodontic re-treatment was initiated, and the posts were unthreaded, to allow for the drainage of the exudates. The old root fillings were removed, and the treatment was completed . After laterally condensing gutta-percha and sealer, a Glick instrument was used to heat sear the gutta-percha and the soft mass was gently condensed into the mesiobuccal canal, against the perforation.

Four months later, a 6mm pocket was still present adjacent to the buccal furcation. The soft tissues were oedematous, and on probing, suppuration was seen. The recall radiograph revealed significant osseous healing at the mesial apex. But, bone breakdown continued to progress from the furcation, to the junction of the middle and the apical third of the roots.

A GTR procedure was initiated, and a full thickness flap was raised to expose the buccal furcation defect. There was extensive interradicular bone resorption. Thorough planning of the root surfaces was done and a Gore-Tex membrane was trimmed to cover the bony defect. It was held in place with a Gore-Tex sling suture, and the flap was repositioned over the membrane and sutured. A periodontal dressing was given and the patient was put on a 6 - week regimen of 0.12% hexidine rinses. At 7 weeks, the Gore-Tex membrane was removed by raising a limited full thickness flap and teasing the material off the bone with tissue forceps. Immature tissue was seen within the furcal defect. The flap was then re-sutured to protect the forming tissues. At a 6 month evaluation, a good response was seen to the GTR procedures. The tooth was asymptomatic and the soft tissues were normal. Probing revealed an attachment gain, and an x-ray showed significant regeneration of furcal bone. 3 months later, an x-ray showed that the bone regeneration had slowed. A leakage was suspected despite the presence of a warm gutta-percha seal.

The chamber was re-entered and the gutta-percha was removed from the mesibuccal orifice. More exudates were drained thus. The dentin was dried with alcohol and the inter-furcal tissue fluids were dried with paper points.

A GI sealer was placed into the canal, and a thick mix of IRM was condensed into the space against the perforation. The pulp chamber was restored with an amalgam core.

4 months later, the tooth was asymptomatic and there was no pocket on probing. Except for the site of the defect, the bone density appeared normal throughout the furcation.

1 month later, a full coverage crown was given.

After a year, the periodontal tissues were normal, and probing depths were between 2 to 3 mm throughout. A radiograph revealed that bone regeneration of the furcation was complete. A thick lamina dura was seen adjacent to the perforation site, and against the extruded sealing materials. The materials, however, did not resorb from the site.

Himel and Alhadainy (1995) **:** studied the ability of dentin preparation and acid etching to improve the sealability of LC-GIC and composite resin, when used to repair furcations over POP barriers.

They used 70 extracted teeth for this in-vitro dye leakage study, and 60 teeth were used in experimental groups, while 10 served as controls. After access preparations, the pulp chamber floors were perforated . Barriers were created in the experimental teeth with POP, and moist cotton pellets were placed between the roots in the furcae. The POP was condensed with a finger plugger, to create a space for the obturating material, and was allowed to set. The 60 teeth were randomly divided into 4 groups of 15 teeth each, as-

Grp 1 – 15 perforations were sealed with LC-GIC without acid etching. Incremental layers were applied and light-cured till the defects were obturated completely.

Grp 2 - 15 dentinal defects of the perforations were treated with etching by 37% phosphoric acid gel for 15 secs, after the dentinal surfaces were prepared like a Class I cavity having a POP floor.

Grp 3- 15 defects were sealed with LC- composite resin incrementally added, after placing and curing the bonding agent.

Grp 4 – The dentin surfaces were prepared and etched, and after the bonding agent was cured, LC-composite resin was applied in increments.

The access cavities were sealed with LC-composite, in all the teeth. The teeth then spent 2 weeks in 2% methylene blue dye, at room temperature.

They were then sectioned longitudinally, and the sections were examined under a stereomicroscope (x20) to evaluate the leakage using an NIH Image 1.47 Macintosh program. The length of the perforation walls was measured from the pulp chamber floor to the coronal end of the POP filling. Leakage was measured as the linear dye-penetration through the dentin-material interface from the apical levels of the repair materials to the coronal ends of the perforation walls.

Their statistical analysis of the data revealed that all the experimental groups showed dye penetration to varying degrees .

Composite resin over POP showed more leakage than the perforations repaired with GIC over POP barriers.

The teeth repaired with composite, without dentin preparation or acid etching, showed leakage of 98.6% of the perforation walls.

Composite, with dentin preparation and acid etching showed 82% of leakage.

GIC without dentin preparation or etching, showed a leakage of 55.7% of the walls of the defects.

The teeth repaired with GIC and dentin preparation or etching revealed the least amount of leakage- 32%.

The investigators concluded that GIC showed a better sealing ability than composite resin. This was attributed to the superior flow property of the material which could seal the apical end of the defect , as well as the adhering property of the GIC, to dentine.

They also speculated that the distance of the light source, which activated the composite resin, might have influenced the result. The GIC, though light – activated, had the property of chemical curing too, and this could have resulted in the superior seal provided by the material as a result of complete curing.

The investigators also added that POP served as a successful barrier, preventing over-extrusion of the materials. However, the debris of POP, between the GIC cement and the dentinal surfaces of the perforation walls interfered with the bonding of the GIC to dentin.

Once this debris was eliminated by dentin preparation or acid etching, the bonding property, as well as the sealability of GIC was enhanced. The authors also added that the treatment technique, was as important as the material being used for the repair.

Jubach (1995) **:** advocated backing up a millimeter in case of an apical perforation, and then filling the canal. If failure occurred, retrograde filling had to be done, and the prognosis in such cases, was generally fair.

In coronal perforations close to the gingival margin, the canal could be filled with lateral condensation of gutta-percha to seal the defect without material extrusion into the bone.

The prognosis, in such cases would be guarded. He advocated prompt closure of the perforations, to achieve the best prognosis. CaOH, could be used for bridging of the perforation by placing the dry material, and covering it with a sealing cement and restoration. He also advised using “common sense”, to understand the internal morphology of the tooth being treated, and thus, avoid trouble.

Pitt Ford and associates (1995) : examined the histologic tissue response to experimentally induced furcation perforations repaired with amalgam and MTA, either immediately or after contamination with saliva.

They used 30 teeth from 7 dogs, for this in-vivo study, and after obturating the canals, perforations were created through the pulp chamber floors, into the furcations. In half the teeth, the defects were immediately filled with amalgam or MTA. The rest of the teeth were left open to salivary contamination for 6 weeks. The presence of a lesion was confirmed by radiographic evidence of bone loss. The defects were then cleansed with NaOCl, dried, and filled with amalgam or MTA. The access cavities were sealed with MTA.

After 4 months, the animals were sacrificed, and their tissues were prepared for histoanalysis. The specimen were scanned for the presence of inflammation, it’s maximum severity, and the extent at the site of the perforations. The presence of cementum covering the repair, bacteria, and epithelium, was noted.

The investigators reported that in the teeth which were repaired immediately with MTA, there was no inflammation! 5 of 6 teeth had formation of cementum, which was continuous with the cementum covering the root surfaces. The extruded material (MTA) into the bony defect showed the deposition of cementum around it. An apparent periodontal ligament separated this cementum, from bone.

Amalgam was always associated with moderate to severe inflammation.

In the specimen in which the repair was delayed, 3 of 7 teeth repaired with MTA had no inflammation. 4 teeth, were inflamed. Amalgam samples, as before, were associated with severe and more extensive inflammation.

The authors concluded that MTA, had histologically proved it's potential as a material for the immediate repair of furcation perforations. The delayed repairs with MTA, revealed more samples with inflammation, that seemed to be linked to bacterial infection.

They further added that though clinical reports indicated conservative treatment of furcation perforations, histologic studies had often demonstrated unfavourable tissue responses at the treatment sites. The aim of treating furcal perforations, according to these authors was the maintenance of healthy tissues against the defects, without continuing inflammation, or loss of periodontal attachment. In already existing lesions, the aim would be the re-establishment of tissue attachment – this has proved to be extremely difficult to achieve, with the currently available materials!

Torabinejad and associates (1995) : evaluated the ability of MTA as a root-end filling material, to prevent bacterial leakage as compared with amalgam, IRM, or super-EBA.

They used 56 single-rooted teeth to study the time it took for Staphylococcus epidermidis to penetrate 3mm thickness of the test materials. The roots were resected and 48 root-end cavities were filled with the 3 test materials. The remaining teeth served as controls. The teeth were then attached to plastic caps of 12 ml plastic vials, with their root-ends in phenol red broth. The apparatus were then sterilized overnight with ethylene dioxide gas. A tenth of a microliter of broth with S.epidermidis was placed into the canals of 46 teeth (40 experimental , and 6 controls) The number of days needed for the microbes to penetrate the materials was determined.

The investigators reported that amalgam, super-EBA, and IRM started leaking at 6 to 57 days.

Most of the MTA samples didn't leak for the entire experimental period of 90 days!

The investigators also added that in a follow-up study(unpublished) a similar set-up was used to place the coronal portions of root-end filled root canals in contact with human saliva , while their root-ends were placed in trypticase soy broth. The number of days required for the microbes in the saliva to penetrate the materials (MTA, amalgam, IRM, and super-EBA) was determined. They found that similar results were obtained, as in the present study.

This study, apparently tested the 3mms of materials under the most severe contamination!

Torabinejad and associates (1995) : investigated the marginal adaptation of MTA as a root-end filling material, compared to the other commonly used materials like IRM, super-EBA, and amalgam. They used the SEM for this study. 88 single rooted teeth were cleaned, shaped, and obturated with gutta-percha and root canal sealer. The root ends were resected , and retrograde cavities were prepared and filled with the test materials. 40 roots were longitudinally sectioned into 2 halves. Resin replicas of the resected root-ends of the remaining non-sectioned roots were also prepared. The longitudinal sections of the roots as well as the resin replicas were mounted on aluminium stubs, and the distance between the test root-end filling materials and the surrounding dentin was measured at 4 points under the SEM.

The investigators reported that the longitudinal sections of the root-end filled teeth showed cracks in the tooth substance, and increased marginal gaps at the dentin-filling interface. MTA had the smallest gaps (2.68 + or – 1.35 micro m). IRM , had the largest gaps (11.0 + or – 7.9 micro m) and the poorest adaptation amongst the four materials tested. The gaps associated with super-EBA and amalgam were in between MTA and IRM.

When the gaps in the longitudinal sections were compared with those in the resin replicas, it was observed that the gaps were smaller in the replicas. Though the other materials had smaller gaps, MTA showed no gaps, in all the samples!

The investigators inferred that the marginal adaptations of the materials could be related to the physical and chemical properties of the materials, their handling during mixing, and application. The superior adaptation of MTA was attributed to the presence of a thin layer of the cement at it's junction with dentin, as well as the possible expansion of the material on setting.

In conclusion, the authors stated that MTA provided a better adaptation and seal, than the other commonly used root-end filling materials.

Torabinejad and co-workers (1995) : examined the tissue reaction of implanted super-EBA and MTA in the mandibles of guinea pigs. They used 7 animals for this in-vivo study. The test materials were placed in Teflon cups and implanted into the bony cavities that had been prepared in the mandibles. Half of the bony cavities in 6 animals received super-EBA, while the other half received MTA implants. Two prepared bony cavities in one animal served as controls.

After the implantations, the flaps were sutured back. Two months later, the animals were sacrificed, and histoanalyzed for the presence of inflammation, the predominant cell type, and the thickness of the fibrous connective tissue around each implant.

The investigators reported that –

a) the tissue reaction to MTA implants was slightly milder than that seen with super-EBA implants.
b) Bone deposition was seen immediately adjacent to 1, of the 5 MTA samples.
c) 3, of the 5 MTA samples were free of inflammation.
d) All 5 samples of super-EBA had thick fibrous connective tissue adjacent to the cement. This was less pronounced in the MTA samples.
e) All the super EBA samples were associated with mild inflammation.

The investigators concluded that both the materials- MTA as well as super-EBA were biocompatible.

The characteristics of an ideal repair material for root-end fillings, according to these authors are- good adherence to the preparation walls, so that the root canal system can be effectively sealed. It should be dimensionally stable, non-absorbable, moisture and corrosion-resistant. Further, it mustn't be electrochemically active, should not stain the periradicular tissues, it must be radio-opaque, easy to manipulate, must be non-toxic, be well tolerated by the periradicular tissues, and finally, it must promote healing!

Torabinejad and associates (1995) : investigated the response of periradicular tissues of dogs, to amalgam and MTA, when used as root-end filling materials. They used 46 teeth, from 6 dogs, for this in-vivo study. The access cavities were made, and the root canals were contaminated, by exposing the pulp to the oral environment for 2 weeks. They were then sealed with cavit for 4 weeks, to ensure the production of periradicular lesions.

The teeth were then randomly divided into 2 groups of 12 teeth each.

Grp 1 – the canals were cleaned , and obturated with gutta-percha and sealer. The access openings were sealed with MTA.

Grp 2 – the canals were cleaned and obturated with gutta-percha, without a sealer. The access cavities were left open to contamination.

After 1 to 2 weeks, each animal was subjected to 2 sessions of periradicular surgery.

Flaps were raised, and the cortical bone was removed. The roots were resected at the junction of the apical and the middle thirds. Root-end cavities were prepared, and one of the cavities in each premolar was randomly selected, to be filled with Zn-free amalgam, and the other, with MTA. The flaps were sutured back. The same method was followed for the other side of the mandible.

Three of the animals were sacrificed 2 to 5 weeks after surgery, while the remaining 3 were killed at 10 to 18 weeks post-op.

The tissues were prepared for histoanalysis. The investigators recorded the severity, extent of inflammation, and the predominant inflammatory cell type. The presence or absence of a fibrous capsule, cemental deposition at the root-end, and on the filling materials as well as the periosteum, and bone formation was also recorded. The histopathologic examination was performed by 2 investigators (double blinded) initially.

A total of 25 amalgam, and 21 MTA samples were studied

They reported that all the roots that were filled with amalgam had moderate to severe inflammation, while only a third of the MTA samples showed moderate inflammation. This difference was significant at the 2 to 5 week period, and at the 10 to 18 week period. The widths of inflammation at the 10 to 18 week period was significantly lesser in the MTA samples.

Cemental formation was not seen in any of the amalgam samples, nor in the gutta-percha samples. All the 10 samples of MTA showed cemental deposition at the 10 to 18 week period. 5 of the 11 MTA samples which were left open to contamination, and 6 of 10 MTA samples that had been filled with gutta-percha and sealer had cemental deposition over MTA. There was more fibrous capsules adjacent to MTA.

The authors also stated that the most reliable and meaningful biocompatibility test for potential root-end filling materials was the histologic examination at various time intervals. According to Craig and Harrison (1993), the periodontal ligament- derived tissue was primarily responsible for dental healing, and the endosteal-derived tissue was responsible for osseous healing.

The authors stated that in the present investigation, MTA didn't prevent regeneration of dental and osseous tissues. They speculated that MTA may have induced cementoblasts to produce matrix for the cemental formation over MTA. The chronic inflammation associated with amalgam samples was attributed to the egress of bacteria into the periradicular tissues secondary to an inadequate seal. In contrast, the MTA samples were associated with either no inflammation, or moderate inflammation, which demonstrated it's superior sealing ability.

The majority of the MTA samples with fibrous connective tissue underwent calcification as the post-surgical time interval increased.

Moreover, in the MTA samples which were left open to contamination, the formation of fibrous connective tissue, cementum ,as well as the low levels of inflammation indicated it's excellent sealing ability, and biocompatibility. The authors inferred that MTA was probably capable of activating cementoblasts to produce the matrix for cementum formation. This could also be due to it's sealing ability , high pH, or the release of substances that activate cementoblasts to lay down a matrix for cementogenesis.

The investigators concluded that MTA did not prevent regeneration of dental as well as osseous tissues when used as a root-end fillin material.

Torabinejad and associates (1995) : investigated and compared the anti-bacterial effects of amalgam, ZnOE, super-EBA, and MTA, on some selected oral bacteria.

Nine facultative, and 7 anaerobic bacteria, which are usually found in infected root canals were used for this study. These included S. faecalis, S mitis, S.mutans, S. salivarius, Staph.aureus, Staph. epidermidis, E. coli, Lactobacillus, and Bacillus subtilis.

The anaerobes were Prevotella buccae, B. fragilis, P.intermedia, P.melaninogenica, F. necrophorum, F. nucleatum, and P.anaerobius.

The bacteria were grown on solid media, and freshly mixed, as well as 24- hour set materials were placed on the inoculated media. They were then incubated for 24 to 48 hours, at 37 degrees C. Impregnated discs with super-EBA liquid served as controls.

The anti-bacterial effects seen with each material were measured in millimeters corresponding to the diameters of the zones of inhibition.

The statistical analysis of their data revealed that the impregnated discs with super-EBA liquid caused varying degrees of growth inhibition for both the types of bacteria used.

Amalgam had no anti-bacterial effect of any sort, against any of the bacteria tested.

Super-EBA pastes had some antibacterial effects on both the types of bacteria tested.

MTA, had an antibacterial effect on some of the facultative bacteria, and no effect on the strict anaerobes.

The investigators concluded that none of the test materials had the complete anti-bacterial effects that were desired, for root-end filling materials. Moreover, the anti-bacterial property of the materials might be short-lived and temporary.

They added that an ideal root-end filling material should also possess bactericidal or bacteriostatic effects, apart from the other physical and chemical properties. Apparently, there were no reports in the dental literature, pertaining to the anti-bacterial activity of root-end filling materials. That there was no "ideal" root-end filling material, was also addressed by the authors, and they stated that long-lasting antibacterial effects from set root end filling materials might be an unreasonable expectation!

Torabinejad and associates (1995) **:** determined the chemical composition, pH of the setting cement and the radio-opacity of MTA.

They also compared the setting time, the compressive strength and the solubility of the material, with amalgam, super-EBA, and IRM. They used the Energy dispersive spectrometer modified with the Micro EDS software, in conjunction with the SEM for the purpose. The MTA was mixed and allowed to set in an incubator, at 37 degrees with 5% CO2 and moisture. Five set specimen with varying proportions of water and powder were examined. For the quantitative X-ray analysis, the specimens were carbon coated to a thickness of 100nm and again mounted in the SEM, using the DVEX system. The pH was measured with a pH meter using a temperature-compensated electrode. The radio-opacity was determined according to the ISO norms. Radiographs were taken with an exposure time of 0.25 seconds to give a radiographic density reading of 2. A total of 5 films were taken for each specimen. The films were processed, and the photographic densitometer was used to take readings of the radiographic image of the specimens, each step of the stepwedge, and the unexposed part of the film. The setting time and the compressive strength were determined according to the ISO, and the British Standards Institution respectively. The setting time was measured with the Gillmore indentor needle. This test was repeated 6 times, for each material!

The solubility of the test materials were determined by the modified method of the ADA specification number 30. Six discs of each material were fabricated and tested. They were then stored in

100% humidity for 21 hours, and then stored in distilled water at 37 degrees for 1 day.

To guage the compressive strength, the specimen were immersed in distilled water for 21 hours to 3 weeks prior to measuring their strength with an Instron testing machine.

The investigators reported that MTA showed specific phases throughout the material. All MTA was divided into CaO, and CaSO4. The former, appeared as discrete crystals and the latter, as an amorphous structure with a granular appearance. The mean value of prisms was 87% Ca, 2.4% silica, and the remainder- oxygen.

In the amorphous structure, 33% Ca, 49% phosphate, 2% C, 3% chloride, and 6% silica.

The pH of MTA, after mixing was 10.2, and it rose to 12.5, at 3 hours. It remained constant after this.

The mean radio-opacity of the material was 7.17 mm of equivalent thickness of aluminium.

The mean setting times of the materials were as follows **:** amalgam(4 mins + - 30 s).

Super-EBA (9 mins + - 30s), IRM (6mins +- 30s); MTA (2 hours +- 5 mins).

