Contemporary root canal filling strategies

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Chapter 8

General discussion and summary

CONTEMPORARY ROOT CANAL FILLING
STRATEGIES
Filling the root canal space effectively is a challenging procedure. Filling materials interact concomitantly with each other and with intraradicular dentin. Also, the filling technique influences the distribution and behaviour of the filling material inside the root canal (Camilleri 2015, Moinzadeh et al. 2015a). The complexity of all these interactions can affect the ultimate performance of the root canal filling. The present thesis addressed the performance of contemporary root canal filling strategies, including novel materials and alternative filling techniques, by a panel of laboratory tests. We were interested in techniques that could easily be implemented, from a technical point of view, in clinical practice while being innocuous to radicular tissues. Particular attention was also given to specific methodological aspects of the laboratory tests that were used.

Nowadays, the launching of newly developed root filling materials together with enthusiastic advertising campaigns for their promotion has become a trend in dentistry. Clinically, it has been so far impossible to claim the superiority of any specific material or filling technique. Laboratory research can be considered as important and necessary for rapidly screening, and understanding the behaviour of new filling materials and techniques. Even though direct extrapolation to therapeutic outcome should be exercised with care, the obtained information could still be useful to clinicians when clinical trials are lacking. For instance in laboratory tests, it is assumed that a filling with adequate sealing properties will hinder microorganisms from penetrating the periradicular tissues in vivo and therefore, will reduce the likelihood of microbe-induced inflammation. While this assumption seems reasonable, others may not be. It is indeed ambiguous how an improvement in the adhesive properties of a root canal filling material (determined by a push-out test) could lead to improvements in treatment outcome, especially
if only a weak correlation exists between adhesiveness and sealing ability as described in chapter 2. It is possible that a relationship between these two properties may exist but could not be identified because of limitations of the testing methods. The development of more elaborate methods for porometry able to test thin slices could improve our understanding of the materials’ sealing properties and allow further investigation of possible associations between adhesiveness and sealability.

Currently the push-out method is widely used in order to rank endodontic filling materials according to their adhesiveness (Collares et al 2015, Moinzadeh et al. 2015b). Materials demonstrating higher adhesive values are considered by some authors as superior to materials less apt to adhere to intraradicular dentin (Oliveira et al. 2015). Contrary to restorative filling materials, it is rather unclear how the adhesive/retentive properties of a root canal filling material can affect the outcome of root canal therapy. Bishop et al. (2008) have postulated that tooth loading may provoke the detachment of root canal filling materials from intraradicular dentin, resulting in the creation of a void that could allow leakage. However, in that study the loads were directly applied on the coronal aspect of decoronated roots, a scenario unlikely to occur in the oral cavity where the occlusal loads are distributed and dissipated.

In addition, the push-out test mainly measures the frictional resistance to the sliding of the material and not its true bond strength (Goracci et al. 2005). This friction component is influenced by the material’s properties such as its elasticity modulus. Due to the Poisson effect, when a material is compressed in one direction, it has a tendency to expand in the two perpendicular directions (Lakes 1993). Poisson’s expansion increases the contact pressure, necessitating an increased load to
overcome friction (Chandra & Ghonem 2001). Materials with different elastic moduli will therefore undergo different amounts of frictional shear and any attempt to compare their true adhesion abilities by the push-out method could consequently be biased (Chen et al. 2013, Pane et al. 2013).

Despite these limitations, the dislocation resistance measured by the push-out test conducted on thin slices is still indicative of the material’s adhesive properties (Pane et al. 2013) and could provide insights on the interactions occurring between filling materials and intraradicular dentin. Relative changes in dislocation resistance for a given material may be attributed to changes in dentin surface or material distribution following the use of different conditioning protocols or filling techniques. In chapter 3 it was demonstrated that a two-step placement procedure could improve the dislocation resistance of methacrylate resin-based root canal fillings, which indicates improved adhesion. While this increase may not be clinically relevant, it was assumed to reflect a reduction in polymerization shrinkage stress compared to a one-step (conventional) placement. This effect could not be detected in the control group using an epoxy resin-based sealer that is known to undergo a different polymerization process, subject to less shrinkage (Klee et al. 1996, Tuttle 2008). The benefit of the two-step placement method was demonstrated as a proof-of-concept that could represent an interesting direction for research on the reduction of the polymerization shrinkage stresses that some resin-based sealers undergo within root canals.

