Interactions between root canal irrigants, sealers and dentin
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Chapter 8

Summary and conclusions
This thesis focused on studying the interactions between root canal sealers and dentine, as well as the influence of irrigating solutions on these interactions. These studies will help us understand the chemistry of bonding of sealers to dentin further and in the course, develop newer materials that can have predictable adhesion to dentin, which could enhance the sealing ability and outcomes of treatment.

Chapter 2 aimed at correlating the adhesion of an epoxy resin sealer to root dentin and the sealing ability of this sealer when used as a root filling material. The adhesion was tested using the push-out bond strength method. Thus far, this was the first paper to study such a correlation. This study concluded that

- Leakage decreased with time
- When root canals were irrigated with sodium hypochlorite followed by decalcifying agents (EDTA or malice acid), the push-out bond strength increased and leakage decreased. This was significantly different from specimens where NaOCl was used as the final irrigating solution.
- A negative correlation was observed between sealing ability and push-out bond strength values ie., treatments that resulted in low leakage also caused the highest bond strength to dentin.
- Conditioning of canal walls by maleic acid, which is a weak acid, resulted in superior sealing ability and higher epoxy resin bond strength compared to EDTA, which is a strong calcium-complexing agent.
- When epoxy resin sealers are used, it appears that a final flush with decalcifying agents could offer superior outcomes in terms of leakage and bond strength, than when NaOCl is used as the final irrigant.

Chapter 3 studied a new irrigation protocol that was introduced by Lottanti et al. in 2009. This concept, called continuous chelation involves using NaOCl in conjunction with a weak acid namely etidronic acid (1:1 mixture of 5% NaOCl and 18% HEBP) This chapter involved the analysis of the bond strength of an epoxy resin sealer to root dentin after irrigation with one of the two protocols - continuous chelation (NaOCl + etidronic acid) or soft chelation (NaOCl followed by EDTA). This study reported that

- the irrigating protocol had a significant influence on the push-out bond strength values ie., adhesion of epoxy resin based root canal sealers to root dentin is directly influenced by the chemical treatment.
- The groups that used the continuous chelation protocol during instrumentation were associated with significantly higher push-out bond strength values compared to the “traditional” soft chelation protocol. The use of 1 : 1 mixture of 5% NaOCl and 18% HEBP during instrumentation followed by 17% EDTA as final rinse was associated with significantly higher bond strength regardless of the root canal region.
Chapter 4 studied the effect of root canal irrigation protocols on the adhesion of a new group of sealers. The sealers tested were bioactive calcium silicate sealers (Endosequence BC, MTA Plus and Tech Biosealer Endo). The push-out bond strength test was used to determine the adhesion between these sealers and root dentin. This paper was unique in that, this was the first study to the knowledge of the authors, to explore the role of time as an influencing factor in the tested outcome. Five irrigation protocols were compared (NaOCl-EDTA, EDTA-NaOCl, NaOCl + etidronic acid, NaOCl-QMix, NaOCl - chlorhexidine). The bond strength was evaluated after two time periods of storage (7 days and 3 months) of the teeth/specimens in phosphate buffered saline to create a clinically relevant environment so as to allow for bioactivity of the materials to take effect. This study concluded that

- Time and the irrigation protocol differentially influenced the bond strength of the calcium silicate based sealers to dentin.

- The bond strength of MTA Plus and Endosequence BC was significantly higher at the 3 months period than at 7 days, in groups irrigated with NaOCl+etidronic acid and NaOCl-QMix. The bond strength of Tech Biosealer Endo did not improve with time.

- NaOCl+ etidronic acid (continuous chelation) improved the bond strength of Endosequence BC sealer and MTA Plus at both the time periods.

- The bond strength of MTA Plus, in specimens irrigated with the continuous chelation protocol was significantly higher than that of Endosequence BC sealer and Tech Biosealer Endo at both time periods.

- This study suggested that using a final flush of acids such as EDTA decreased the bond strength of calcium silicate based materials, while the use of weak acids such as etidronic acid enhanced the bond strength.

- The use of chlorhexidine as a final irrigant significantly reduced the bond strength of the MTA based sealer (MTA Plus), while the use of QMix (a mixture of chlorhexidine and EDTA) showed significantly higher bond strength values.