MTA powder consists of fine hydrophilic particles and the main components present in the material were tricalcium silicate, tricalcium aluminate, tricalcium oxide, and silicate oxide. In addition, there were small amounts of other mineral oxides that were responsible for the physical and chemical properties of this material. Bismuth oxide powder had been incorporated for radio-opacity. MTA was slightly less radio-opaque than the reinforced ZnOE - based cement Kalzinol. It was more radio-opaque than IRM and super-EBA. Electron probe micro-analysis of MTA showed that Ca and phosphorus were the main ions present in MTA. Since these ions were the principal components present in the dental hard tissues, MTA could prove to be biocompatible when used in contact with cells and tissues.

The hydration of MTA powder resulted in a colloidal gel, which solidified to a hard structure within 3 hours. Generally, a fast-setting cement had been advocated for root-end fills, but the disadvantage of these materials could be attributed to the fact that the faster a material sets, the more it shrinks. The compressive strength of MTA, though initially weak, it's value increased with time, and was comparable to that of IRM and super-EBA. This was attributed to the effect of moisture

The investigators concluded that MTA had adequate physical properties that were required of a root-end filling material.

Abedi & Ingle (1995) : stated that most commonly used materials in endodontics are gutta-percha and sealer. But for certain tasks like perforation repairs or root end fillings, a special purpose material is needed. Though, the "Ideal" special purpose material is still elosive, to address the shortcomings of most of the materials available today, MTA has been developed at Loma Linda University to seal off the pathways of communication between the root canal system and the external surface of the tooth.

The results of the physical properties, biocompatibility and clinical studies with MTA have been promising, offering for the first time, the possibility of regeneration of tissues rather than just repair.

They also stated that most of the materials presently used have found their way in endodontics, from the restorative field without much considerations of the special conditions and requirements of the periradicular tissues.

Kettering and Torabinejad (1995) : examined IRM, super EBA & MTA for mutagenic potential, by the Ames test. Strains of S.typhimurium LT-2, (TA 98, R-factor strain and TA 1535, non-R-factor strains) were used in a standard Ames mutagenicity assay.

They reported no increase in revertant bacterial colony counts with any of the test materials.

The investigators concluded that super EBA & MTA are not mutagenic and stated that because MTA seals better than most of the used root end filling materials, is less cytotoxic than these materials, and is non-mutagenic.

Moreover MTA is more radio opaque than IRM & Super EBA. Its not affected by blood contamination and the compressive strength is similar to IRM and EBA, but less than amalgam.

None of the materials were completely anti-bacterial and implantation tests and usage tests in experimental animals must be conducted to assess the clinical potential of this material.

Biggs and associates (1995) : evaluated the condition of in-vitro retrograde fillings of amalgam, GIC, and EBA cements after 10 years of storage in physiologic saline. The authors assessed the durability of amalgam and alternate materials that had been subjected to conditions that simulate the periapical environment. Sixty one extracted incisors were divided into 6 groups of 10 teeth each, with 1 tooth as control.

Half of the teeth were resected with a high- speed bur and half, with a low speed bur. They were prepared for retrograde fillings, and EBA and GIC were placed in 10 teeth each, of the high and low speed groups. Zinc containing amalgam was placed in 10 teeth of the high-speed group, and zinc-free amalgam was placed in 10 teeth in the slow speed group.

The teeth were then stored in saline for 10 years! After this period, the apical portions were photographed at x30 magnification, and evaluated by the authors for marginal discrepencies , root crazing, staining, voids, and roughness.

The investigators reported that overall, EBA cement and amalgam sealed better than GIC in every category, except root crazing.

They concluded that perhaps, as some studies suggested, EBA may replace amalgam as the retrofill material of choice. Failure of endodontic surgery including retrofills had been attributed to the poor marginal adaptation, metabolic intolerance to the materials and their break-down products, and mechanical failure of the material due to solubility and corrosion.

The authors stated that long term studies evaluating amalgam suggest that the breakdown products of the material may contribute to the high failure rate of surgically treated endodontic cases. Studies suggesting the use of EBA or GIC, to be more suitable as compared to amalgam [Frank et al (1992)], Dorn and Gartner (1990); Inoue et al (1991)], are promising, but further evaluation must be done.

Goon and Lundergan (1995) **:** reported a case of a long-standing undetected perforation of the furcation of a lower molar, n a 27 year old patient. There was osseous breakdown, loss of attachment, and a chronic draining periodontal pocket about 6mm deep was also present. A radiograph revealed large threaded posts in the mesial and the distal canals, as well as an inadequate endodontic treatment. There were independent lucent lesions at the apex of the mesial root, as well as in the furcation, and a perforation was suspected.. Endodontic re-treatment was initiated, and the posts were unthreaded, to allow for the drainage of the exudates. The old root fillings were removed, and the treatment was completed . After laterally condensing gutta-percha and sealer, a Glick instrument was used to heat sear the gutta-percha and the soft mass was gently condensed into the mesiobuccal canal, against the perforation.

Four months later, a 6mm pocket was still present adjacent to the buccal furcation. The soft tissues were oedematous, and on probing, suppuration was seen. The recall radiograph revealed significant osseous healing at the mesial apex. But, bone breakdown continued to progress from the furcation, to the junction of the middle and the apical third of the roots.

A GTR procedure was initiated, and a full thickness flap was raised to expose the buccal furcation defect. There was extensive interradicular bone resorption. Thorough planning of the root surfaces was done and a Gore-Tex membrane was trimmed to cover the bony defect. It was held in place with a Gore-Tex sling suture, and the flap was repositioned over the membrane and sutured. A periodontal dressing was given and the patient was put on a 6 - week regimen of 0.12% hexidine rinses. At 7 weeks, the Gore-Tex membrane was removed by raising a limited full thickness flap and teasing the material off the bone with tissue forceps. Immature tissue was seen within the furcal defect. The flap was then re-sutured to protect the forming tissues. At a 6 month evaluation, a good response was seen to the GTR procedures. The tooth was asymptomatic and the soft tissues were normal. Probing revealed an attachment gain, and an x-ray showed significant regeneration of furcal bone. 3 months later, an x-ray showed that the bone regeneration had slowed. A leakage was suspected despite the presence of a warm gutta-percha seal.

The chamber was re-entered and the gutta-percha was removed from the mesibuccal orifice. More exudates were drained thus. The dentin was dried with alcohol and the inter-furcal tissue fluids were dried with paper points.

A GI sealer was placed into the canal, and a thick mix of IRM was condensed into the space against the perforation. The pulp chamber was restored with an amalgam core.

4 months later, the tooth was asymptomatic and there was no pocket on probing. Except for the site of the defect, the bone density appeared normal throughout the furcation.

1 month later, a full coverage crown was given.

After a year, the periodontal tissues were normal, and probing depths were between 2 to 3 mm throughout. A radiograph revealed that bone regeneration of the furcation was complete. A thick lamina dura was seen adjacent to the perforation site, and against the extruded sealing materials.The materials, however, did not resorb from the site.

Jubach (1995) **:** advocated backing up a millimeter in case of an apical perforation, and then filling the canal. If failure occurred, retrograde filling had to be done, and the prognosis in such cases, was generally fair.

In coronal perforations close to the gingival margin, the canal could be filled with lateral condensation of gutta-percha to seal the defect without material extrusion into the bone.

The prognosis, in such cases would be guarded. He advocated prompt closure of the perforations, to achieve the best prognosis. CaOH, could be used for bridging of the perforation by placing the dry material, and covering it with a sealing cement and restoration. He also advised using “common sense”, to understand the internal morphology of the tooth being treated, and thus, avoid trouble.

<u>Arens and Torabinejad (1996)</u> : presented 2 case reports, describing MTA as a suitable material for large furcation perforations. A 64 -year old male patient had pain and swelling associated with a post, which had perforated the furcation at the mesial aspect of the distal root. A 12 mm pocket was observed, on the buccal and the lingual aspects of the tooth. A large radiolucency was present between the apex, to the crest between the roots.

The post was removed with ultrasonics, and in the process, the defect was enlarged to 4x5 mm. The defect was irrigated with 2.5% NaOCl, and then semi-dried. MTA was placed in the pulp chamber with an amalgam carrier. A radiograph revealed extrusion of the material into the periradicular tissues and that the defect was closed. The patient's pain and swelling subsided within 24 hours.

3 days after treatment, the buccal mucosa returned to it's normal consistency and colour, and there was only slight sensitivity to percussion.

At 6 weeks, the patient was totally symptom-free, and the pockets had healed. A 3-month recall radiograph revealed reduction of the radiographic lesion, indicating bone regeneration. A 1-year recall radiograph revealed complete resolution of the defect.

Another case of a 13- year old patient in whom there was a furcal perforation of a molar, 7x10 mm large, and associated with a 6x11 mm radiolucency between the roots. After irrigation and drying, MTA was placed into the perforation site with a large wet cotton pellet over it, and the access was closed with IRM.

One week later, the tooth was asymptomatic and the patient had only mild discomfort. At 6 weeks post treatment, the IRM was replaced with amalgam. The 12- week recall showed that there was no probing defect, no symptoms, and normal soft tissue status. A 9-month recall indicated significant resolution of the furcal radiolucency.

The authors stated that MTA was an ideal compound for the repair of large furcation perforations, as a barrier was not needed. The extruded material showed no adverse effects, indicating it's biocompatibility. The limitations posed by other repair materials had been eliminated. Moreover, cemental deposition was also seen. They added that the success of treatment lay in removal of contaminants with burs, ultrasonics, and NaOCl. The high pH of the cement promoted healing.

In conclusion, they found the "positive results of these worst case-scenarios" in humans to be so good, that they speculated about the more promising results that would be shown by MTA, in the treatment of recent perforations.

Allam (1996) **:** proposed a 2 step technique which, according to him was a "conservative approach" to the treatment of stripping perforations, and included surgical correction of the defects.

The first step was the classic endodontic phase in which hemorrhage control, canal disinfection and drying, followed by obturation with lateral condensation was advocated. A thermo-mechanical pack at 1500 rpm to create a dense intracanal mass, and to produce an overflow of gutta-percha through the perforation was done.

The second phase comprised reflection of a triangular flap, making of a bone cavity with a round bur and irrigation, and exposing the defect. The cortical bone coronal to the surgical defect was preserved. Curettage of the inflamed tissue was then done, followed by removal of the excess gutta-percha with a hot spatula. The gutta-percha was then cold-burnished and the flap was sutured back in place.

The author said that this technique was used by him since 2 years, and 10 cases were repaired thus. Seven were lower molars, with distal perforations of the mesial root and 3 were upper molars with mesio-buccal root strippings. Three cases had old perforations with bone destruction, while the rest were treated immediately after the perforation occurred. He described 2 cases, in which strips of the lower molars had occurred. The patients were teens, and the procedures were deemed successful when recall visits revealed healing, at 1 year, and at 15 months post- treatment respectively.

He added that a few years ago, extraction was the only solution for strip perforations. But today, with the outcome of surgery, the treatment of strips could show positive results, allowing for complete osseous repair. A strip couldn’t be treated as a lateral perforation, as unlike the latter, they have larger, wider, and oval cavities with thin walls. Here, giving the defect a retention form was not feasible(unlike lateral perforations), and hence the delivery of a dense fill by the orthograde approach was essential to seal the periphery of the existing strip.

Bates and associates (1996) : determined the longitudinal sealing ability of MTA in comparison with amalgam with cavity liner and super-EBA. The fluid filtration method was used to affirm whether MTA could be used as a root-end filling material. They used 76 extracted teeth for this n-vitro study, and after the canals were cleaned and shaped, the roots were resected. Ultrasonic preparation of the root-ends was done under telescopic (x2.0) magnification.

Seventy two roots were randomly divided into 3 test groups according to the materials being tested, and then, filled. Micro-leakage was observed and assessed at 24 hours, 72 hrs, 2 weeks, 4 weeks, 8 weeks, and 12 weeks.

The investigators reported that MTA demonstrated excellent sealing ability throughout the 12 weeks of the experimental period. Super-EBA was also associated with good sealability. The micro-leakage of both these materials was significantly lesser than that shown by amalgam.

The authors concluded that MTA was superior to amalgam amd comparable with super-EBA, in preventing micro-leakage, when used as a root-end filling material.

Pitt Ford and associates (1996) : compared the dental pulp responses seen in monkeys, after pulp capping with MTA and CaOH. They used 12 incisors for this in-vivo study and gauged the pulpal inflammation. After 5 months, the animals were sacrificed and the tissues were prepared for histoanalysis.

The tissue sections were assessed for the presence of a dentin bridge, inflammation, and bacteria on the walls of the cavity.

The investigators found no inflammation in 5 of the 6 specimen capped with MTA. All the 6 teeth had a complete, continuous thick dentine bridge formation, and no bacteria were seen. There were no soft tissue inclusions.

CaOH-capped pulps, on the other hand, showed severe pulpal inflammation in all the teeth, and an incomplete dentin bridge had formed in only 2 specimen. 1 sample had bacteria in the cavity wall.

The investigators concluded that since MTA sealed the pathways of communication between the root canal system and the external surface of the teeth effectively, it was suitable for pulp capping in vital pulp therapy.

Abedi and associates (1996) : used cuspids of 6 dogs, for an in-vivo study, and examined the amount of hard tissue formation and the degree of inflammation adjacent to MTA and CaOH preparations. The histomorphometric analysis of their data revealed a significantly higher frequency of calcific bridge formation and less inflammation in the MTA- group, as compared to the CaOH group.

Torabinejad and associates (1997) : investigated the response of the periradicular tissues of monkeys, to MTA and amalgam, when used as root-end filling materials in teeth in which bacterial contamination of the root canals was avoided. They used 3 monkeys, from whom the incisors were selected, for the study. The pulps were extirpated and the canals were filled with laterally condensed gutta-percha. The access cavities were sealed with amalgam. Buccal flaps were then raised and root-end resections and preparations were performed. Half of the root-end cavities were filled with MTA, while amalgam was placed in the remaining teeth.

5 months later, the animals were sacrificed, and the tissues were prepared for histoanalysis. The investigators scanned for the concentration, extent of inflammation, the predominant inflammatory cell type in the periradicular tissues next to the root end filling materials. The presence or absence of bacteria within the tooth, fibrous capsules, cemental deposition on the root end, and on the filling materials, as well as new bone formation, was also recorded. The examination of the specimens was done by two investigators without the knowledge of which material had been placed in the root end. They reported that the periradicular tissues revealed no inflammation in 5 of the 6 root-ends filled with MTA. A thick layer of

cemental deposition was also seen in the specimen. Periodontal fibres had inserted into the new cementum, mimicking Sharpey's fibres. All the specimen associated with amalgam showed periradicular inflammation, and no cementum had formed over the material. Based on the results of this study and the earlier experiments the authors stated that amalgam is unsuitable as root end filling material as it did not prevent microleakage, nor did it allow for the regeneration of the dentoalveolar structures.

The investigators concluded that amalgam usage, should be discontinued, as a root-end filling material. They added that the reason for the presence of polymorphs may be related to the corrosion product action. The layer of cementum over the MTA showed irregularities in some samples though no defects nor soft tissue inclusions were seen. The investigators attributed the formation of cementum over MTA, to its sealing ability, biocompatibility, or its alkaline pH while setting. Moreover, it was not an irritant, like the existing root end filling materials.

Chau & Associates (1997): determined the ability of CPC when used as a perforation repair material and the effect that a CPC matrix has on LC-GIC as placed as a furcation perforation repair material. They used 30 extracted molars and 10 teeth were used in each of 3 experimental groups while 10 served as controls.

Access openings were made in the 30 experimental teeth and perforations were made in the center of the pulp chamber floor. All preparations were randomly divided into three groups of 10 teeth each.

Group 1 – The defects were repaired with CPC. The powder was mixed to a putty like consistency with 1M solution of sodium phosphate diheptahydrate ($Na_2HPO_4 - 7H_2O$). The paste was placed into the defect with a Messing gun and gently condensed into the defect. CPC was added till the defect was completely filled.

Group 2 – 10 defects were repaired with LC – GIC. The GIC was carried in small amounts into the chamber, on the tip of an explorer and was allowed to flow apically into the defect. It was then light cured. Layers were added and cured till the defect was completely filled.

Group 3 – 10 defects were obturated with CPC paste as in group 1. After 15 minutes the coronal 1-2mm was removed from the defect with a spoon excavator. GIC was then added to this void and cured as in group 2. In the defects were filled upto the level of the pulpal floor.

All the procedures were done under a stereomicroscope (X10) a moistened cotton pellet was placed between the roots and no attempt was made to prevent the overextrusion of the repair material. All the teeth were kept in a humidor at 100% humidity and 37^{o}C for 2 days to allow complete setting of the CTC. The teeth were then immersed in India ink for 48 hours. After removal from the dye they were dried for 1 day and sectioned under a dissecting binocular microscope.

For group 1,2 the leakage was measured as the most coronal linear extent of dye-penetration from the most apical extent of the perforation. For group 3 the leakage was measured as the most coronal linear extent of dye-penetration from the apical surface of the GIC. The maximum dye-penetration for each defect was independently recorded, by 3 board -certified endodontists.

The pulp chambers and the access preparations of all the teeth were filled with LC composite resin.

The investigators reported that all the experimental groups showed dye-penetration to a significant extent. The greatest leakage was shown by perforations repaired with GIC over a CPC matrix (90%). Extrusion of CPC was seen in all the samples of group 1 and in 8 of the 10 samples in group 3. There was no extrusion of GIC in any of the group 2 & 3 specimens.

The authors stated that these defects should be immediately repaired and the biocompatibility, sealing ability and the control of the materials are major considerations pertaining to the repair. They speculated that the more viscous mix of the GIC used in the present experiment could have contributed toward the absence of its extrusion beyond the furcation.

They concluded that CPC had a sealing ability comparable to LC-GIC. The advantage of CPC was the biocompatibility and its austioconductive ability. Moreover, its usage as a matrix has a good potential if the removal of the excess CPC from the dentin walls could be accomplished. This would enhance the sealing ability of the repair material placed above CPC. Bony repair at the furcation would also be stimulated and therefore, CPC may significantly improve the prognosis of teeth with furcation perforation.

White & Certosimo (1997): presented a case in which combination therapy was effectively used to treat a persistent periodontal lesion and a perforated root canal that were surgically induced during an orthognathic procedure.

A 32 - year old woman had a persistent lesion associated with tooth no.6. She had undergone a LeForte I osteotomy with multiple section in the maxilla and a bilateral suggital split osetotomy in the mandible to correct a skeletal/ dental class II malocclusion. The mesial root surface of the tooth gave the radiographic appearance of a sectioned root surface. The mesial surface had a persistent radioluscent area. The patient had no discomfort in the area of the lesion after the initial surgical procedure.

Five months later the tooth developed a draining fistula and the pulp tester was used to confirm the absence of any response. An ortho grade approach was done 3 months after the initial endotherapy since the patient had persistent discomfort on mastication. The mesial surface showed a radioluscency until the referral to the periodontist 54 months after the orthognathic surgery. A 10mm pocket was present at the mesial surface and a 7mm deep pocket was seen on the distal aspect of tooth no.7. Both teeth had

Class I mobility and bleeding and pus exudation was evident upon probing. A radiograph confirmed a lucent area along the mesial surface of the tooth no.6 with loss of root structure in the apical third of the root. Gutta-percha was close to the root surface. The periodontist did a root planing and subgingial currittage and 8 weeks later a recall check revealed persistent bleeding and purulence on probing. There had been no reduction in the probing depth.

An open flap debridement of the area to allow a direct assessment of the lesion and revealed the existing problem. So the surgical appointment was co-ordinated with operative dentistry to provide restorative support. A full thickness flap was elevated and the osseous defects and the root surfaces were debrided with sonic scalers. A combination of 1 & 2-wall intrabony defect was seen at the mesial surface of tooth no.6. The vertical defect ranged from 4-6mm. A 5 x 2mm segment of gutta-percha was exposed starting about 4mm apical to the CEJ. The dentist prepared the area over the exposed GP and etched the root surface with polyacrylic acid for 10 seconds. The site was then repaired with GIC with a syringe and it was covered with a preburnished matrix to ensure the correct contour. After three minutes the matrix was removed and warnished was applied on the restoration. 15 minutes later the polishing of the restoration was done with fine diamonds and polishing disks with water spray. The root surfaces were then conditioned with cotton pellets saturated with tetracycline (pH 1) for 3 minutes. Tetracycline hydrochloride was also mixed with DFDB allograft and placed in the defect (Kramer

1992); Schallhorn and McClain (1988). The defect was not overfilled and expanded PTFE membrane was placed to cover the defect. The surgical site was closed with e-PTFE suture.

Doxycycline 100mg/day was prescribed for two weeks along with hexidine twice a day for 4 weeks. The patient returned at weekly intervals until the membrane was removed after 6 weeks. A red and a rubbery consistency of the soft tissues was found in the coronal portion of the defect.

Two years after the initial surgery, the periodontist took an IOPA, and a clinical examination revealed that teeth nos. 6 and 7 showed normal probing depths, without any bleeding. Mobility was absent.

A surgical re-entry of the area was done since the patient complained of "a different feeling" in the area. Flap elevation showed no residual evidence of the previous bony defect. The material in the area of the defect gave the clinical presentation of bone. IOPAs revealed an increase in the volume of bone and bone density in the mesial surface of tooth no.6 between the pretreatment X-ray and the 2 year reentry X-ray.

After flap closure the patient did not find any "unusual feeling" in the area of the surgery. The tooth no.7 was restored with a PFM crown 6 months after the reentry procedure.

The authors concluded that a complete fill of the 1 & 2-wall bony defect had occurred. Moreover, bone formation was also noted (Gottlow and Associates, 1986).

They speculated that the position of the bone on the distal surface of tooth no.7 may have significantly contributed to the ultimate volume of the bone filled achieved in the present case. Tetracycline was used because of its ability to expose collagen fibers (Lafferty et al. 1993) and also to remove the smear layer. The other possible advantages of tetracycline were its ability to bind to the demineralized surface [Bjorvatn et al. 1985], while retaining its anti-microbial activity and its adsorbtion to an its later release from dentin.

In conclusion the author stated that although no histologic specimen were available in the present case, the clinical and X-ray findings supported concept of a combination of root conditioning, osseous grafting and GTR to achieve the repair of an osseous defect adjacent to a perforated canal. GIC was also successful in sealing a root surface perforation adjacent to the periodontal lesion. Hence, this multi-diciplinary approach resulted in the preservation of a tooth and prevented its extraction.

<u>Alhadainy and Abdalla (1998)</u> : evaluated the effect of calcium sulphate or HA matrix, on the sealability of a RM-GIC to repair the dentin defect of furcal perforations. They used 55 extracted molars for this in-vitro microleakage study. After gaining access, and extirpating the pulps, perforations were created in 45 teeth, and moist cotton pellets were placed between the roots. The teeth were then randomly divided into 3 test groups [15 teeth/group], while 10 teeth served as controls.

Grp 1- 15 perforations were repaired with RM-GIC.

Grp 2- 15 perforations were repaired with calcium sulphate, as a barrier under GIC. The calcium sulphate was placed with a messing gun into the moist defect, and the powder was added till the moisture from the pellet was saturated. After it set, the dentin surfaces were prepared with a bur to make a small cavity with a CaSO4 floor. RM-GIC was then placed into the perforation.

Grp 3 – 15 defects were repaired with HA, under GIC. After the HA set, dentin surfaces of the defect were prepared in the same manner as in group 2, such that there was a small cavity with a HA floor. RM-GIC was then placed into the defect.

The repairs were done with a stereomicroscope [x10], and the access cavities were sealed with composite resin. The teeth then spent 2 weeks in 2% methylene blue dye at room temperature. They were then sectioned parallel to their long axes, and examined under a stereomicroscope [x20], to evaluate the dye penetration. The perforation image was transmitted onto a Macintosh computer using the NIH Image 1.47 Macintosh program. Leakage was measured on each section, on all the walls of the defect.

Their statistical analysis of the data revealed that perforations sealed with RM-GIC alone showed 22.79% of mean leakage in the walls of the perforation.

Calcium sulphate under RM-GIC showed a mean leakage of 17.49% and HA under RM-GIC showed a mean leakage of 16.87%.

In all the specimen of group 1, the GIC flowed into the space that clinically, would have been occupied by inter-radicular bone.

In groups 2 and 3, POP and HA provided a successful barrier against extrusion of the hybrid GIC.

The investigators concluded that the removal of the debris of POP would improve the bonding property of the GIC, but moisture adversely affected the sealability of GIC. The sealing of the defect per se, depended entirely on GIC, as POP and HA could be expected to allow dye leakage, due to their physical properties.

They stated that dentin must not be etched, as the acid may penetrate through the POP or HA, into the underlying tissues. The investigators added that a technique had been developed in this study, in order to overcome the problems in repairing furcal perforations - like moisture, poor accessibility, and the fact that these defects act as bottomless pits.

The aim of perforation repair, according to the authors, was to seal the dentin defect and to allow for a suitable condition, for the formation of new periodontal attachment. Light cured materials were superior in sealing the defects when compared with their chemically-cured counterparts.

Extrusion of the repair material was a common problem associated with repair of perforations. They added that POP was a good barrier and had the ability to exclude epithelial tissue from the site of bone formation. It had a rapid rate of resorption that coincided with the rate of new bone growth [Frame (1975)].

Nakata and co-workers (1998) : compared the sealability of MTA and amalgam, when used as repair materials for furcal perforations. They used the anaerobic bacterial leakage model, for this study on 42 extracted molars. Perforations were created in 39 teeth, and they were then randomly divided into 2 experimental groups of 18 teeth each. 6 teeth served as controls. A dual chamber anaerobic leakage model was assembled. Brain heart infusion (BHI) broth with yeast extract, hemin, menadione and the chromogenic indicator bromcresol purple were used as the culture broth for *Fusobacterium nucleatum.* The leakage of F. *nucleatum* was compared between the 2 groups and statistical analysis of the data revealed that –

None of the 18 samples of group 1 [MTA], showed any leakage during the experimental period of 45 days. Amalgam on the other hand, leaked significantly more, and the leakage was detected between 21 to 38 days.

The investigators stated that since anaerobes predominate in endodontic infections, the use of an anaerobic leakage model was clinically relevant, and that these results were consistent with the findings of Torabinejad and associates (1995).

The authors speculated that in this study, the contraction of the alloy [amalgam] could have contributed towards the leakage. Nelson and Mahler [1990] had found this amalgam [high copper, zinc-free] to be the best in preventing leakage. MTA, with it's hydrophilic property and it's composition which is similar to that of dentine, had an upper hand over the other materials like LC-GIC, Ca(OH)2, ZnOE, super-EBA, amalgam and tricalcium phosphate, in sealing the defect. The inadequate sealing property of the other materials could have been responsible for the constant presence of inflammation [Balla and associates 1991].

The authors also stated that it was doubtful whether MTA had an anti-bacterial property as such, but the marginal adaptation of MTA, under the SEM had shown the smallest gap sizes [2.68 μm), whereas amalgam had shown gaps upto 18.8 μm.

The distinct physical and chemical properties of the materials could have been responsible for the results obtained in this study. In conclusion, the authors stated that MTA was significantly better than amalgam, in preventing leakage of *F.nucleatum* past furcal perforation repairs.

Stockton and Suzuki (1998) **:** stated that 50% of perforations occur during post-space preparation [Bakland (1995)]. The prognosis of perforated teeth ranged from poor, to good- small supra-gingival crown perforations had little effect on the outcome of treatment, whereas the coronal half of the roots, when perforated, had the poorest prognosis. Apical perforations, according to the authors, “falls somewhere in between” these.

They stressed that posts do not reinforce teeth, but served their purpose, in retaininig the core. The safest way of avoiding mishaps during post-space preparation was to remove gutta-percha with a heat carrier. The space could be enlarged parallel to the long axis of the tooth, with files, to achieve the desired diameter. The most prevalent types of mishaps during post space preparations were due to the use of end-cutting drills, and making over-sized preparations. The authors advocated the usage of non end-cutting safe instruments, for the post space preparation. Microleakage could be prevented, by fitting the post within 0.5 mm of the gutta-percha filling. A radiographic evaluation, prior to the cementation of the post would be helpful in determining the position of the post.

They stated that though researchers had not yet determined the “ideal” post length, the common guidelines indicated that 4 to 5 mm of gutta-percha would have to remain undisturbed, and the length of the post would have to be equal to that of the anatomic crown or ½ to 2/3 the length of the root contained within the bone. If a post was needed, say, in posterior teeth, the MB and the ML canals of lower molars, and the MB canals of the upper molars should be used only in exceptional cases, and usually, the larger roots are preferred, like the palatal root of the upper molars, and the distal root of the lowers.

That the width of the post had little to do with retention of the core, as such, whereas it could considerably increase the risk of root perforations, was addressed by the authors. Atleast 1 mm of remaining tooth structure between the walls of the prepared canal and the outer surface of the root, should be present, as the preservation of tooth structure was of prime importance.

Clinicians could reduce the occurrence of perforations by altering their techniques for preparation of the post-space. Cervical perforations, when created, increased the likelihood of causing periodontal breakdown.

The ideal objective of treatment of post perforations was to repair the defect without preventing the re-establishment of the epithelial attachment. This would depend on the position as well as the size of the perforation. A perforation immediately apical to the epithelial attachment would pose a delicate situation- surgical repair could lead to loss of the epithelial attachment.

Externalization of the defect would provide for the re-attachment, further apically on the root. Two approaches could be employed- a) an apically repositioned flap, and bone re-contouring or, b) orthodontic forced eruption.

A full thickness flap with a sulcular incision and 2 vertical incisions could be raised, and the bone is then removed, to expose the defect. A class III preparation design must be created, with mechanical retention. After sealing the defect, the interproximal bone should be re-contoured to attain the desired anatomic contour. The flap can then be repositioned apically.

Materials like super-EBA, and Zinc polycarboxylate could enhance the prognosis.

The authors advocated a surgical approach for the repair of post - related perforations, as material extrusion would frequently occur with the intracoronal approach.

A follow up of 2 years would be prudent.

GTR procedures, according to the authors, would find a suitable place in endodontic surgeries.

If hemisection has to be done, say, in the lower molars, a pre-formed post, placed prior to the procedure would be better, as the placement of a post after hemisection would be exceedingly difficult. After complete healing, full coverage crowns could be placed, and the prognosis, generally, would be good.

<u>Fischer and co-workers (1998)</u> : determined and compared the bacterial leakage of MTA with commonly used root-end filling materials like IRM, Super-EBA, and zinc-free amalgam.

They used 56 extracted teeth with straight canals, and they were kept moist throughout the experiment. After taking initial radiographs, the canals of 48 teeth were mechanically prepared for a retrograde fill, to a depth of 3 mm, and their roots were resected at 90 degrees to the long axes. The teeth were then steam-sterilized for ½ an hour under a laminar air-flow hood. The test materials were then placed in 40 retro- prepared canals. The teeth were then divided into groups of 10, and each group was root filled with a different material. Eight teeth served as controls.

Twelve – mm plastic vials were used to suspend the prepared teeth in phenol red dextrose broth. A hole was bored through the center of each cap of the vials. The teeth were then inserted into the fabricated hole, upto the level of the CEJ.

The placement was such that only the roots would be exposed the bacterial growth medium. The broth reached a level of 2 to 3 mm above the resected root ends. *S.marcescens* was then inoculated into the canal of each tooth. The entire apparatus was then placed in an incubator at 37 degrees C. To ensure the viability of the bacteria throughout the test, the contents of each canal were replaced with fresh samples of the bacteria, twice a week.

The phenol red broth vials were monitored for colour change four times a week. The experimental period was 120 days.

The investigators reported that amalgam-filled samples leaked within 10 to 63 days.

IRM samples leaked within 21 to 73 days. Super-EBA samples leaked within 24 to 91 days.

The MTA samples did not leak till 49 days. At the end of the experimental period, 4 samples of MTA had not leaked! The statistical analysis of their data indicated that MTA was the most effective root-end filling material, against penetration of *S. marcescens*.

The investigators attributed the much superior sealing ability of MTA, to it's setting expansion in a moist environment.

The authors concluded that MTA should be given serious consideration, when a root-end filling is indicated, and also added that to date, no material had been found to satisfy all the requirements of an "ideal" root-end filling material. Gutta-percha, ZnOE, Cavit, composite resin, and gold foil, which have been used for retrograde filling, had their limitations, in achieving this goal of providing a good seal.

Imura and co-workers (1998) **:** evaluated the sealability of LC-composite resin in the repair of furcation perforations in lower molars, when used in combination with plugs of CaSO4 or CaOH, by measuring the coronal microleakage with India ink.

They used 90 extracted teeth, and embedded them in a POP block after coating the roots with silicone.

The 90 teeth were then randomly divided into 2 groups-A and B.

Grp A comprised of 80 teeth, 20 of which were used in each of the 4 experimental groups.

Grp B comprised 10 teeth, which served as controls.

Grp 1 – 20 perforations were repaired with amalgam condensed over the defect.

Grp 2 - 20 perforations were repaired with the composite All Bond II system. A little composite was applied to the base of the defect with a plastic instrument and condensed, and cured. The walls of the defect were etched with 32% phosphoric acid for 15 seconds. 5 coats of primer were applied only to the dentin walls. 3 coats of the composite resin were cured, to seal the defect.

Grp 3 – 20 defects were repaired with POP [CaSO4], as a barrier under the resin. Over extrusion was expected, but the resin provided a mechanical barrier. Excess paste was removed from the walls of the perforation, to enable placement of the composite resin.

Grp 4- 20 defects were repaired with CaOH as a barrier under the resin. The CaOH was placed in the base of the perforation, and light cured composite was then placed to seal the defect. The root canal orifices were then covered with Cavit, and the access cavity was left open.

The teeth then spent 4 days at 37 degrees, in India ink. They were then longitudinally sectioned, to measure the dye penetration from the coronal level of the repair material, to the apical end of the perforation.

The investigators reported that all the experimental groups showed dye penetration to varying degrees.

The composite resin group showed a mean dye penetration of 68.31%, followed by amalgam, which showed 67.62% penetration.

Resin applied over POP showed the least dye penetration- 54.92%.

Amalgam and resin showed over-extrusion into the space that would've been occupied by the periodontal ligament.

POP and CaOH provided a successful barrier against material extrusion into the furcation area.

The investigators stated that the material of choice for sealing perforations must prevent leakage from the oral cavity, into the furcation. Light cured materials when used for repair had some drawbacks like extrusion, as control of the repair material was difficult [Petersson and associates 1985].

POP and CaOH, had shown to be useful barriers. Though dentin bonded composite resins were effective in preventing dye penetration [Leonard and associates [1996], there was no significant difference between this material and the other groups tested in the present study.

The authors speculated that the lack of bonding could be due to the thin dentin-cementum perforation wall, and the problems in delivering the material.

Repair of perforations was a difficult task, and the contraction of the resin adhesives during polymerization was a negative point, preventing an adhesive bond formation between the resin and the dentin walls. Light intensity [Philips 1982], and the site as well as the type of dentine were important factors, as bond strength varied according to regional differences [Suzuki and associates,1991]. Contamination of the dentin surface with excessive moisture, solution, or air voids also affect bonding [Walshaw and McComb 1996].

The investigators concluded that a predictable and a reliable delivery system for the resin was needed, to overcome the difficulties in resin application.

Koh and associates (1998) : investigated the reason behind the cementogenesis induced by MTA, by studying a cell capable of producing matrix, which in turn, can be calcified. They studied the cytomorphology of osteoblasts in the presence of MTA and examined the cytokine production.

Cytokines activate other cells, and are low molecular weight glycoproteins secreted as a result of cell stimulation, and are very extremely potent. They are involved in coordinating bone metabolism [Thomson and associates 1986].

MTA and IRM were prepared and placed in separate petri-dishes. Osteoblasts [cell line MG-63], grown to confluence in Hams F12/Dulbecco's modified Eagles medium were seeded into the dishes. They were then incubated for 1 to 7 days, and the specimens were viewed by SEM. For the cytokine evaluation, cells were grown either alone or in dishes wih the test materials, for 1 to 44 hours. The media were removed for ELISA analysis of interleukin IL-1α, IL-1β, IL-6, and macrophage colony stimulating factor [MCSF].

The SEM revealed healthy cells in contact with MTA at 1 and 3 days. Cells in presence of IRM appeared rounded. ELISA assays showed increased levels of all IL's at all periods when the cells were grown in the presence of MTA. In contrast, cells associated with IRM, and cells grown alone, produced undetectable amounts of IL.

The investigators stated that the cells used in this study had an aneuploid chromosome pattern and multiplied rapidly, with an unlimited life span. Their phenotype was more predictable too. Very few root-end filling materials, had induced hard tissue formation. They added that the SEM examination of the cytomorphology of established cell lines in the presence of root-end filling materials and the cytokine production, as ways of assessing cytotoxicity, have not been used before.

In conclusion, the investigators stated that the tissue response with IRM was toxic, as seen by the depletion of cell numbers and the marked rounding of the cells. Aged IRM, which was “hoped” to be less toxic due to a complete set, showed similar toxicity as the freshly mixed IRM. The toxic component was eugenol. Cells in contact with MTA were seen to be growing in intimate contact with the cement.

Wu and associates (1998) : stated that a tight and long-lasting seal of root-end fillings is of prime clinical importance. A hundred standard bovine root sections, each 3 mm high and with a central pulp lumen of 2.6 mm in diameter, were filled with five commonly used or potential root-end filling materials. At 24 h, or at 3, 6, or 12 months after filling, leakage along these filling materials was determined under a low headspace pressure of 10 kPa (0.1 atm) using a fluid transport model. During the first 3 months, the percentage of gross leakage (> 20 microliters day-1) increased noticeably for Tytin amalgam (from 20 to 100%) and Super-EBA (from 0 to 55%), whereas it decreased noticeably for mineral trioxide aggregate (MTA; from 55% to 0%). Thereafter, the increased leakage of amalgam and Super-EBA decreased with time, whereas the improved seal of MTA was maintained until the end of the experiment. At 3-, 6-, and 12-month time intervals, both glass ionomer cements (Fuji II and Hi Dense) and MTA showed less leakage than the conventional amalgam and Super-Eba, of which amalgam leaked more.

Makkawy and associates (1998) : tested the null hypothesis that there’s no difference in cytotoxicity of eluates from amalgam and 2 R-M GIC’s, on human PDL cells. The cytotoxicity was measured in terms of cell viability, as determined by mitochondrial enzyme action of the PDL cells.

The MTS assay was used to determine cytotoxicity of these perforation repair materials. 12 4x6 mm cylinders of each material were made and placed in 5 ml of alpha-minimum essential medium supplemented with 100 micro g/ml of penicillin, 50 micro g/ml of gentamicin and 5% fetal bovine serum for 24, 48, and 72 hours. 100 micro liters of eluate was transferred to triplicate wells containing PDL cells previously plated at a density of 10,000 cells/ well, in a 96-well plate, and incubated for 24 hours at 37 degrees with 5% CO_2.

Alpha minimum essential medium with supplements provided baseline data. Optical density at 490 nm, directly proportional to the number of viable cells was determined according to the manufacturer's instructions.

Statistical analysis of the data showed that both, the material, as well as time, affected the cell viability. With amalgam eluate, significant inhibitory effect on cell viability was seen at 24 hours, compared to the control and the other 2 tested materials.

At 48 and 72 hours, all 3 materials showed slightly slight inhibitory affect on the cell viability.

The investigators concluded that the use of R-M GIC as a root perforation repair material initially (<24 hours) may result in a more favourable response by PDL cells, than amalgam.

Since the introduction of GIC's, modifications in their formulations have been endorsed for use in several clinical applications. In case of perforations, moisture control impaired the goal of sealing the defect. The chemical bonding of GIC to the tooth structure supported its use in the repair of perforations. Wilder and associates [1996] had shown that the shear-bond strength of R-M GIC's, to dentin, was not affected by material viscosity nor by the surface moisture of the dentine. However, as a perforation repair material, it would be in an intimate contact with periodontal tissues, and hence it's biocompatibility was a must.