- The bond strength of Tech Biosealer Endo, which is based on a tricalcium silicate formulation along with phyllosilicate, was not improved by time or the irrigation protocol.

The focus of Chapter 5 was to identify the chemical interactions between three root canal sealers (epoxy resin, silicone and calcium hydroxide based) and root dentin, as well as the influence of irrigation regimens on that interaction. The chemical interaction was analysed using Fourier Transform Infrared Spectroscopy (FTIR) and the impact of such interaction was assessed by measuring the push-out bond strength. This study showed the following conclusions

- The bond strength of the epoxy resin sealer (AH Plus) was significantly higher than that of the silicone sealer (Roeko Seal) and calcium hydroxide sealer (Sealapex) in all the root thirds (coronal, middle and apical).
AH Plus showed significantly higher bond strengths when root canals were irrigated with NaOCl-EDTA and NaOCl - QMix compared to the other irrigation protocols (EDTA-NaOCl, NaOCl-water).

The bond strength of the silicone sealer (Roekoseal) was not measurable in any of the specimens.

FTIR analysis confirmed that there was a chemical interaction between AH Plus and dentinal collagen. When NaOCl was used as the final irrigant, such a chemical interaction did not occur. This was corroborative to the results of the bond strength analysis wherein groups where NaOCl was the last irrigant showed least bond strength values. This was the first publication till date in the endodontic literature to confirm chemical bonding between AH Plus and dentinal collagen.

**Chapter 6** characterised a commercially available MTA based sealer (MTA Plus) after exposure to root canal irrigating solutions. This materials characterisation study provided interesting insights into what happens to calcium silicate based materials that are exposed to irrigants and helps understand how they influence the biomineralisation process. MTA Plus was exposed to NaOCl, EDTA, a mixture of NaOCl and etidronic acid or QMix solutions. Specimens were then assessed by scanning electron microscopy, X-ray diffraction (XRD) and Fourier Transform Infra Red Spectroscopy. In addition, leaching of calcium ions was assessed by inductively coupled plasma-optical emission spectroscopy. The study showed that

- Reaction and hydration of the MTA Plus powder occurred regardless of the immersion medium

- Specimens immersed in NaOCl + EA showed a very strong peak for calcium hydroxide in the XRD analysis

- Immersion of cement samples in the mixture of NaOCl and etidronic acid resulted in formation of a highly crystalline surface

- MTA Plus exposed to EDTA demonstrated a cracked surface devoid of any crystals. There was very minimal formation of calcium phosphate crystals.

- Fewer calcium phosphate crystals were observed with the NaOCl, EDTA and QMix irrigants.

**Chapter 7** studied the retreatability of two mineral trioxide aggregate based root canal sealers, considering an epoxy resin sealer as control. Two MTA based sealers were evaluated - MTA Plus and MTA Fillapex. Cone Beam Computed Tomography was used to evaluate the remnant root filling material. This study gives an indirect indication of the bioactivity (biomineralisation) of the MTA based sealers and thereby the chemical bonding. This study concluded that
- none of the sealers were completely removable

- It was easiest to remove MTA Fillapex in terms of amount of removed material as well as time taken to remove the material. The possible reason is that MTA Fillapex contains only about 13.2% MTA in a base of salicylate resin.

- The time required to reach working length was significantly higher for the groups filled with epoxy resin sealer.

This thesis, in essence, served to identify how root filling materials are influenced by root canal irrigating solutions and sequences. The studies encompassed in this thesis showed that irrigating solutions had an impact on the adhesion of epoxy resin based, calcium hydroxide based, silicone based and calcium silicate based sealers in a differential manner. With reference to the epoxy resin sealer, AH Plus, the irrigation protocol influenced its bond strength (adhesion) to dentin, which also improved the sealing ability.

Although one may not be able to directly extrapolate these results to clinical outcomes, it helps understand mechanisms by which root canal sealers bond to dentin. The first study to confirm that epoxy resin sealers bond chemically to dentin collagen was a part of the web of studies encompassed in this thesis. From the materials science perspective, this helps understand and develop sealers that would bond to dentin without being influenced by the irrigation protocol. Furthermore, important data was obtained with reference to bioceramic/calcium silicate based sealers that could possibly improve treatment outcomes.