The results of the present study, according to the authors, showed that all 3 materials were cytotoxic, as compared to control cultures. Hence the null hypothesis should be rejected, as both parameters- time as well as the material affected the PDL cell viability. The investigators also speculated that as the cytotoxic elements leached, they either complexed with other molecules in the medium, or broke down into smaller components, rendering them less toxic. RM-GICs, could be a viable alternative to amalgam, as a root perforation repair material.

<u>Roth (1998)</u> : reported the successful management of 2 cases of perforations, in which Geristore was used to repair the defects.

<u>Rud, Rud, and Munksgaard (1998)</u> : examined the healing results of surgical Gluma [bonding agent] and Retroplast [composite resin] seals of root perforations which were not suited for immediate orthograde treatment. Surgical treatment was performed on 100 iatrogenic perforations, of which 94 showed radiolucencies of the bone adjacent to the perforation. 83 defects were associated with an exposed post, which had perforated the roots. Of the 100 teeth, 60% were maxillary and 40% were mandibular teeth.

31 perforations were at the molar furcal areas. Mesially located perforations comprised 52%, buccal perforations- 21%, and distal perforations comprised 23%. Lingual/palatal perforations were rare. Mid-root defects were more common than coronal or apical perforations.

All the cases were sealed with the resin composite- Retroplast, bonded to the adjacent root dentin with the bonding agent- Gluma. The range of age of the patients was 19 to 85 years. The cases were examined after 1 year [1st recall] and if needed, after 1 and1/2 to 11 years [mean 4.1 years]- latest recall.

The authors observed that the presence or absence of bone on the roots between the perforation and the cervix, at the time of operation had no significant effect on the healing result, and that the radiographic classification of “partial healing”, with a border of cortical bone or a lamina dura often remained unchanged, for many years.

At the latest recall, the healing result of 65 teeth originally having root perforations elsewhere than the furcation, was-

71% complete, 11% partial, 3% uncertain, while 15% failed to heal.

Furcation perforations showed 30% complete healing, 41% partial healing, 11% uncertain healing, while 18%, failed to heal.

The authors emphasized that a tight seal would re-establish the periodontal ligament and lamina dura adjacent to a root perforation. Bacteria and their toxins would be prevented from entering the periodontal tissues. Gluma-Retroplast provided such a seal.

The method employed was thus-

a) access was gained to the defect by elevating a flap (facial or palatal) and removing the bone.

b) The root dentin around the defect was slightly hollowed, and treated with gluma, and the area was sealed with retroplast, which had a 2-minute working time, and was coloured, to enable its precise application.

c) In the anterior and the premolar region, the lingual or the palatal perforations were accessed from the buccal aspect. Inter-radicular bone and some root substance had to be removed during the process.

d) Retroplast was used to replace the lost root substance.

e) Intra-radicular perforations on maxillary molars were accessed either by resection, or by the removal of one of the buccal roots.

f) The perforated posts were resected at their ends, until they were below the root surface. The surrounding dentin was slightly hollowed. Loose posts were cemented prior to sealing with retroplast.

Healing was classified on the basis of radiographs and clinical symptoms, into 4 categories [Rud and associates, 1972], as complete healing, partial healing, uncertain healing, and finally, failure.

The authors concluded that non-surgical means should be given the first preference, in the repair of perforations. However, large defects - especially with over-fillings, and large radiolucencies near the osseous crest, as well as in cases in which posts were involved, surgery would have to be done.

They added that non-surgical treatment must be monitored for 1 year, after which if no improvement was seen, surgery with gluma-retroplast would have to be done, at the earliest.

Furthermore, complete healing with re-formation of the periodontal membrane space could not, however be expected to occur adjacent to the sealed perforation, even if the seal was tight, and the material was biocompatible. A communication could exist, from the bony defect around the perforation, to the gingival pocket. This could lead to infection adjacent to the retroplast seal. Gingival hygiene with gingivectomy could result in partial healing, and in some cases, complete healing could occur.

Bone loss could be extensive, in which case, healing would occur only to a certain distance on the perforated root.

Slyuk, Moon and Hartwell (1998) : evaluated the effect of time and moisture on the setting, retention and re-adaptation characteristics of MTA when used to repair furcation perforations. They used 32 extracted teeth for this in-vitro study. Perforations were created in the center of the pulp chamber floors, parallel to the long axes of the teeth, and saline-moistened gelfoam matrices were placed below the perforations. Preliminary examination with the light microscope (x40) revealed poor adaptation of MTA , to the walls of the defect, as there was no moisture.

The teeth were then randomly divided into 4 groups, and all perforations were repaired with MTA, and covered with either a wet or a dry cotton pellet for 24 or 72 hours.

The force needed to displace the material from the perforation was measured by Instron testing, till 0.2 mm displacement of MTA occurred. The specimens were sealed in 100% humidity for 14 days, and the push out test was performed again, for all the groups.

The results revealed that MTA resisted displacement at 72 hours, to a significantly greater extent than at 24 hours.

Slight displacement of the material at 24 hours revealed it's ability to re-establish resistance to dislodgement from the dentinal walls. Presence of moisture in the perforation during the placement of the cement increased the adaptation of MTA to the walls of the perforations.

The investigators concluded that a moistened matrix [with L.A solution] could be used, to prevent under or over filling of MTA prior to placement of the cement.

A wet/dry cotton should be placed in contact with MTA and covered with a temporary restoration for 72 hours before placing a permanent restoration. Wetting the MTA improved its flow and adaptation to the dentinwalls

Jantarat J, Dashper SG, Messer HH (1999) : This study tested the sealing ability of amalgam and Ketac silver placed with and without plaster of Paris as a matrix. A bacterial penetration technique was used to test the seal. Perforations created in the pulpal floor of extracted human mandibular molars were repaired as follows:

- Group 1, amalgam;
- Group 2, amalgam plus plaster as a matrix;
- Group 3, Ketac silver; and
- Group 4, Ketac silver and POP [17 teeth/group].

Leakage was measured by placing bacteria (Streptococcus sobrinus) in the pulp chamber, and recording the time taken for bacterial growth in a medium bathing the root surface. The investigators reported that a plaster of Paris matrix improved the seal with amalgam, but not with Ketac silver.

Ketac silver provided the best seal, but all materials showed complete leakage within 22 days.

Holand & Associates (1999) : studied the reaction of rat connective tissue to the implantation of dentin tubes filled with MTA or $Ca(OH)_2$.

40 rats were used by them for this study, in the experimental groups. 12 rats served as controls. The dentin tubes were prepared from human tooth roots. The length of the tubes was 7mm and they were irrigated, autoclaved before placement of the test materials. The tubes were filled with MTA or $CaOH_2$ in water and immediately implanted into the subcutaneous region of the experimental rats.

The animals were sacrificed 7 and 30 days, post-operatively. Tissue samples were prepared for histo-analysis under a light microscope.

The investigators reported that in the calcium hydroxide group large granulations, birefringent to polarized were observed. These were Von, Kossa technique positive and were located near the tube opening. In the interior of the tubes the similar structures were observed. This formed a layer at different depths within the tubules. The calcified area normally showed cellulse nucleous inclusions in its mass. Surrounding this area was connective tissue, with a mild to moderate chronic inflammation. Giant cells were also observed.

The morphological data was similar at the 30-day period, showing the granulations positive to Von Kossa's technique. The birefringent granulations were also observed within the tubules. The connective tissue around the irregular calcified areas was fibrous, had giant cells, and a mild chronic inflammatory reaction.

The samples of MTA showed almost the same picture as observed with calcium hydroxide. The 7-day sections showed large granulations positive to Von Kossa and birefringent to polarized light. These were in contact with the filling material and usually less in number than those observed in the calcium hydroxide specimens. Extensive areas of irregular tissues highly positive to the Von Kossa technique were seen around the apical foramen and next to the birefringent granulations. Similar structures were seen within the dentinal tubules forming a layer at different depths.

The connective tissue around the tubes showed fibroblastic proliferation and a mild to moderate chronic inflammation with some giant cells. The tissues were basophillic and highly Von Kossa positive.

The 30-day specimens showed the same picture.

The investigators concluded that the results with both the materials studied were similar. MTA and calcium hydroxide had similar properties in terms of hard tissue deposition in the form of calcite crystals, probably. They attributed this to the presence of calcium oxide in MTA that could react with tissue fluids and form calcium hydroxide.

Mittal & Associates (1999) : evaluated the sealing ability of 5 materials when used over a POP barrier, to repair furcal perforations.

They used 90 extracted teeth for this invitro study and randomly divided them into 5 experimental groups and 1 control group (10 teeth).

In the experimental groups of 15 teeth each, POP barriers were created in the perforations and then sealed with silver amalgam, GIC, self cured composite resin, IRM and AH26.

The access openings were sealed with composite resin. The teeth were then submerged in a solution of 2% methylene blue dye for two weeks. The samples were then sectioned and the linear dye leakage was evaluated and statistically analysed.

The investigators reported that maximum dipenetration was seen with amalgam followed by [in decreasing order] GIC, composite resin, IRM and finally AH26 which showed the best sealing ability. Amalgam showed the highest amount of dye leakage [100%] compared with the other experimental groups.

They added that AH26 had a better flow than composite and its volume shrinkage was also better. Its adhesive property was good and it had the ability to set in humid conditions. Moreover, after setting, it was bio-inert [Tagger & Tagger 1986] and allowed for easy penetration of the lateral canals as well.

The prognosis of endotreated teeth according to these authors depended on factors like time, location, adequacy of the perforation seal, and the size of the defect. The aim of treatment is maintained healthy tissues against the perforations without continuing inflammation or the loss of periodontal attachment. They also found furcation perforations to be a "perplexing" problem in endodontic therapy. They added that the defects were also extremely damaging to the periodontal health.

Salman & Associates (1999) : evaluated a bio-resorbable membrane [Atrisorb] as a matrix under R-M GIC sealents in the repair of furcal perforations in vivo.

They used 6 dogs for this study and selected 36 lower posteriors. Access cavities were made, pulp was extirpated and the canals were filled with ZnOE. The pulp chamber floors were then perforated and the teeth were divided randomly into 3 groups.

Group 1 – 15 teeth were sealed with RM-GIC alone till the defect was obturated.

Group 2 – 15 teeth were sealed with Atrisorb under RM-GIC. The third group comprised of 6 teeth which served as controls.

In the second group the Atrisorb was prepared and a barrier corresponding to the size of the defect was cut and placed over the defect.

RMGIC was then placed on the margins at the circumference of the membrane, to seal the membrane to the chamber floor. The material was prevented from flowing under the membrane and into the underlying connective tissue. Light activation was then done to cure the material.

3 months later the animals were sacrificed and vertical sections of the specimen teeth were prepared for histo-analysis. The investigators reported that there was no difference between the results for GIC alone and a barrier under GIC.

They concluded that the placement of a resorbable barrier at the chamber aspect of a furcation perforation did not result in any superior healing compared with the use of RM-GIC, when used alone. They added that a high rate of epithelialization was seen, in the experimental groups.

In RM-GI used alone, 7 out of 15 teeth showed a severe inflammatory reaction. 7 teeth had moderate inflammation, and only 1 tooth was associated with mild inflammation.

In the *Atrisorb under the GIC*, 9 out of 15 teeth had severe inflammation while 6 teeth showed moderate inflammation. Resorption of the cementum was seen in most of the specimens in both the groups.

The authors stated that resorbable barriers had been shown both clinically as well as histologically to produce favourable periodontal regenerative outcomes. Communication of the supporting tissues in the perforated area with the gingival sulcus could result in an irreversible periodontal lesion initiated by the trauma of the defect and its subsequent associated inflammation. Over extrusion of the repair materials was also a common problem and many attempts had been made to overcome this, for instance an indium foil, dentin chips under root canal sealers, HA barriers under amalgam. These methods have generally proven to be of a limited value in terms of successful management of perforation repairs. Moreover bio-compatible materials like Calcium hydroxide, Cavit, Tricalcium phosphate and HA have also not shown any good prognosis in the repair of furcation perforation.

If a membrane could degrade by itself, then it would obviate the need for its removal at a later stage, so that any possible persistence of a dead space, which could encourage bacterial proliferation could be overcome.

Schwartz & Associates (1999) : reported 5 cases in which MTA was used for the management of problems like vertical root fracture, apexification, furcation and strip perforations, and the repair of resorptive defects. The elimination of clinical symptoms and radiographic findings of complete healing was also seen.

The surgical operating microscope and micromirrors were used for more efficiency during the procedures and the authors founded to be very helpful in the successful management of complicated cases. The use of MTA as a sealer material for large defects had been clinically as well as radiologically demonstrated. This along with calcium hydroxide used temporarily, would also enhance the prognosis.

The canals associated with perforations were obturated with thermoplasticized gutta-percha and ZnOE sealer after the perforations were repaired with MTA.

In 1 case a 29-year old man had a resorptive defect that had resulted in a communication between the pulp and the adjacent bone. A diagnosis of pulp necrosis with external root resorption was made and calcium hydroxide was placed at the first appointment.

2 weeks later at the recall, the patient had no symptoms or complaints. The calcium hydroxide was removed and the dried canal was inspected with the help of a surgical operating microscope. This showed that the defect was situated at the distolingual aspect of the root and was filled with granulation tissue. Calcium hydroxide was placed into the tooth, again. The next month a radiograph was taken and the calcium hydroxide dressing was replaced. The X-rays showed that calcium hydroxide had further expanded into the resorptive lesion indicating the additional debridement of the granulation tissue. At the 3rd month recall, an X-ray taken showed that the calcium hydroxide had filled the resorptive lesion and had extended into the bone.

A month later although the patient was asymptomatic, probing depths had not changed (4mm). The CaOH was removed and the canal apical to the resorptive lesion was obturated with gutta percha and sealer with the help of the microscope. A thick mix of MTA was pressed into the defect and the residual calcium hydroxide in the bone and the outer portions of the defect prevented the extrusion of MTA outside the root. Several moist paper points were placed in the canal (for MTA to set). A temporary restoration was used to seal the access. At the next appointment, the MTA feld hard to an explorer, and a post-space was created. This extented several millimeters apical to the defect. The post was cemented and the tooth was restored with composite as an interim restoration and also to serve as a core. A six-month recall check-up showed that the tooth was asymptomatic throughout the treatment.

In another case a 27 year old man had a perforation into the furcation of the mandibular first molar. Tenderness to biting pressure and mild pain, were the complaints of the patient. There was radiographic evidence of bone loss in the furcal area and in the peri-apical areas. The filling materials were removed from all the 3 canals, which had been filled previously. The microscope was used during the procedure and the distal as well as the mesiofacial canals were obtuated routinely with gutta-percha and sealer.

The mesial lingual canal was then obturated apical to the perforation. MTA was backed in the coronal portion of the canal, upto the orifice. No barrier was used and some of the MTA had extruded into the defect. Within a few days the tooth became asymptomatic. The 3- week recall visit showed that the tooth was free of pain and responded normally to percussion, palpation and biting pressure.

An amalgam buildup was given and after 6 months the radiolucency in the furcation had resolved and the probing depths were no more than 3mm.

A 72-year old man had a lower first molar associated with a strip perforation in the mesio facial canal during root canal treatment, one month before. A class I furcation involvement was present on the facial aspect of the tooth. The probing depth was 4mm and there was no bone loss radiographically in the furcation. At the one-month recall visit the condition of the tooth had worsened and an X-ray showed a significant lucency in the furcation. An 8mm pocket was probed. The tooth was tender on percussion and had spontaneous pain. The mesio facial canal was emptied of the gutta-percha to a point apical to the defect. The coronal portion of the canal was obturated with MTA to seal the defect. Then a combination of gutta-percha, sealer and MTA were pushed into the furcation during obturation.

A buccal flap was then reflected and the excess material was removed from the furcation. Visualisation of the defect through the furcation on the distolingual surface of the mesiobuccal root was accomplished with the operating microscope and micromirrors. A smooth repair surface was created and the flap was repositioned and sutured. Two days later the sutures were removed and a 2 week recall visit the gingiva had healed nicely whereas the tooth remained tender to percussion and biting pressure. There was no spontaneous pain however. At 6 months the patient was totally asymptomatic with normal responses to pressure and percussion tests. Radiographic evidence of new bone formation into the furcation was evident and the probing depth remained at 4mm.

The authors concluded that MTA was a promising material with an expanding founding of research. The research that was done, till date was very thorough and compelling. Several of the cases presented in the present article had a follow up period of less than 1 year. But, the authors added, the success of a new material can best be judged with long term studies.

Bryan and associates(1999) : reviewed the etiology, diagnosis, the prognosis and the material selection, associated with the non-surgical repair of furcation perforations.

They stated that several materials were studied, for the repair of perforations, but there was "no agreement amongst the various authors, about a material, which could yield a predictable result".

The "determinants of success", according to these authors, was "a source of confusion" amongst the various materials. Histological studies, had shown that none of the repair materials used till date, had given an ideal result- that is, the repair of the defect, as well as the re-attachment of the periodontal tissues.

Clinically successful case reports had the drawback that the area of concern-the periradicular tissues, could not be studied histologically in humans.

Though material selection was important, for a good prognosis, none of the materials had re-established the periodontal architecture. The ability to create a good seal, with a biocompatible material was a more essential factor, according to them.

Amalgam, Cavit, and calcium hydroxide were the most frequently used materials for the repair of perforations. All these materials had mixed reviews, throughout the endodontic literature.

The recent introduction of GIC's as furcation perforation repair materials showed some promise- especially the light cured systems.

Matrices, would only prevent extrusion of the repair material, but would not reduce the chances of a pocket formation, and epithelial down-growth [Himel and Alhadainy 1995].

HA, tricalcium phosphate, DFDB were other materials that could be used as matrices, or as perforation repair materials. These were also associated with mixed reports of success and failure.

MTA, according to the authors, produced results which neared the properties needed of an "ideal repair material". They added that the choice of MTA, would be an excellent idea, in the management of furcation perforations.

The authors concluded that furcal perforations had a poor prognosis, and to give a chance for its repair, a perforation would have to be sealed immediately, the bacterial contamination must be reduced, and a good repair material must be selected, which possessed good biocompatibility, as well as sealability .

Most of the traditionally used materials like amalgam, cavit, calcium hydroxide, GIC's HA, tricalcium phosphate and DFDB had not produced consistent results. MTA, showed promise in that respect, and could significantly advance treatment modalities for the repair of furcation perforations.

They added that though the prognosis of a furcation perforation was doubtful a proper diagnosis, and management of the defect could profoundly enhance its prognosis, in a positive manner.

The poor prognosis of furcal perforations was generally associated with the development of a chronic periodontal lesion, and the technique sensitivities involved, in the application of the repair-material application.

It had been suggested, that if a dentist or a researcher was more skilled with a particular method, and with a material, more favourable results could be attained [Harris 1976; Lemon 1992], as case reports demonstrated that material selection was partially dependant on the ease of manipulation.

Holland and associates (1999) : observed the reaction of the apical tissues of dogs, after filling their root canals with MTA and gutta-percha, or GIC, for 6 months.

They used 2 dogs, for this in-vivo study, and chose 32 root canals from them, as experimental groups.

The teeth were accessed, and the pulp chambers were opened, the pulps extirpated, and apical perforations were created by over-instrumentation. The chambers were then sealed off with ZnOE.

After 1 week, the canals were opened again, and filled with either laterally-condensed gutta-percha and MTA, or with GIC (Ketac Endo).

The pulp chambers were filled with a layer of ZnOE, and the access cavities were sealed off with amalgam.

Each experimental group comprised of 15 teeth

180 days later, the animals were sacrificed and segments of the jaws, each having one tooth, were prepared for histoanalysis.

The investigators reported that -

In the MTA group, closure of the main canal by new cemental deposition was seen in all specimens. The accessory canals were also sealed completely, by cemental deposition! In most of the specimens, the ingrowth of connective tissue, into the main root canal was seen.

There was no inflammation at all, in the periodontal ligaments, of all the MTA samples.

In the GIC group, partial closure of the foramen was seen in only 2 cases. The material had over-extruded, in some cases, and this caused varying degrees of inflammatory reaction. Overall, it was mild in most of the cases. The periodontal ligaments associated with the extruded material showed a slight enlargement.

A few accessory root canals were seen, wherein partial, or a total closure had occurred.

There was only a mild or no inflammation seen, in the periodontal ligament, in cases where overfilling had not taken place.

The investigators concluded that both the materials- MTA, as well as GIC, were biocompatible, but that MTA showed better biologic properties.

They added that this study showed that MTA had the ability to stimulate hard tissue deposition, and also contemplated about the similarities in the mechanism of action of MTA and calcium hydroxide.

If the goal of “total closure” of the root canal system could be desired, after root canal treatment, then, according to these authors, MTA had fulfilled this goal very well!

The biological properties of the material MTA, could make it an ideal root canal filling material.

GIC, showed less favourable results, though it was also biocompatible.

<u>Johnson (1999)</u> : reviewed the root-end filling materials that were commonly used, as well as supported by dental literature, like amalgam, composite resin, IRM, Super-EBA, and MTA.

According to the author, any material, if used judiciously, under specific conditions, apt surgical techniques, and proper handling, would produce a successful surgical outcome.

Whenever possible, the non-surgical method should initially be contemplated, in failed cases of root canal treatment. The identification of the cause of the initial failure must be understood, if proper treatment is to be rendered.

He added that "every available dental restorative material or cement had been used, at one time or the other", for the purpose of a root-end filling.

The clinical success, according to him, after surgical root canal therapy with/without a root-end filling had been reported to range from 58 to 96% [Grung et al 1990; Dorn and Gartner 1990; Rapp et al 1991; Frank et al 1992].

Amalgam, which was the most widely used root-end filling material, for generations, was now being challenged by the newer materials, and thereby "creating a lot of confusion and uncertainity" regarding the choice of a material, for the purpose of a retrograde filling.

The author suggested that instead of the 6 to 15 properties required, of an "ideal filling material", only 3 choices like-

1) Biocompatibility,
2) Apical sealability, and
3) Handling property

could be considered as critical factors, in the choice of a repair material. Moreover, long-term clinical success as shown by well - controlled prospective human studies, was lacking, since "none of the currently available materials had been thoroughly investigated, with respect to the 3 criteria".

MTA, was an "interesting" material, and had received much attention, since it had proven to be more superior, if not, equal, to all of the materials used for root-end filling. The positive points of the material, like minimal inflammation, cytotoxicity, the induction of hard tissue formation, as well as the regeneration of periodontal ligament fibers, its marginal adaptability, and its capability of setting in the presence of blood, were addressed by the author. He added that the handling of MTA, required practice, and furthermore, long-term results of clinical trials would be required, to prove its apparent superiority over the rest of the materials that are currently used. Since root-end fillings do not need a high compressive strength, it would serve the purpose well.

Amalgam usage had been under severe criticism recently, when investigators had found that better materials could be used, in order to provide for better results. Though its biocompatibility was acceptable, the misuse of the material could be, in part, be blamed for its several disadvantages [scatter of particles, expansion, tissue-staining, and corrosion], when used as a root-end filling material. A dry field was of importance, if this material could be used to its advantage.

The current trends in preparing the root-ends perpendicular to the long axes of the roots with ultrasonics, would make it's placement and handling, a tough task, with the conventional instruments of its placement and condensation.

IRM and Super-EBA, though clubbed together, had distinct qualities of their own, like IRM seals best when a thick mix is made, and when it is inserted as a single mass, rather than incrementally, because it does not adhere well to itself.

Super-EBA was difficult to mix, and required practice, though it could effectively seal the apical end of the prepared cavity if used with a spoon excavator [with the convex end], and then condensed with an aptly sized instrument. Refining the set cement would enhance its marginal adaptation.

The main problems with these materials (IRM &Super-EBA) were that their radio-opacity was similar to gutta-percha, since such materials must be more radio-opaque than the canal-filling materials. But the addition of opacifiers could change their physical and chemical properties.

But in general, the ZnOE reinforced cements induced mild cytotoxicity which diminished, as it set, and they [the cements], had also performed well in the *invitro* and *in vivo* tests in animals, as well as in retrospective human studies [Oynick and Oynick 1978; Dorn & Gartner 1990; King et al 1990].

Composite resins in combination with DBA, was another technique borrowed from conservative dentistry, and applied in endodontics. The biocompatibility of DBA, as well as that of composite resins was acceptable. Conservative root-end preparations could be made, and some authors [Andreasen et al 1993; Vignaroli et al 1995; Rud et al 1996] had suggested a concave preparation, rather than a conventional deep cavity. Bonding of the entire root end surface after apicectomy could seal the exposed dentinal tubules as well as the main canal(s).

But, these polymerizing resins leave an uncured oxygen-inhibited surface layer and may interfere in the healing process. This layer, if removed with a cotton swab, before closure of the surgical site, would enhance its compatibility as well as the healing process.

Since composite resins vary widely in their compositions and their physical as well as chemical properties, it is of importance to select a reliable material, which has proven to be biocompatible [Dragoo 1996].

According to the author, a “leak resistant” apical plug, was possible, with the usage of DBA with composite resin.

In conclusion, the author stated that the choice of the filling material for the root-end, was important, for the long-term success of the surgical procedure.

There was no consensus as to the selection of a single material, for use in all kinds of cases. He suggested the following recommendations -

a) root end resection alone, without a retrograde filling was not a good idea, generally, unless the quality of the orthograde filling, both coronally as well as apically was well sealed.

b) Given specific conditions, apt surgical methods, and proper handling of the sealing material, any of the discussed materials, like amalgam, composite resin, Super-EBA, IRM, or MTA could contribute towards a successful outcome of the procedure.

c) Cavit, gutta-percha (injected, or cold/heat burnished) must not be used.

d) Amalgam is acceptable, but requires a deep root-end preparation and a dry field.

e) Super-EBA, was a good material, but had its drawbacks due to difficulty in its handling. The penetration depth and a dry field were less critical, with this material.

f) IRM was similar to Super-EBA, but its solubility over a period of time, was its drawback.

g) Composite resins with DBA, were suitable for retrograde fillings, but these materials are very technique sensitive. A dry field is a must, in the case of these materials, and the operator would have to master the multi-step application process.

h) MTA, may emerge as the root-end filling material of choice, if well-controlled clinical trials confirm the promising preliminary results and research.

Poi & associates (1999) : described a clinical case where intentional replantation was chosen as a treatment option , in the management of a perforation. A 30 year-old man had a perforation in the distal region of the root, near the bone crest. The cause was a fractured broach, which had lodged itself in the periodontal membrane of the patient!

Extraction of the tooth and the removal of the broach, followed by replantation of the tooth, was considered.

The implantation was done in a manner such that the tooth was slightly extruded, exposing the perforated area and re-establishing the biological width of the periodontal ligament.

The tooth was stabilized for 4 weeks, with a 0.7 mm orthodontic wire, and composite resin, from tooth no. 4 7 to 4 3.

Due to operator's lack in experience, and the emergency of the case, the endodontic therapy was postponed to another visit, with the access cavity left open, for 2 days.

In the next visit, the root canal preparation was done and Ca $[OH]_2$, CMPC, as well as an iodoform paste were placed as intracanal medicaments. These, as well as the splints were retained for 4 weeks.

The splint was then removed, and the dressing was replaced.

45 days later, the dressing was substituted with a mix of $Ca(OH)_2$ with sterile water, and was changed every month, for a period of one year.

Prior to filling the canal, a x-ray was taken, which indicated normal bone, without any root resorption. The canal was then filled with laterally condensed gutta-percha and Sealapex. A temporary crown was placed at this time, and after 3 months, resorption of the root was not seen, and so, a post was cemented into the canal.

18 months later, a fixed partial prosthesis was placed.

After 8 years, when the patient was recalled for a clinical evaluation, resorption of the tooth-root was not seen, and the abutment tooth was functional.

The authors added that despite the high percentage of success (52%-95%), and the "relative absence of root resorption reports[Kingsbury et al 1971], intentional reimplantation was generally considered to be the last means of saving the tooth, prior to extraction, and that it should be done only when other modalities of treatment would compromise the long-term prognosis of an involved tooth, and failure could be expected[Grossman 1966; El Deeb 1971; Weine 1980].

They concluded that this 8-year follow up suggested that the technique represented a viable treatment option. Despite the periodontal damage caused by the broach, and the perforation, the injury had not provoked resorption, which was an important risk factor in such instances. They attributed the successful outcome to adequate biomechanical preparation, as well as the Ca(OH)2 dressings.

The success of reimplantation was generally considered questionable not least because many patients drop out of the post-treatment follow-ups [Grossman and Ship 1970]. This may suggest treatment failure. But, in the present case, rigorous and strict clinical control was responsible for the monitoring, of the long-term success.

In some clinical situations, intentional reimplantation could solve unconventional problems, for instance, obstacles like calcifications, dilacerated roots, lateral perforations, broken instruments which cannot be removed by an intracoronal approach, or when an apicectomy could lead to periodontal pocket formation.

Adamo & Associates (1999) : compared the traditional and the newly developed root end filling materials for resistance to bacterial microleakage. They used 60 extracted teeth and randomly divided them into 5 groups, further root end filling with MTA. Super-EBA, Composite resin with Pro Bond dentin bonding agent. Amalgam with and without ProBond and positive and negative control groups. The root canals were instrumented and root end presections were done. The filling materials were placed in 3mm ultra sonic retro-preparations. The samples were sterilized for 12 hours in ethylene oxide. With the newly designed model system, the apical 3-4mm of the roots were immersed in BHI culture medium with phenol red indicator within the culture chambers. The coronal access of each specimen was inoculated every 48 hours with *S.salivarius*. The culture media were observed every 24 hours for colour change, which indicated bacterial contamination. The samples were observed for a period of 12 weeks.

The investigators reported that at 4 weeks 10% of specimens from each experimental group showed leakage. At 8 weeks, 20% of the specimen filled with amalgam without DBA, Super-EBA and MTA showed some leakage. At 12 weeks, monor differences between the materials were seen.

The investigators concluded that there were no statistically significant differences, in the rate of microleakage among the 5-

groups tested. They added that the most commonly used root end filling material was amalgam. But its disadvantages outweighed its advantages.

Super-EBA and IRM were moisture sensitive and eugenol could irritate the peri-apical tissues. Solubility was another negative point.

MTA had shown its advantage in sealing ability as a root end filling material as well as a repair material for lateral root perforations. In the present study MTA and Super-EBA provided a better seal than amalgam during the first two weeks, but subsequently this difference diminished.

The potential advantages of the newer dentin bonding agents and composite resins could circumvent some of the drawbacks of materials currently been used.

Bruder (1999) : stated that the management of perforations into the periodontal ligament space during endo or restorative procedures "is an ongoing problem in dentistry". The introduction of microscopes and new instruments and materials have resulted in more controlled and predictable surgical as well as non-surgical outcomes of endodontic treatment. New techniques could now be used to manage perforations effectively.

Germain (1999): stated that a mid root strip perforation can be a difficult problem to treat. Surgical treatment is "arduous" and has a poor prognosis. The classic repair materials, which had been used for the non-surgical management of perforations, had met with variable successes. MTA, according to the author, "seems to have incredible promise for sealing these defects with a good long-term prognosis".

Ersev & Associates (1999) : tested the mutagenicity of clinically used endodontic materials after setting for 24 hours, against different strains of *S.typhimurium* in order to broaden the basis of information pertaining to the mutagenic activities of the material ingredients. In addition the cytotoxic effects of eluates of the endodontic sealing cements set for 24 hours and 1 week, were quantified colorimetrically (MTT assay). In L929 mouse fibroblasts. They stated this approach might lead to a reduction of the numbers of implantation studies necessary to determine the biocompatibility of the sealing cements.

The various materials tested were – Traitement SPAD, Endomethasone N, Tubli-Seal, CRCS, Ketac-Endo, Silver free AH26.

The materials were set for 24 hours and 1 week and then eluted for 24 hours in a cell culture medium (cytotoxicity testing) and dimethyl sulfoxide or physiological saline (mutagenicity testing).

The samples that were tested for cytotoxicity were prepared as follows – the freshly mixed materials were filled in glass rings and set for 24 hours and 1 week at 37^{o}C in a humidified chamber. 1 to 6 test specimens were then eluted in 10ml of cell culture medium at 37^{o}C for 24 hours in 5% CO_2 atmosphere. The Ames test was used to test the mutagenic properties and the samples were set on aluminium sheets for 24 hours at 37^{o}C in a humidified chamber. The materials were then ground, and the powders were eluted in 2ml of dimethyl sulfoxide (DMSO) and saline for 1 day at 37°C. The tested strains of the bacterium were TA97a, TA98, TA100, and TA102.

The investigators reported that the eluates of Traitment SPAD were 5-30 times more toxic than silver free AH26, tubli-seal, CRCS, endomethasone-N. The rank order of the toxic effects depended on the setting time of the mixed materials. DMSO and saline eluates of traitment SPAD, tubli-seal, endomethasone-N, CRCS, Ketac-endo were not mutagenic in the Ames test.

Both eluates of the sliver free AH26 set for 24 hours were weakly mutagenic to TA102.

The investigators concluded that silver free AH26 when mixed may contain 2 mutagenic substances – Bisphenol A diglycidylether and formaldehyde. They added that it should be known that since the root filling materials are frequently exposed over a long period of time, to the human tissues, their health risk should be kept at a minimum, by non-touch methods.

Ozata & associates (1999) : compared the apical leakage of Ketac-Endo, Apexit, and Diaket.

They used fifty freshly extracted anterior teeth, for this *in-vitro* study, and the anatomical crowns were removed at the amelocemental junction, and step-back preparation of the roots canals was performed with K-type files to size 40 using 2 ml of 5.25% NaOCl irrigant after each file change.

The roots were then randomly divided into five groups, of 10 roots each—

Three experimental, and two control groups.

The experimental groups were as follows:

Group 1-10 teeth were filled with Apexit

Group 2- 10 tooth-roots were filled with Ketac-Endo, and in

Group 3- 10 roots were filled with Diaket.

The root canals were filled with one of the sealers and gutta-percha using lateral condensation. After the specimens were stored in 100% humidity at 37 degrees C for 2 wks, they were then immersed in 2% methylene blue for 7 days. Each tooth was split into two sections, and the dye penetration was evaluated independently by three examiners, using a stereomicroscope at x20 magnification.

The stastistical analysis of their data showed that there was no significant difference between Apexit and Diaket. However, there was significantly more leakage within the samples of the Ketac-Endo group.

Shabahang S, Torabinejad M, Boyne PP, Abedi H, McMillan P. (1999) : stated that calcium hydroxide had been the material of choice for apexification. They compared the efficacy of osteogenic protein-1 and MTA, with that of calcium hydroxide in the formation of hard tissue in immature roots of dogs. Sixty-four roots of premolars, were used by the investigators.

After the induction of experimental peri-radicular lesions, the canals were debrided and filled with calcium hydroxide for 1 wk. After the removal of calcium hydroxide, the root canals received one of the treatment materials in a balanced design. The animals were euthanized 12 wks later, and the tissue samples were prepared for histoanalysis. The degree of hard tissue formation and amount of inflammation were evaluated histomorphometrically.

Statistical evaluation of their data revealed that Mineral trioxide aggregate produced apical hard tissue formation with significantly greater consistency. The difference in the amount of hard tissue produced among the three test materials was not statistically significant. Furthermore, the degree of inflammation was not significantly different between the various test groups.

Torabinejad and Chivian (1999) : in their description of the clinical procedures of the application of MTA in root perforations, presented some case reports -

A lower molar with a large mid-root perforation caused by a post, which had been placed, was reparied with MTA. At a recall evaluation 3½ years later, clinically as well as radiographically, complete repair of the defect was apparent.

In another case, an upper incisor with an extensive internal root resorption perforating to the external surface was described. After treatment with MTA, a radiograph taken 18 months post-op, revealed the absence of any periradicular pathosis.

In a third case, an upper incisor which had been obturated with a sliver point, was associated with a distolingual perforation. The tooth was rotated with a forceps in order to gauge the size and the extent of the defect. After MTA treatment, a 5-year recall evaluation showed that the resolution of the lateral lesion was complete radiographically, as well as clinically.

The authors added that none of the materials that were used, for the repair of perforations could seal the pathways of the pulp effectively. In addition, the communication between the root canal system and the periodontium had to be sealed with materials that could prevent bacterial leakage.

Since the repair materials would be in direct contact with vital tissues, a favourable regeneration of the involved tissues, including bringing them back to their prediseased status, would be an ideal goal.

The main disadvantage of the various materials used till date included microleakage, varying degrees of toxicity and sensitivity to moisture.

The authors added that since MTA provided an effective seal against the penetration of dyes, as well as bacteria and their metabolites like endotoxins [Tang et al 1997], it could also be used as a coronal plug [3-4mm], after obturation of the root canal system. Furthermore, MTA could be used prior to procedures like internal bleaching of discoloured teeth.

<u>De Bruyne and co-workers (2000)</u> : presented a case report, in which they described the aftermath of treatment with Ca[OH]2, as well as the management of necrosis of the buccal gingiva and the mucosa, along with the treatment and follow-up, of a root perforation.

An upper central incisor, which was perforated in the buccal aspect, was repaired with Ca[OH]2 intra-canal dressing . The defect was initially not recognized by the dentist, and this resulted in the introduction of a large amount of non-setting Ca(OH)2 paste under the gingival tissues through a dehiscence on the buccal aspect of the root.

One day later, the upper lip of the patient had swollen considerably, and after 2 days, the gingiva showed a sudden perforation in the area. The patient, however, had no pain. The necrotic gingival zone was treated with rinses of 3% H2O2 and 2% hexidine, once in 2-3 days.

A daily application of hexidine gel was also prescribed. The gingival perforation healed and closed completely within 2 months, and a 2 mm gingival recession from the CEJ, was measurable.

A surgical approach was planned, but executed after 6 months. The temporary filling material from the access cavity was removed, and the introduction of a file in the apical part of the canal was complicated by the palatal inclination of the tooth crown, and the presence of a n extensive mid-root ledge.

A combination of surgery and root canal preparation was done in one session. After the flap was reflected, the buccal bony dehiscence in the mid-root region was visualized. The buccal opening in the root allowed the visualization of the opening of the apical part of the root canal.

The canal was then cleaned, shaped, and obturated with cold lateral gutta-percha condensation, and AH-26 sealer. The perforation was sealed with GIC. The scar tissue from the healing soft tissues, and the periosteum, were cut through, in order to mobilize the flap.

The root surface was conditioned with citric acid [pH=1], for a minute. The flap was then replaced coronally, and closed with Gore-Tex sutures. Flap compression was done, and the access cavity was sealed with GIC.

10 days later, the sutures were removed and the surgical area was cleansed. The healing was uneventful, according to the authors.

After 3 months, the patient was asymptomatic, and the buccal gingival recession from the CEJ, had reduced to only 1 mm.

After 6 months, the maximum probing depth was 3 mm, and this indicated that a new attachment over the treated root surface had formed. A radiographic examination revealed a normal status, and the gingival recession remained stable.

The investigators concluded that as long as Ca[OH]2 did not come into direct contact with the surrounding soft tissues, problems wouldn’t occur. And even if they did, they would be mild in nature.

In the present case, since the buccal bony plate was absent, the Ca[OH]2 had come into contact with the periodontal tissues, and had caused the alkaline burn. The authors advocated the immediate removal of any extruded material, to avoid such complications.

They further added that Dunham and associates [1966] had investigated the effects of repeated Ca[OH]2 treatment on the epithelium of hamster cheek pouches, and had noticed that after the initial alkaline burn, the lesions progressed and showed cellular atypia.

Himel and associates [1985], in their in-vivo experimental animal model study, had found that Ca[OH]2 was associated with continuing inflammatory reaction along with bone necrosis in repaired mechanical perforations.

Sahli [1988, 1990] had described the destruction of the epithelium present in the periradicular lesions, following the use of Ca[OH]2. Connective tissue invagination, as well as healing had occurred subsequently. In these cases, the necrotizing ability of the Ca[OH]2 had resulted in a positive outcome.

Baiesen and Brodin [1991] had found that Ca[OH]2 was actually neurotoxic.

Alacam and associates [1993] had found that Ca[OH]2 had a cytopathological effect on vital cells, which was comparable to the adverse reaction seen with NaOCl extrusion into the periradicular tissues.

Fuss and associates (2000) : evaluated the sealability of silver GIC (Chelon silver) and compared it with amalgam, in the treatment of large furcal perforations, in vitro.

They used 25 extracted molars, and access cavities were made, and during the experimental procedures, the teeth were placed on wet towels in a closed jar at room temperature. The canals were prepared, and filled with amalgam and varnish. Naturally occurring coronal leakage through the intact pulp chambers was determined quantitatively, for each tooth, using a modified fluid transport model under pressure of 1.2 Atm. Each tooth was then disconnected from the system, perforated at the furcation, and the defects were then sealed with either chelon silver (10 teeth) or amalgam (10 teeth). Five teeth served as controls. The teeth were then incubated for 24 hours, at 37 degrees C, in 100% humidity.

They were then re-connected to the modified fluid transport system and the coronal leakage under pressure was evaluated at 1, 2, 6, 15, and 24 hours.

The leakage through each tooth was compared with that of its own intact pulp chamber floors before perforation, and the groups were compared with each other.

The investigators reported that gradual leakage was found in all the groups, at a mean of 0.017 microl/min and 0.007microl/min for amalgam and chelon silver respectively.

Chelon silver- repaired perforations leaked significantly less than those repaired with amalgam.

Radiographs revealed that amalgam extruded through the defects, in all the teeth, whereas chelon silver filled the perforations to the external outline of the roots, without extrusion!

The authors added that materials like amalgam, $Ca(OH)_2$, and GIC had not shown satisfactory results.

The advantages of chelon silver were its quick setting property, radio-opacity, ease of manipulation, and minimal or no extrusion into the periradicular tissues.

The investigators concluded that chelon silver could be an adequate sealer, for the repair of furcation perforations.

GIC, on the other hand, did not require condensation and hence, tissue irritation could be avoided. Moreover, within a few minutes of passive application of the material, a strong, radio-opaque seal was evident, which allowed for the completion of the root canal treatment, and the final restoration, without interference.

The sealing property of this material was attributed to its micro-mechanical adherence only. Hence, the authors speculated that in clinical situations, any material used over a base of chelon silver would improve the long-term sealing ability, without the risks of chemical and mechanical irritation of the periodontal tissues.

<u>Holt and Dumsha (2000)</u> : examined how bone cement would act as a retro-filling material, as compared to the conventionally used materials, with respect to it's sealability, when used as a root-end filling material.

They used 90 teeth, for this in-vitro leakage study, and the roots were instrumented and then obturated, with gutta-percha and Sealapex with lateral condensation.

The gutta-percha was then removed to a depth of 3 mm, apical to the access openings, and the access cavities were then etched, primed, and filled with APH composite. The teeth spent 48 hours in a humidor. Apicectomies were then done, and retroprepared to a depth of 3 mm. The teeth were then randomly divided into 4 groups of 20 teeth/group, depending on the retro-filling materials, while10 teeth served as controls.

Grp 1- 20 teeth were filled with amalgam, with cavity varnish.

Grp 2- 20 teeth received Super-EBA.

Grp 3- 20 teeth received Optibond Solo dentine bonding agent, and Prisma TPH composite.

Grp 4 – 20 teeth received Surgical simplex bone cement. This group was again sub-divided into 2 groups-etched, and un-etched.

All the teeth were placed in a 37°C bath, for 1 week. They were then placed in $AgNO_3$, for 2 hours. They were then rinsed, and placed in a developer solution for 2 hours. Then, they were stored in a humid environment, till leakage was measured under a microscope (x10). The teeth were grooved, and split longitudinally, to measure leakage. The leakage was measured from the most apical part of the tooth, to the most coronal extent of Ag- precipitate.

The investigators found that the mean leakage for the unetched bone cement was 1.5 mm, and for the etched bone cement, it was 1.31 mm. The mean leakage for Super-EBA, amalgam, and composite, were 1.71 mm, 0.59 mm and 0.92 mm respectively.

The statistical analysis of their data revealed that amalgam leaked significantly lesser than unetched bone cement and Super-EBA. The composite samples leaked significantly less than Super-EBA. There was no significant difference between amalgam, composite, and etched bone cement, nor between composite, etched bone cement , and unetched bone cement. Furthermore, there was no significant difference between etched, unetched, and Super-EBA groups.

The investigators concluded that bone cement could provide an acceptable seal. Though all the materials provided an adequate and a comparable seal, bone cement may prove to be superior due to its low toxicity [Davis and associates (1993)], and excellent biocompatibility, which would allow for the re-attachment of tissues. The cement also exhibited long-term biocompatibility with bone, with inter-locking of the cement with the soft and hard tissues of the bone without cell necrosis [Schmalzred and associates (1993); Boss and associates (1993)]. The antibiotic properties of the bone cement would be desirable as a retro-filling material. The authors speculated that although there was no clinical evidence in the dental literature, a bacteriostatic or a bacteriocidal agent could promote a more expedient post-surgical healing.

Behrend and associates (1996) had shown that the residual smear layer could be a potential leakage source for bacteria, but the present study, indicated that there was no difference in the leakage, in the presence or the absence of the smear layer.

Bone cement had been used without any negative effects, in orthopedic procedures like hip arthroplasty, wherein large amounts of the material would be used. It had been used for 20 years, in the field of medicine and surgery. The much lesser amounts of bone cement that would be needed in endodontics would also produce a much lesser exothermic reaction and a much lesser amount of free monomer.

Keiser and co-workers (2000) : investigated the cytotoxicity of MTA , as compared with Super-EBA and amalgam using human PDL fibroblasts, and an assay that assessed the metabolic activity of cells after exposure to extracts of the test materials.

They used a cell viability assay (MTT assay) for mitochondrial dehydrogenase activity in fibroblasts after 24 hours exposure to extracts of varying

concentrations of the test materials, in both –freshly mixed, as well as in the 24-hour set states, and controls were also used.

The differences in mean cell viability values were assessed, and the statistical analysis of the data revealed that in the freshly mixed state, the sequence of toxicity at the lower concentration was-Amalgam>Super-EBA>MTA.

At the higher concentration, the sequence of toxicity was amalgam, Super-EBA>MTA (there was no difference between amalgam and super-EBA).

In the 24-hour set state, the sequence of toxicity at a low extract concentration was –Super-EBA>MTA, amalgam (no difference between amalgam and Super-EBA), and at a higher extract concentration, the sequence was Super-EBA>amalgam>MTA.

The investigators concluded that MTA proved to be less toxic to the PDL cells than Super-EBA at all concentrations- in both the freshly mixed, as well as the set states. They supported the use of MTA as a root-end filling material, which was suitable for the root-end environment.

The authors also added that the repair process that takes place in the periradicular tissues after root-end surgery comprised of healing of the excisional wound of the bone, with regeneration of trabecular bone and the re-formation of a functional periosteum and cortical plate.

The ultimate success of surgery, according to the authors depended on the regeneration of a functional periodontal attachment apparatus, including the cementum overlying the resected root-end surface, the periodontal ligament, and the alveolar bone [Andreasen and associates 1972].

This would occur more predictably, if the exposed root canal after the resection would be filled with a material which not only sealed the canal to prevent the egress of bacterial antigens, but also allowed for the formation of a normal periodontium across its surface!

To date, none of the materials used, like amalgam, composite resins, ZnOE, EBA cements, GIC, polycarboxylate cements, cavit, and gutta-percha, among others, allowed for the regeneration of a normal periodontium across the entire resected root surface.

The assay used in the present study was the tetrazolium salt MTT, to gauge the reaction only in living, metabolically active cells.

Tai and Chang (2000) : observed the long-term effects of 3 commonly used perforation repair materials, like amalgam, composite resin and GIC, on cultured human PDL cells for the relative kinetics of cell recovery after incubation with the test materials.

They used the cell viability and the proliferation assays, for the purpose.

Twenty- seven 5x4 mm cylinders of each material were fabricated for the study.

The investigators reported that all the materials were cytotoxic to the PDL cells. Moreover, the type of the material, as well as the time, affected the cell viability and proliferation.

Resin exhibited the most cytotoxic effect, followed by GIC, and amalgam during the 14- day incubation period.

Amalgam and GIC slightly inhibited cell viability and proliferation in the first 24 hours, compared to the control.

The investigators stated that amalgam or GIC, may initially react favorably, to PDL cells, than resin. They added that the method used in the present study allowed the long-term observation of human cellular reactions, and hence, it might be a preliminary screening test for the initial biocompatibility of the dental materials.

The fact that repair materials would be in intimate contact with the periodontal tissues, would make it necessary to screen the potential toxicity of these materials. PDL- derived cells are responsible for the regeneration and the normal maintenance of the PDL. According to the authors, the in-vitro testing of the cytotoxicity should be done with the most appropriate normal human cells [Hanks and associates(1981); Yesilsoy and associates(1985)]. The in-vitro model had the advantage, to isolate and study the cellular events apart from the complex interactions of the cells to the perforation repair materials, which would occur during periodontal regeneration procedures, in-vivo. Moreover, tested materials, not elution, directly contacting the fibroblasts could mimic the clinical conditions more accurately.

The fact that the host-repair response could overcome these irritating effects of these materials might be responsible for the rare observations of clinical evidence in such cases. But, the biocompatibility of these materials, was an important factor, apart from their physical and the chemical properties.

Hulsmann and co-workers (2000) : in their literature review on root canal irrigation complications, stated that Bhat(1974) , had reported an iatrogenic perforation in a central incisor , in which H2O2 of unknown concentration was injected into the adjacent soft tissues. A swelling on the upper lip occurred rapidly and the patient had difficulty in breathing. The canal was left open, and antibiotics were prescribed, along with cold compressions. The oxygen released from the H2O2 caused an emphysema, which resolved after a week.

Grob (1984) had reported a case of an iatrogenic apical perforation in an upper lateral incisor, wherein 3% NaOCl had extruded beyond the apex. The patient had severe pain followed by a rapid swelling of the left cheek. Eight days later, an abscess had developed, due to the spread of infected material from the root canal into the periapical tissues. Surgical treatment was instituted, and large amounts of pus and necrotic tissue were found. Hyperaesthesia, and extreme sensitivity to cold temperatures was reported by the patient, for upto 4 years after the accident.

Reeh and Messer (1989) had reported a mid-root perforation in a central incisor, in which 1% NaOCl was injected through the defect.

The patient had immediate severe pain and swelling, followed by fistulation and erythema, which extended to the infraorbital area. Parasthesia of the floor and the ala of the patient's nose persisted for more than 15 months!

Becking [1991] had reported 3 cases of NaOCl injection into the periradicular tissues. In the first case, an unknown concentration of the solution had extruded through an apical perforation in a lower second molar. Progressive swelling of the left side of the mandible occurred, which extended to the patient's neck. The next day, mucosal necrosis, along with anaesthesia of the mental nerve was apparent. After antibiotic and analgesic therapy, the symptoms of pain and swelling subsided in 5 days. Paraesthesia of the nerve, resolved after 10 days, and healing of the mucosa took 2 months.

In another case report, an upper canine in a 55 year old patient was perforated at the apex, and was associated with an acute pain attack due to extrusion of 3% NaOCl through the foramen. Oedema and ecchymosis of the left cheek and profuse bleeding from the root canal was observed. Infiltration anesthesia along with analgesics and cold compresses were advised. The canal was left open for drainage, and the next day, the pain had resolved, but the swelling had increased. Massive intraoral ecchymosis was seen. The symptoms resolved after 1 week without additional treatment.

A right lower cuspid, in a case, was perforated between the crown and the root, and the wedging of the irrigating needle through the perforation caused extrusion of 3% NaOCl and 5% H_2O_2 into the periradicular tissues. The patient experienced extremely severe pain and a burning sensation in his lower lip. Massive swelling of the lower lip occurred immediately. The pain resolved rapidly, whereas the swelling persisted for 3 weeks. Mild paraesthesia in the lower lip was felt by the patient, and it remained for more than a year! One week after the incident occurred, an ulcer developed in the region, and it healed after 2 months, with minor scar tissue formation.

The authors concluded that NaOCl, in various concentrations was most frequently used as an endodontic irrigant, due to its tissue dissolving ability and its antibacterial activity. Most of the irrigant-related mishaps occurred due to incorrect determination of the working length or apical and lateral root perforations. Wedging of the irrigating needle, was also a common cause for these mishaps.

The authors emphasized on the precautionary measures, to avoid such accidents. The operator should ensure that the irrigating solution must leave the canals coronally, via the access cavity, and a low, constant pressure should be used. The fact that the contact of the irrigating solution with the periradicular tissues couldn't be totally avoided [VandeVisse and Brilliant 1975], was also added by the authors. Hence, a dilute concentration of the irrigant, which could retain an adequate anti-bacterial property, could be used. A concentration of 0.5% NaOCl would be non-toxic to the vital tissues, and could also be washed out by the blood circulation [Spangberg and associates (1973), Baumgartner [1992]].

The dentist, however, must remain calm and assist the patient in terms of re-assurement and information, pertaining to the cause and the nature of the incident. Though there was no “standard” therapy for the management of such complications, intervention depended on the nature and the severity of the incident. Local anesthesia could be helpful, along with analgesics. Cold compresses could be used initially, to aid in the reduction of any swelling, and after 1 day, warm compresses and mouth rinses could be advised, in order to increase the local microcirculation. Antibiotics could be prescribed only in cases where a high risk of infection spread would be suspected. Minor cases wouldn’t need antibiotics. The patient, should be informed that the resolution of the symptoms, and healing, would take a few days, or weeks and that complete resolution would occur in most instances.

The use of non-irritating solutions like saline or hexidine would be prudent, when the root canal treatment would be resumed. In most cases, extraction of the tooth, or a surgical intervention would not be necessary.

Behnia, Strassler and Campbell (2000) : reported a case of a perforation in the distal mid-root area of a maxillary lateral incisor. The perforation was caused due to excessive post space preparation, and it’s insertion.

The authors used a novel method of treatment, combining a surgical, and an orthograde approach with a biocompatible restorative material and a clear plastic light-transmitting post (Luminex). They said that usually, post-placement related perforations are detected much later, as the clinical a result of this action may go undiscovered until a radiographic or clinical evidence of an infection is apparent.

The procedure was described thus-

Phase 1—Re treatment of the tooth was done, and the post was loosened with ultrasonics and then retrieved with a hemostat. Puss and blood drained from the access opening when the post was removed. NaOCl irrigation followed, and the canal was dried. CaOH was placed as an intracanal medicament while the access was sealed with a temporary filling material.

Phase 2—One week later, after the swelling and the acute inflammation subsuded, a combined surgical and an orthograde procedure was done, to seal the defect.

A full thickness flap was raised, and the surgical site was observed with a surgical microscope. The granulation tissue was curetted and the defect was exposed by removing bone.

Prior to preparing the canal for bonding, Luminex was fitted 2-3mm short of the perforation site. The internal aspect of the root canal was etched, rinsed, and then dried. Dentin bonding agent was applied with a microapplicator, at the site of the defect, as well as in the canal. The adhesive was light cured for 10 seconds.

Geristore was mixed and loaded into a needle tube. It was then injected into the canal from the access opening.

The post was then inserted into the Geristore, to the pre-determined length. This pushed the resin into the canal and allowed the Geristore to be well adapted to the root walls, and slightly through the perforation. The resin was light-cured at this site for a minute, and within the canal, for 2 minutes.

The excess resin ionomer was removed from the perforation site, and the area was rinsed with saline. After the defect was sealed, apicoectomy was performed. The root-end preparation was accomplished with ultrasonics, and a retrograde filling of Geristore was placed.

The flap was sutured back, and no surgical dressing was given. The Luminex was removed with a hemostat. The access was restored with a temporary filling material.

The post space created by luminex, allowed for the permanent post placement at a follow-up.

At 6 weeks post-op, there was no sign of infection, and healing progressed satisfactorily. 2 months later, a pre-fabricated post was placed with a composite resin core, and the tooth was prepared, impressed, and restored with an all ceramic crown.

At a 1-year recall evaluation, radiographic evidence of healing at both the surgical sites was noted.

The authors concluded that the choice of material used to seal perforations should be based on sound clinical judgment. They had used Geristore and Luminex , as it allowed for all the requirements of controlling the placement of the resin ionomer as well as the post to retain the resin core. The Luminex aided in creating a "new root canal" that was subsequently used for the post placement, and also for all -ceramic crowns.

Cummings and Torabinejad (2000) : determined the effects of systemic doxycycline, on the crestal alveolar bone loss, in their in-vivo study, after periradicular surgery in dogs. They used 5 dogs in 2 phases of this study. Root canal therapy had been completed prior to surgery, in the experimental as well as the control groups.

In the 1st phase, after reflecting full-thickness flaps in the lower quadrant, notches were made in the enamel of the premolars with a round bur (x2.5 magnification). The measurements were taken from the reference notches to the height of the alveolar crest. After this, the averages were recorded, and the periradicular surgeries were initiated. These comprised osteotomies, root-end resections, root-end fillings with either MTA or amalgam. The flaps were then sutured back in place, and they were removed 7 days later.

After 60 days, the flaps were reflected in the quadrants that had undergone periradicular surgeries previously. The difference between the reference notches and the crest of the alveolar bone was measured again.

The average amounts of bone loss between the first measurements and the second measurements were recorded, as the amounts of bone loss in the control group.

After completing the surgeries in the control side, the surgeries in the experimental group were done on the contra-lateral quadrants of the same dogs.

Except for giving each dog 4.4 mg/kg/day of doxycycline p.o. for 10 days after periradicular surgery, the same protocol used in the 1st phase of the experiment was followed, for the 2nd phase of the investigation.

Sixty days after the 2nd surgeries, the animals were sacrificed, to examine the periradicular reactions to the root-end filling materials, as part of another study.

At that time, the amounts of bone loss after the 2nd surgeries were recorded. The difference in the amount of bone loss between the groups was calculated.

The statistical analysis of their data revealed that –

All the dogs in the experimental and the control groups had lost some crestal bone after periradicular surgeries.The amount of bone loss in the control group was 0.97mm with a standard deviation of o.19. When the same dogs received Doxycycline(control group), the mean bone loss reduced to 0.57 mm.

There was a significant difference between the amounts of bone loss in the 2 groups

The investigators concluded that systemic application of Doxycycline reduces the amount of bone loss after reflection of full-thickness flaps in dogs.

Sasaki and associates (1992) had reported that when osteoblasts were made diabetic by streptozocin , and then treated with tetracycline, their structure and function were restored to normal.

They added that studies done earlier [Grevstad (1993)] had also found the amount of bone loss after periradicular surgery was significantly lesser, when Doxy was administered.

The investigators speculated that the ability of the antibiotic to prevent bone loss could be due to its ability to block the activation of MMPs, by binding divalent cations like Zn and Ca. Chambers and associates (1985) had reported that MMPs played a crucial role in removing the organic osteoid in the bone surface and exposing the bone mineral to osteoclastic activity, and that if MMPs were inhibited, either minimal, or no bone loss occurred.

Tetracyclines also had the ability to block osteoclastic function, by reducing osteoclast acid production and reducing the ruffled border area [Rifkin and associates (1992)].

Gabler and Creamer(1991) had reported that tetracyclines suppress neutrophil-mediated tissue damage by inhibiting their migration, degranulation, and the synthesis of oxygen-free radicals.

Gomes and associates (1984) had investigated a number of antibiotics and they had reported that only tetracyclines inhibited bone resorption!

Fuss and associates (2000) : evaluated the sealability of silver GIC (Chelon silver) and compared it with amalgam, in the treatment of large furcal perforations, in vitro.

They used 25 extracted molars, and access cavities were made, and during the experimental procedures, the teeth were placed on wet towels in a closed jar at room temperature. The canals were prepared, and filled with amalgam and varnish. Naturally occurring coronal leakage through the intact pulp chambers was determined quantitatively, for each tooth, using a modified fluid transport model under pressure of 1.2 Atm. Each tooth was then disconnected from the system, perforated at the furcation, and the defects were then sealed with either chelon silver (10 teeth) or amalgam (10 teeth). Five teeth served as controls. The teeth were then incubated for 24 hours, at 37^{O}C, in 100% humidity.

They were then re-connected to the modified fluid transport system and the coronal leakage under pressure was evaluated at 1, 2, 6, 15, and 24 hours.

The leakage through each tooth was compared with that of its own intact pulp chamber floors before perforation, and the groups were compared with each other.

The investigators reported that gradual leakage was found in all the groups, at a mean of 0.017 microl/min and 0.007microl/min for amalgam and chelon silver respectively.

Chelon silver- repaired perforations leaked significantly less than those repaired with amalgam.

Radiographs revealed that amalgam extruded through the defects, in all the teeth, whereas chelon silver filled the perforations to the external outline of the roots, without extrusion!

The authors added that materials like amalgam, $Ca(OH)2$, and GIC had not shown satisfactory results.

The advantages of chelon silver were its quick setting property, radio-opacity, ease of manipulation, and minimal or no extrusion into the periradicular tissues.

The investigators concluded that chelon silver could be an adequate sealer for furcation perforations.

The GIC, did not require condensation and hence, tissue irritation could be avoided. Moreover, within a few minutes of passive application of the material, a strong, radio-opaque seal was evident, which allowed for the root canal treatment and restoration, without interference. The sealing property of this material was attributed to its micro-mechanical adherence only. Hence, in clinical situations, any material used over a base of chelon silver could improve the long-term sealing ability, without the risks of chemical and mechanical irritation of the periodontal tissues.

Glickman and Koch (2000) : addressing the issue on the "endodontic revolution" like the changes in the field of this discipline, stated that new materials , techniques, and instruments had entered the market, to assist the dentist in providing more predictable and reliable endodontic treatment. Moreover, these new systems could make endodontic services more effective and efficient.

They described these advances, for the benefit of the dentists who would be interested in incorporating these advances into their clinical practice. As the population expands and ages, the demand for endodontic treatment could be expected to increase, as patients would seek dental options to keep their teeth for a lifetime.

The authors described about the Ni-Ti rotary instrumentation, microscopic endodontics, digital radiography, the various obturation systems, biocompatible sealing materials, and the such, which have helped clinicians to tackle a wider variety of complex cases. However, diagnosis, in fact, "has become more challenging", and over-all, the case management "has become more complex, as geriatric and medically compromised patients are more inclined to seek treatment and save their teeth".

As long as the basic principles of endodontics are followed, these changes could enhance the predictable outcomes, when performing treatment.

The authors also addressed the need of the major improvement in the key endodontic areas, pertaining to research and development.

Ni-Ti rotaries had made instrumentation faster, easier, and safer (non-cutting tips) than the conventional hand instrumentation. Consistent and a more predictable shaping of the root canal system, was now possible. The Crown-down modality [Morgan and Montgomery (1984)], and the rotary techniques reduced inter-operative as well as post –operative pain for the patient, and made irrigation more effective, in terms of cleaning the apical regions of the root canals while the step-back method was associated with more procedural errors. The incorporation of hybrid and modified techniques of root canal instrumentation have overcome the earlier problems of rotary instrumentation.

The authors also cautioned about the judicious use of these new methods, and the comprehension of their limitations, to limit procedural mishaps. The radial lands in combination with the non-cutting tips significantly reduce canal transportation.

Enhanced magnification and illumination systems have raised the “awareness level” of what the operator visualize and perform. The simple fact that the ability to see better, had made microscopy, and endoscopy popular and had opened up a “whole new world of exploration”.

The management of perforations had now become more predictable, by the non-surgical as well as the surgical methods, in terms of magnification, as well as the incorporation of microsurgical armamentaria like ultrasonic retro-tips for more conservative root-end surgical procedures as well as for the removal of cemented posts. Bevelling of the root-end, which was necessary earlier for visualization of the root canal could now be overcome by resecting the root end perpendicular to the long axis of the root. This would eliminate the chances of opening up more dentinal tubules, and would also reduce the amount of bone elimination and allow for the preservation of root structure.

Micropaddles for treating strip perforations are now available.

Endoscopy with fiberoptic probes to explore the internal as well as the external components of the root canals has made the management of mishaps, easier. Patient education via images taken from the probe and projected onto a video monitor has improved the doctor-patient relationship too.

Currently, however, the microscope is just a tool, and not a part of the “standard of care” in endodontic therapy- but this would change shortly, when research proves that a higher degree of success could be obtained.

MTA, “is one of the newest and the most promising materials to enter the realm of endodontics in many years”. Histologically, it had shown its superiority over the currently used materials. In clinical scenarios, like perforations, there were no other viable options. Further developments in the material, like a white powder [instead of the gray one that’s being currently used), would eliminate any potential for staining of the tooth structure, where esthetics is important.

Jukic & Associates (2000) : Tested the mutagenic activity of AH+ and its components and compared it with the mutagenicity of AH26 by means of Salmonella/microsome assay.

One half of each material was processed immediately, while the rest was set for one hour and one month, respectively. After one month, the samples were completely polymerized, and for further study they were pulverized with a polytron apparatus. The mixed materials were extracted in dimethyl sulfoxide, innert solvent [1g/5ml], immediately after mixing, or after setting 1 hour or 1 month for 24 hours at 37^{o}C. The extracts were aliquoted and stored at –20^{o}C for mutagenicity testing.

The mutagenicity tests were conducted by the standard plate incorporation test. Two test strains of S.typhimurium TA-98 and TA-100 were used to detect frame-shift and base-pair mutation respectively. Dimethyl sulfoxide samples of 0.75, 1.5 and 3.0 μl were plated into Wogel-Bonner's basal agar plates with 2.0 ml of soft agar.

0.5 mM L-histidine-0.5mM biotin solution had been previously added. Overnight culture of TA 98 or Ta 100 [0.1ml], both without or with metabolic activation [0.5 ml of –S9 mixture or 0.5 ml of +S9 mixture], was added to the plate.

The S9 mixture contained 50 μl of hepatic S9 prepared from male Wister rats. Immediately before mutagenicity testing, the S9 fraction was passed sequentially through Millipore membrane filters (0.45 μm and 0.22 μm filter uits) to remove any contaminating microorganism. Each sample was plated in triplicate, and its revertants were scored after 48- hr incubation at 37^{o}C. As a positive control [known mutagens] for this assay, 2-aminofluorene was used. Duanomycin at a concentration of 20 μg/plate without S9 and 645 μg/plate of methyl methanesulfonate were used as an additional control of the TA 98 and TA 100 strains, respectively. The mutagenicity was expressed as the number of revertants, per plate, per microliter of dental materials.

The investigators reported that extracts of AH+ were mutagenic after only 1 hr setting to strain TA 100 without S9 in a concentration of 0.75 μl/plate. Toward strain TA 98 with S9, AH+ extracts were weakly mutagenic either immediately or 1 hr after mixing in all cocentrations. Mutagenicity was eliminated when the material had set for 1 month. For the TA 98 strain with S9, mutagenic activity was observed after a setting for 1 month.

AH26, immediately after mixing, and after 1 hour of setting time, changed from a weak positive, to a very strong response for mutagenicity in strain TA 100 in doses of 1.5 μl/plate and 0.75 μl/plate. However, AH26 showed less mutagenic activity toward strain TA 98 than toward TA 100, both immediately after mixing and with 1 hr of setting time. The dose of 3.0 μl/plate was predominantly toxic. Mutagenic activity was evident 1 month after mixing in strain TA 98 with S9 and in strain TA 100 without S9.

Paste A of AH+ proved to be mutagenic and showed a 10-fold increase of bacterial growth in a TA 100 strain without S9 when compared with the negative control. Toward strain TA 98, the mutagenic activity was weaker, but it was more pronounced with metabolic enzyme S9. The mutation rates of strains TA 98 and TA 100 were enhanced approximately 2-fold, which indicated a weak mutagenic effect, of paste B.

The investigators concluded that in this study, 2 of the 5 bacterial strains recommended by Maron and Ames [1983] had been used, so the obtained data could be assumed as "preliminary". Although AH+ showed less mutagenic activity toward these bacterial strains, the correlation in results between this, and previous studies on AH26's mutagenic potential in bacterial tests and in mammalian cells assay indicated the need for further experiments on the mutagenicity of these two sealers, especially AH+. Only a positive result in a battery of tests is indicative of potential risk to human health, either of patients or of dental professionals who handle the material. The investigators added that before conducting such a battery of tests, they could not establish a definitive conclusion, about the mutagenic potential about AH26 and AH+".

Kulkarni & Associates **(2000)** **:** Evaluated the ability of calcium sulphate barrier to control the extrusion of the repair materials into the furcal area, and studied the effect of these barriers on the sealability of amalgam and LC-GIC.

They used 64 extracted molars for this in vitro study. 60 teeth were divided into four groups, perforations were created and moist cotton pellets were passively placed between the roots in the furcal area during repair. No attempt was made to prevent material extrusion.

Group 1 – 15 perforations were repaired with amalgam and it was condensed into the defect against the pulp chamber floor with an amalgam condenser.

Group 2 – 15 defects were repaired with calcium sulfate as a barrier under amalgam. The hemihydrate powder was placed into the moist perforation with a plastic instrument till the moisture from the cotton was saturated. It was then condensed with a plugger to create a space for the repair material, and the mix was allowed to set. Amalgam was then condensed against the set barrier.

Group 3 – 15 defects were repaired with GIC added in increments, and condensed. Every increment was light cured for 40 seconds. This procedure was repeated till the defect was filled.

Group 4 - A Calcium sulfate barrier was made in 15 perforations, and LC-GIC was used to repair them.

All the access cavities were sealed with LC-composite and the teeth were submerged in 2% methylene blue for a week, at room temperature.

Longitudinal sectioning and evaluation under a stereomicroscope (X40) comprised of measuring the leakage on each wall, as the amount of linear dye penetration.

The statistical analysis of their data revealed that calcium sulfate provided a successful barrier against overextrusion of the repair material, though the sealing ability of amalgam and GIC was significantly reduced because of it.

GIC over CaSO4 was found to be a better combination in terms of extrusion and sealability.

The investigators concluded that the use of CaSO4 as a matrix had good potential, especially if excess was removed from the perforation walls. This apparently enhanced the sealability of the repair materials placed over it. It also stimulated bone repair at the furcal area. They added that the use of CaSO4 may improve the prognosis of teeth with furcal perforations.

Lee (2000) : Described the technique to deliver MTA as a root end filling material to a difficult surgical site by formation of MTA pellets. He stated that, the delivery of MTA had focussed mainly on carrier and syringable type devices such as, Retroamalgam carrier and the Centrix syringe. In surgical situations these devices would be difficult to use because of the location of the surgical site and the small size of the root end preparation.

The technique described was thus – the mold for the MTA pellets could be made by cutting a groove into a 0.5 inch x 0.5 inch x 2.0 inch plastic blocks with a number 169 fissure bur.

The length of the grooves could vary from 2-4 mm. Several grooves, which could vary from ½, to the full circumference of the bur, and the length of the grooves could vary from 2-4 mm. Several such grooves could be made, each about 4-5mm apart.

After root end resection and ultrasonic instrumentation for the cavity preparation, MTA could be prepared such that after 30 seconds the mix would exhibit a putty- like consistency.

The MTA could then be immediately placed into the grooves with a cement spatula, and the excess material outside the grooves could be wiped clean with a moist cotton swab.

The pellet could then be scooped out of the grooves with a No.3 Hollen back instrument, and delivered to the root end preparation.

Pluggers could be used, to condense the material into place. Depending on the size of the canal and the size of the pellets it could take about 2-5 pellets, to fill preparation.

The placement of MTA must be fast, according to the author, as the small pellets dehydrate fast. When the MTA mix is dry, it would become crumbly and unmanageable. The use of several grooves on each of the four surfaces of the plastic block would help with the speedy placement of multiple pellets of MTA.

Covering the plastic block with a moist gauze, would also help prevent dessication of the MTA.

The goal of a root end resection, preparation and filling was to eliminate the exposure of the periradicular tissues to the microorganisms in the root canal space. If the preparation was inadequate, failure would result.

The author concluded that the carrier - type devices, which were most often used for the delivery of MTA, were difficult to use. This MTA pellet - forming and delivery technique could overcome these difficulties.

Lussi & Associates (2000) : compared the quality of seal after aging of three root canal filling materials. Obturation with NIT was compared with cold lateral condensation of gutta-percha after either NIT or hand instrumentation.

They used 60 extracted teeth and standardized radiographs of all the teeth were taken to assess the curvature of the roots. The teeth embedded into silicon impression compound in such as way as to be able to project the most marked curve of the root on the X-ray. X-rays were taken using a specially designed fixture to hod and orient the blocks. The outlines of the canals were transcribed from the radiographs onto transparent fill and the degree of curvatures was determined. The teeth were arranged in an ascending order of their curvatures and were divided into 10 pools of 6 teeth each. One tooth after another was then randomly sealed from each pool and assigned to one of the 6 treatment groups. The root canals of 3 groups were prepared by hand instrumentation while those of the remaining three groups were prepared by the NIT. The sequence of treatment of the various experimental groups was at random. Three different sealers used were a) AH+

b] Apexit

c] Pulp canal sealer EWT.

In the hand instrumented canals the balanced force technique was used. The canals were rinsed with 3 ml of 2.5% NaOCl after instrument. A total of 50 ml of NaOCl per tooth was used.

The sealers were mixed, and coated on the walls of the canals. Obturation was done by lateral condensation. Excess gutta-percha and sealer were removed with a hot spoor excevator. The chamber was filled with IRM. Upon completion of the cleaning with NIT, the teeth were prepared for the obturation process. AH+, Apexit, and pulp canal sealer EWT were agitated under a reduced pressure environment for 10 minutes to reduce bubbles from mixing. The obturation was done with a specially designed vacuum pump. The pressure in the canals was reduced to 8 hPa. The sealer reservoir was then opened and the sealer was sucked into the root canal system. The obturation paste flowed into the tooth first. Subsequently 1, size 20 gutta-percha cone was slid into the canal as far as it would go. The chamber was then filled with IRM.

The specimens of both groups were then stored for 6 months in 0.9% NaCl solution with thymol at 37°C. The solution was changed every second week. After 6 months the teeth were thermocycled 5000 times between 5°C and 40°C, with a resting period of 30 seconds in every bath.

An extra tooth was added as a control to each of the six experimental groups. All the specimens including the controls were placed horizontally in black ink and exposed to a reduced pressure atmosphere of 66.5 hPa for 2 hours. After releasing the negative pressure the teeth were left in the ink for another 88 hrs. They were then made transparent so that the dye penetration would become measurable. Each root was oriented in such a way as to make the largest extent of the dye penetration visible through a microscope. The extent of coronal dye penetration was measured with a stereomicroscope at X20 magnification. Starting at the ground coronal surface dye penetration was measured to the nearest 0.1mm with a measuring eye piece.

The investigators reported that due to the equilibration procedures, no statistically significant differences between the groups were found.

The teeth cleansed and filled with NIT showed a statistically significant lesser dye penetration than the hand instrumented teeth only for Apexit-filled group. Within the hand obturated group, pulp canal sealer EWT showed significantly more dye penetration than the other materials.

The investigators added that besides thorough cleansing and disinfection successful endo-therapy also required a tight seal against bacterial migration. The conventional methods for filling of root canals would produce entrapment of air bubbles. Along such paths bacteria and/or their metabolites as well as other substances serving as a substrate could seep through to the orifices of side canals or to the main apical foramen. These bubbles could be formed during mixing of the sealer also. The NIT method however, aspirates the obturating material into the main canal as well as the side canals and also into the dentinal tubules. Since, obturation of root canals should seal the canals for extended periods of time, the quality of such obturations after artificial aging was investigated. In the oral cavity, the teeth are exposed every day to different environmental conditions, and chemical stress that might have an influence on root canal fillings. To expedite aging of the teeth there were alternatingly exposed to different temperatures in a thermocycling device. Assessment of the sealing properties of root canal obturations had been attempted with various methods. The most widely used technique was the measurement of the linear dye penetration. The NIT filled roots received only one gutta-percha point in the sealer. This point was not adapted to the canal since the canal was not instrumented with standardized files. The gutta-percha point was used exclusively to make reentry easier in case of need. Since, the sealer was vibrated and vacuumized before application with the NIT. This could explain the increased tightness of the NIT obturations.

The aim of root canal therapy according to these authors was the treatment of infection and the prevention of infection. Unless the canal is closed by obturation, irritants metabolites and microorganisms that could cause periapical breakdown had the opportunity to return. This could lead to the recurrence of the lesion. The NIT does not enlarge the root canal system at all, nor are irregularities of the walls removed. Comparative studies showed NIT to produce equivalent or better results than hand instrumentation regarding the cleanliness of the canals and the quality of the obturation.

Leonardo and associates (2000) : evaluated the cytotoxicity of 4 Ca(OH)2 root canal sealers- Sealapex, CRCS, Apexit, and Sealer 26, and one ZnOE base sealer(Fill canal).

They used 120 rats for this in-vivo study, and the sealers were spatulaed

Earle 199 salts with minimum essential medium (MEM) were used as a culture solution, and were injected into the peritoneal cavities of the rats. 3 ml of the injected was removed, and placed into sterile Leighton tubes. The rats were sacrificed separately.

A rectangular 4 x 3 cm cover glass in which a central groove had been made, was put into each tube, thereby creating a 1 mm diameter circumferential receptacle, into which the sealers were deposited separately.

The tubes were then stored at 37 degrees C. After 20 hours, by which time the macrophages adhered to the cover glass, cultured were washed, using MEM aith a 10 ml syringe.

When only macrophages were present on the cover glass under microscopy, the culture was separated and 5 ml of MEM containing heparin and serum were injected.

Five cultures were made of each of the 6 groups, and the specimen were incubated at 37 degrees C, for periods of 12, 24, 48, and 72 hours, totaling 120 cultures.

The tubes were opened at predetermined intervals, and the cover glasses were removed, fixed with ether alcohol, and stained with hematoxylin and eosin. Microscopic evaluation was performed, and the statistical analysis of their data revaled that Sealapex caused the most cytotoxic alterations in macrophage cultures, at all time periods. Cell rupture and fragmentation were marked in cultures tested with Sealapex, followed by Apexit. Fill canal, Sealer 26, and CRCS showed minimal cytotoxic variations, with Fill canal being the least toxic. In the control group, nuclear fragmentation did not occur.

The toxicity of Sealapex was attributed to its high alkalinity.

The investigators added that all materials used in endodontics must be biocompatible, and that they should be well tolerated by the host tissues.

One method of testing the biocompatibility of the materials was the analysis of an in-vitro model of the cellular response, for the in-vivo cellular reactions to the filling materials. The advantage here was that all factors and variables could be controlled [Arenholt and associates (1990); Barbosa and associates (1993)]. The toxicity of the sealers could be evaluated by observing morphological alterations in cell cultures, and by analyzing these cultures under electron transmission or scanning light microscopy, with or without radioisotope labeling. The morphological alterations may show intra or extra- cellular toxicity resulting from exposure to the materials [Leonardo (1992)].

A biocompatible material, should neither prevent nor hinder tissue repair, but, should aid in the re-organization of the injured structures, so that the repair could foster biologic sealing of the root apex and isolate foreign bodies [Holland and Souza (1985)].

They concluded that Sealapex caused the largest macrophagic cytolysis halo, and that Apexit caused cytolysis, but, to a lesser degree. This was reported earlier, by Beltes and associates [1995).

Silva and associates [1997], had also shown that Apexit induced an inflammatory reaction when injected into the root canals of dogs, and Leonardo and associates(1997)], had shown its unfavourable reaction, in rats.

CRCS, was the least aggressive, in the present study.

Witherspoon DE, Ham K. (2001) : stated that numerous procedures and materials have been utilized, to induce root-end barrier formation. Mineral trioxide aggregate (MTA) was introduced to dentistry as a root-end filling material. It has been advocated for filling root canals, repairing perforations, pulp capping, and root-end induction. Mineral trioxide aggregate reacts with tissue fluids to form a hard tissue apical barrier. As a result, MTA shows promise as a valuable material for use in one-visit apexification treatment, primarily for treating immature teeth with necrotic pulps.

Schmitt D, Lee J, & Bogen G (2001) : stated in this review, MTA's physical and biological properties and the clinical techniques for direct pulp capping, apexification, and also for the repair of failed calcium hydroxide therapy.

They stated that MTA was a new material, recently approved by the FDA for use in pulpal therapy, as it has been reported to have superior biocompatibility and sealing ability and less cytotoxicity than other materials currently used in pulpal therapy.

Nahmias & Bery (2001) : presented case reports wherein MTA was used. A 42 year old female with an endodontically treated primary retained molar prestned herself for a clinical evaluation. A sinus tract was present although the tooth was asymptomatic. The radiographic evaluation revealed lucencies related to all the roots. Severe apical resorption was seen and this further compromised the prognosis of the tooth. At the initial appointment the old filling material was removed from the canals and they were then cleaned and shaped with sodiun hypochlorite. Calcium hydroxide paste was then applied for 6 months to establish an apical stop. The canals were obturated with MTA due to the unusual internal anatomy of the tooth. A wiating period of 6 months ascertained proper healing prior to the placement of the final restoration. A radiograph taken at this time showed an excellent bone-fill in close apposition to the root system and the MTA.

A 52-year old male had an endodontically treated lower molar with crown-lengthening procedures that had been recently performed. The patient had a mild discomfort associated with the tooth. A sinus tract was seen in the lingual aspect, and a lucency was noted in the furcation area. Retreatment of the root canals was done and the patient was informed about the possibilities of a furcal or a strip perforation. The SOM, revealed a strip perforation in the distal aspect of the mesiolingual canal. The perforation was sealed with MTA after controlling the bleeding with calciun hydroxide. The rest of the canal was obturated with thermoplastic gutta-percha and the access opening was bonded. 1 month later at a recall the patient had no symptoms, and the sinus tract was no longer present. The probing depths were within the normal limits, only 1 month after treatment with MTA. At a 6-month recall, the radiograph showed significant healing of the pre-existing furcal lesion.

The authors concluded that in addition to being used as a root end filling material, MTA could be used for procedural errors like perforations so that “consistent healing” could be expected. MTA was easy to use, and its long-term prognosis had been proven to be excellent. This material, according to the authors, "promises to be one of the most versatile materials of this century".

Baek and Kim (2001) : evaluated whether the bone regeneration could be improved in experimentally induced through and through mandibular defects, in ferrets, and whether there was a quantitative and a qualitative difference, of the regenerated bone with different GTR membranes.

They studied 16 induced osseous defects in 8 ferrets. The trans-osseous defects were covered with Gore-Tex or Vicryl or Guidor membranes, which served as the 3 test groups. The flaps were repositioned on the outer side of the membranes and were sutured.

The animals were sacrificed after 6, and 12 weeks post-op, respectively, and the tissues were histoanalyzed.

The investigators reported that –

a) the control group showed the ingrowth of the sulcular epithelium into the defect.

b) Gore-Tex was associated with good bone formation.

c) Vicryl, was found to have favoured the highest degree of bone formation.

After 6 weeks, the defects had nearly healed, with fibered, lamellar bone.

After 12 weeks, mainly lamellar bone was seen. The Guidor group had induced a little bone formation.

The investigators concluded that GTR membranes would generally promote and improve bone regeneration in bone defects of endodontic origin.

The concept of GTR (using PTFE- polytetra fluoroethylene) was initially described by Nyman and associates (1982), and was aimed at preventing the connective tissue from entering the bone defects during the healing process.

<u>Daoudi MF (2001)</u> : Presented a case report, in which an iatrogenic perforation had occurred, in the upper lateral incisor of a 59 year old woman.

The operating microscope (x1.7 to x 35) was used for the purpose of magnification, and Ca(OH)2 was used as an interim dressing material, and gutta-percha, as the sealer.

The tooth had served as a bridge abutment, for an appliance from tooth number 12 to 23.

The aesthetics of the prosthesis being poor, it was indicated for removal and the perforation had occurred during the removal of the post-retained bridge, and regaining access to the root canal system.

The symptoms and signs, of the patient, along with an x-ray, as well as an apex locator, confirmed that a perforation had occurred in the mid-root area.

The bridge was temporarily re-cemented, and the patient was rescheduled for the next day. The patient was asymptomatic, and during this period, the bridge was removed, the canal was thoroughly cleansed, and dried.

The OM was used, to locate the site of the perforation, and also to assess in detail, the degree of damage that might have been caused.

An endodontic explorer was used, to assess the borders of the perforation in detail. The perforation was located at the distobuccal aspect of the mid-root, and it was about 1.5 mm in diameter, with an oval shape. The canal was prepared with the modified double-flared technique, with 3% NaOCl, and sterile water.

The calcium hydroxide was packed into the perforation, and the canal, as a temporary dressing. The access was sealed with IRM .

After 8 weeks, the Ca(OH)2 was replaced, and a “clot-like” plug, at the perforation site, was seen (under magnification) and was thought to be healing tissue.

8 weeks later, the root canal was obturated, and a warm vertical condensation technique was used, for the purpose (Touch N Heat, analytic Tech model 5004).

The perforation was sealed with a perforation repair instrument (West EIE, San Diego CA, USA) to pack the repair material . A x-ray taken, showed a fully obliterated canal.

At a 3- month recall, the canal of the tooth (1 2), was prepared to receive a cast gold post and core. The OM was used, to ensure that there would not be any disturbance of the perforation site. A post was cemented, and a temporary bridge was given, for a period of 6 months. The tooth was asymptomatic at this time, and hence, the fixed bridge was seated.

3 years post operatively, a x-ray taken revealed a normal PDL thickness/width, and the patient was asymptomatic.

The author concluded that the use of new materials and techniques in the practice of endodontics, could lead to a more conservative approach of tackling the problems of treating a perforation. "Promising results could now be achieved.", according to the author. However, both the operator as well as an assistant would have to train themselves, for proper co-ordination, and this, in turn, could make it possible for them to enhance or, take their skills to a higher level of precision . He also added that materials like amalgam, IRM, Glass polyalkenoate cements, and composites had been used for the repair of perforation, but none of these, had consistently proved to be predictable, in terms of the prognosis of the tooth, and they were associated with varying degrees of success.

MTA, in that matter, had shown promising results!

Douthitt, and associates (2001) : characterized the regeneration of the periodontium in the absence of both, periradicular bone, as well as the buccal cortical bone, after placement of a bioresorbable membrane. Premolars of 9 dogs were chosen, for this in-vivo animal study. The teeth were randomly assigned to the mambrane or the control groups, at the time of the initial 27-week group surgery. The remaining teeth on the contralateral side were treated 18 weeks later, to produce a 9-week observation period.

The investigators performed the histological and the morphometric assessment of the periradicular wound healing after using Guidor, a bioresorbable membrane, over a buccal dehiscence.

The teeth had all of their pulps extirpated, and the canals were obturated with Diaket. The access cavities were sealed off with copal varnish and amalgam.

The flaps were reflected, and buccal dehiscences were created, after removing the cortical as well as cancellous bone.

The root ends were then resected, and those with Diaket fillings were polished with ultra-fine finishing diamonds.

After the resection of the root ends of both the groups, a mesiodistal groove was placed at the level of the alveolar crest, upto a depth of 0.5 mm. The apical-buccal line angle of the resection and the coronal groove served as the reference points for the morphometric analysis. The alveolar bone was removed completely from the buccal root surfaces of both the teeth, from the coronal aspect of the marginal bone, to the coronal margin of the periradicular surgical access. A defect 3 mm in width, was created and the root surface was denuded off its periodontal ligament, by curettage. The root ends as well as the bone surfaces of each tooth, were burnished with ferric chloride solution for 30 secs.

The 3rd and the 4th premolars of the left and the right side of the mandibles were randomly assigned to the Guidor(test), and the control group, at the time of the 27 week-group surgery. The remaining teeth on the contra-lateral side were treated 18 weeks later, to produce a 9-week group. One tooth in each quadrant received at random, a Guidor, which covered both the roots. The other tooth in the quadrant served as a control.

The membrane was placed in level with the alveolar crest and the buccal defect, and about 3mm beyond the defect, in all the dimensions. The reflected tissue was placed coronal to the coronal aspect of the membrane, thus, submerging the membrane.

The flaps were replaced and sutured with vicryl.

Nine weeks after the 2nd surgical procedure, The tissues were prepared for internal fixation with formalin. The histoanalysis comprised of gauging the tissue reaction to the material, the integrity of the resorbable membrane at 9, and 27 weeks, the degree of periodontal regeneration, and the degree of inflammation.

A microscope was used for the morphometric analysis, and the investigators reported that-

a) The 27–week membrane group showed a greater connective tissue height than the control group, or than either of the 9-week groups.

b) The mean amount of alveolar bone regenerated was significantly more, in the 27-week membrane group specimens.

c) The mean junctional epithelial measurements were significantly more for the control, as well as the 9-week group.

In conclusion, the investigators stated that the use of a bioresorbable membrane enhanced bone regeneration when a buccal defect was present, at the time of peri-radicular surgery.

They also added that one objective of surgical periodontal therapy was the predictable regeneration of the periodontium, at the site of previous periodontal breakdown.

New cementum, a functional periodontal ligament, as well as new alveolar bone had to form, as the essence of the therapy would vest in this property of selective colonization, which would allow the slower, bone-forming cells, to re-populate the bony defect and the root surface, prior to the encroachment of the area by the faster proliferating epithelial cells, which would create an apical migration of the gingival

attachment apparatus[Gottlow and associates 1984, 1986]. The new connective tissue attachment could thus be gained, by guiding the cells to the earlier diseased root surface. The stabilization of the root-clot interface was another advantage.

Holland and associates (2001) : observed the healing process after intentional lateral root perforations were created, in dog teeth, and repaired with MTA, using Ca(OH)2 cement as a control.

They used 48 root canals, from 4 dogs, for this in-vivo study, and after the pulps were extirpated, the root canals were instrumented, and obturated. The filling was then partially removed, and perforations were created in the lateral area of the root, at the border between the middle and the coronal thirds of the roots.

The defects were immediately sealed with either MTA, or Sealapex. The access cavities were sealed with Cimpat and amalgam.

After 30 and 180 days respectively, the animals were sacrificed, and the tissues were prepared for histological analysis.

The investigators reported that – in the MTA group

a) 30 days post-op, four specimen, had shown deposition of new cementum over the material.

b) The neo-cementum was seen as a thin basophilic layetr, and the periodontal ligament was free from inflammation.

c) 7 specimens showed small areas of ankylosis, next to the defect, while 3 specimen revealed that only a few chronic inflammatory cells were seen, when the material extruded into the periradicular tissues.

Sealapex group –

a) 6 samples were seen, associated with chronic inflammatory reaction, and 12 specimen had ankyloses, albeit in amall areas.

b) 9 specimen showed over-filling.

c) The bone tissue in direct contact with this material showed a basophilic layer, and the periodontal ligament adjacent to the defect, was necrotic!

d) Some basophilic areas and points of ankylosis were also seen.

At 6 months – the MTA group showed:

a) 9 cases, with cemental deposition on the material.

b) 10 specimen, were free of inflammation.

c) The neo-cementum was eosinophilic, cellular, and sometimes, formed as an irregular layer.

d) In 4 of the specimens associated with over-extrusion, 2 showed a few giant cells and a mild chronic inflammatory reaction was also noted.

e) No ankylosis with any of the specimens.

Sealapex group :

a) 3 specimens were seen, with cementum, deposited over the material. This, however, was observed in the areas, just adjacent to the defect.

b) 3 specimens showed under-filling of the material, and this was associated with the in-growth of connective tissue and bone, into the cavity.

c) Neo-cementum was also seen, around the walls of the perforation.

d) All the specimens treated with Sealapex exhibited chronic inflammation, with giant cells and macrophages, which showed the filling material to be within their cytoplasm.

e) Ankylosis wasn’t seen, and 6 specimen were under-filled.

The investigators concluded that the results reported with MTA were "very interesting", and that their study supported its usage, for the repair of root perforations.

They added that the hard tissue deposition which was seen with MTA, as well as in the Sealapex groups, meant that these materials had similar properties- that is, the promotion of hard tissue formation. This was attributed to the calcite crystals [Holland et al 1982; Seux et al 1991] that were seen, in the specimens, as well as the presence of fibronectin, which was considered to be the initial step, in the formation of a hard tissue barrier. They speculated that the calcium oxide, that was present in the MTA, could have undergone a reaction with tissue fluids, and then formed calcium hydroxide. This last product could form the calcite crystals [Holland et al 1999].

MTA, actively promoted hard tissue formation, rather than being "inert", or being an irritant, unlike the other materials used for the purpose of perforation repair. Different materials had been used, for this purpose, according to the authors, but none, however, could meet most of the properties required of an "ideal" repair material.

Greer & Associates (2001) : investigated and compared the ability of different materials to seal a surgically resected root end against leakage in vitro. They used 40 extracted teeth and instrumented them upto a size 40 file which extended 1mm beyond the apex.

1mm of the root apex was removed, and the preparation, 3mm deep was done. The roots were randomly divided into 4 groups (10 roots each and filled with the test materials).

The materials tested were IRM, super EBA, Dyract & Geristore.

The canals were left open to exclude coronal leakage so that only the apical leakage could be gauged. Each root was then affixed to a fluid filtration device and subjected to a pressure of 14 cm of water (normal pulp tissue pressure).

The seal was evaluated for 5 minutes at 1, 7, 30 & 180 days. The statistical analysis of their data revealed that the compomers Dyract and Geristore were equal or superior to IRM, and equal to super EBA in the ability to reduce the apical leakage when used as a retrofilling material.

They added that the sealing ability of the compomers was comparable with super EBA and its handling properties were also superior in terms of working time, ease of manipulation and handling.

Studies done earlier had demonstrated that the compomers were biocompatible like super EBA (Oynick & Oynick 1978, Dorn & Gartner 1990, Dragoo 1997).

None of the teeth tested, achieved a completely fluid tight seal. IRM and Super EBA were selected to compare with the two compomers since it had been proved that these ZnOE reinforced cements had a success rate of 91% to 95% over a 10 year observation period (Dorn & Gartner 1990).

The root end filling materials currently used, range from amalgam to IRM and super EBA cements, to the newer dual-cured composite resins.

Compomers which are a mixture of composite resins and glass ionomer cements "are becoming popular in restorative dentistry" due to their strength, esthetic qualities of composite restorative materials and their bonding efficiency without the need for acid etching to dentin. Moreover they released fluoride and inhibit recurrent caries. These hybrids are easier to place due to their 1-component, no-mix direct delivery system. Their biocompatibility was significnat, in that the gingival tissues adhered to the materials, resulting in a clinical attachment when placed sub-gingivally. This feature may allow fibroblasts of the PDL to attach to, and reform around a root apex in which a compomer root end filling is placed.

Rud& Associates (2001) : Presented the frequency of peri-apical healing of the first, second and third mandibular molars, operated and sealed using a bonded composite resin and reexamined at various times post-op.

From 1994 to 1997, patients with 726 lower molars with periradicular periodontitis were referred to the authors for root end sealing with Gluma and Retroplast. Of these 87 cases were eliminated for variosu reasons. The remaining patients representing 639 molars were recalled after about 1 year and /or subsequently (>1.5 yrs). 84% of the cases responded to the recall.

The buccal axis to the roots was gained and the flap was raised to enable visibility of the area near the apices. The approach was made by removing part of the buccal bone leaving the roots covered with only a thin layer of bone, except in the apical region (where the bone was removed to allow access to the root end).

The roots were resected and examined with an operating microscope and whenever possible a 90º resection of the root was done. Accessing the lower molars was difficult and the resection in such cases was more oblique. The bone cavity was curetted and the whole root end was made slightly concave with a large round bur.

With a miniature brush, a solution of 0.5 mol L^{-1} EDTA, having a pH of 7.4 was rubbed onto the root ends for 20 seconds. The ends were then rinsed with saline and dried. The DBA Gluma Desensitizer was then applied for 20 seconds and dried. Finally, the root end was covered with retroplast [a 2 component- auto polymerizing composite resin). After mixing for 10 seconds small amounts of retroplast were applied to the root end with a small excavator. The entire root end was covered, leaving the periodontal membrane free. 2 minutes after curing on the mixing pad, the unpolimeryzed air inhibited surface layer was removed with 96% ethanol. A miniature brush was also used for this and the process was repeated twice.

The flaps were placed and sutured leaving the marginal horizontal incision in place, to allow for drainage. The sutures were removed 2 days later.

Amongst the 726 operated molars, half of them showed sub-acute or acute symptoms at the time of the operation. 14% of the molars were associated with an abscess or pus during the operation.

24 patients had post-operative paraesthesia in the lip and the chin from the inferior dental nerve.

The investigators reported that of the 834 roots recalled between 6 months and 12.5 years post-op, 92% showed complete apical healing, 1% showed uncertain healing and 7% exhibited failure. In the patient group of 71 to 89 years, 36 roots showed an average of 97% complete healing. 25 failures, which were re-treated surgically, showed an 80% healing when examined at a later date.

The investigators concluded that the root end sealing of mandibular molars with dentin bonded resin composite was "a promising technique" during 92% complete healing in cases examined between 6 months and 12 years post-operatively. They added that except for previous reports (Rud et al. 1989, 1996) the endodontic literature gave only limited information on retrograde root end filling of lower molars. The special operation technique [Rud et al 1989, 1991) with Gluma and retroplast showed that the cavity preparation on the resected root end of mandibular molars was not needed!

<u>Holland and associates (2001)</u> : studied the reaction of dog dental pulp, after pulpotomy and subsequent protection of the remaining tissue with MTA or Portland cement [PC].

They used 18 teeth, from 1 dog, and selected 26 roots, for this in vivo study. After gaining access, the pulp chambers were excavated, and the pulp stumps were covered with MTA or PC. Each material protected 13 pulp stumps respectively, and the coronal access cavities were sealed with ZnOE and amalgam.

After 60 days, the animal was sacrificed, and the tissues were prepared for histomorhologic assessment. They checked for the continuity, the morphologic aspects and the thickness of the hard tissue bridge that had formed. In addition, the inflammatory reaction, the presence of giant cells, the particles of the repair material, and the presence or absence of microbes were also scanned for.

The statistical analysis of their data revealed that –

MTA : 10 specimen showed no inflammation, along with a hard tissue bridge, as well as vital pulp tissue. The calcific bridges varied in thickness, were tubular, and continuous with the lateral dentin that had formed after treatment. Moreover, they were complete, and only a few samples had tunnel defects. New odontoblastic layers were seen in most of the cases. 2 samples only, showed a mild chronic inflammatory reaction, but there was an eosinophilic layer close to the dentine bridge, that had formed.

Portland cement : revealed similar findings to that of MTA.

In short, no statistically significant difference was found, between the 2 tested materials.

The investigators concluded that both these materials, had similar properties, and that their findings were similar to the studies done by

Soares [1996]; Pitt Ford [1996]; Faraco Jr [1999]; Holland et al [2001].

While Soares had reported that 89.28% of the cases had tubular dentine formation, Pitt Ford et al had reported a 100% complete tubular dentin formation.

The investigators added that Wucherpfenning and Green [1999], had reported that MTA and PC seemed identical microscopically, macroscopically, as well as by X-ray defraction analysis.

Furthermore, Estrela et al [2000], had also described similar results with both these materials, and the authors added that the calcite crystals that had formed, along with fibronectin, were the initiating steps in the formation of a hard tissue barrier.

They also addressed the fact that MTA had only one additive-bismuth oxide, when compared to PC, and that it could be assumed that this particular additive, had no effect on the property of the material, as both were comparable, in terms of the results obtained.