A root canal filling with high sealing properties is supposed to have low porosity. Three main types of pores can be distinguished within filled root canals (Fig 8.1), namely transport pores (open at both ends) that connect the coronal aspect of the root canal to its apical end; closed pores
(closed at both ends) located inside the bulk of the filling material or between the filling and the intraradicular dentin, with no connection with the peri-apex or the coronal access of the canal; and cul-de-sac pores (open at one end) communicating either with the peri-apex or with the coronal access and ending in a dead-end inside the canal/material (Marsh 1989). Because of its set-up, only transport pores can be identified by the fluid transport method. In chapter 4, we evaluated the sealing ability, after post space preparation, of root canal fillings made with gutta percha and different sealers using either the single-cone or the lateral compaction techniques. The fluid transport method with a wetting fluid was used and revealed significantly less fluid flow through the root canals filled either with lateral compaction with an epoxy resin sealer, or with the single-cone using an epoxy or a methacrylate resin sealer, compared to the root canals filled with the single-cone technique and a calcium silicate-based sealer. These findings hint towards the ability of the single-cone technique as a potential alternative for the lateral compaction technique. The fluid transport method only provides the summed fluid flow of all transport pores with no possibility of morphologically characterizing pore geometry.
Contrary to the fluid transport method, microCT could theoretically detect all types of pores and represent a promising method for quantifying and morphologically characterizing them. Hence our next objective in chapter 5 was to develop a standardized protocol for the analysis of the porosity associated with root canal fillings as revealed by laboratory microCT and to apply it to the analysis of root canal fillings ex vivo. The protocol was based on well-established computer algorithms and does not require any subjective visual estimation of thresholds for segmentation. Subsequent research should confirm the repeatability and reproducibility of this analytical method. This protocol was then successfully applied to compare the void fraction associated with the lateral compaction and with the single-cone techniques, using gutta percha and a calcium silicate sealer. Our findings demonstrated that the placement of a calcium silicate sealer,
with a single gutta percha cone matching the shape of the last instrument used to shape the root canal, is associated with a lower void fraction than lateral compaction. The presence of iatrogenic voids (*spreader tracks*, illustrated in Fig 8.2) resulting from the inability of accessory gutta percha cones to effectively fill the space created by the spreader, appeared to contribute to the high porosity observed with this technique. Anatomically, these tracks could easily lead to the creation of “transport pores”. The simplicity of the single-cone technique, as well as the absence of spreader tracks and of strain-inducing forces due to compaction may represent a valuable alternative for the widely-used lateral compaction technique. Nevertheless, an important limitation of the single-cone technique is its reliance on the sealer to occupy a relatively large volume fraction in oval canals.

Hygro-expandable cones (HEC) made of hydrogel-coated nylon could represent a way to circumvent this problem. Some hydrogels are able to take up significant amounts of water from their surrounding and undergo swelling (Kabiri *et al.* 2003). The swelling ability of the HEC has been demonstrated *in vitro* by immersing the cones in water (Didato *et al.* 2013). In chapter 6, we resorted to several laboratory imaging methods to evaluate the behaviour of a HEC in root canals. The fillings made with the HEC and a calcium silicate sealer appeared to have filled the root canal space perfectly based on laboratory microCT. However, phase contrast-enhanced microCT and stereomicroscopic examination revealed important delamination defects at the interface between the hydrogel and the sealer as well hydrogel tearing. It is likely that the relatively poor contrast inherent to the laboratory microCT method could not discriminate the moderate differences in greyscale values between the hydrogel, voids and dentin.
Figure 8.2: Three-dimensional rendering of root canal filling made with lateral compaction. The arrows point to a spreader track.

This illustrates the physical limitation of conventional microCT in the evaluation of structures presenting low contrast. The delaminations could, however, clearly be demonstrated by the other two methods. The observed delaminations are reminiscent of defects previously identified in methacrylate resin-based filling due to their polymerization shrinkage (Kim et al. 2010), as illustrated in 3.6. The mechanism behind the present finding should, however, be a different one. Hydrogels consist of a network of crosslinked polymer chains representing a 3D mesh with the interstitial space filled with fluid. The water transport in this space will provoke the
swelling or deswelling of the hydrogel (Swan et al. 2011). In the root canal, the loss of water from the hydrogel in favour of the hydrophilic calcium silicate sealer could provide a plausible explanation for the delamination that may have been caused by the shrinkage of the hydrogel. The delamination defects ran along the whole specimen, representing transport pores, which are clear pathways for leakage. Interestingly, in one specimen no delamination was observed, but tearing of the hydrogel, revealing the possible presence of internal tension within the material. These findings illustrate the complexity of the interactions between different materials when placed against each other as well as the effect environmental conditions could have on specific materials.

The role played by the environment is again illustrated in chapter 7. The behaviour of a calcium silicate repair material kept in different in vitro conditions, namely immersed in water, HBSS and blood, was evaluated. Different hydration patterns were observed with each test fluid, and calcium phosphate deposits could be demonstrated on the specimens that had been immersed in HBSS or blood. The presence of these deposits is believed to indicate the bioactive potential of a material, i.e. its ability to create bonds with osseous tissues (Niu et al. 2014). A specimen retrieved from a patient during a surgical procedure demonstrated the presence of calcium carbonate onto its surface, which results from the reaction between calcium hydroxide and environmental carbon dioxide. Calcium carbonate has theoretically the ability to make direct contact with bone but without an apatite layer at the interface as expected from a bioactive material (Neo et al. 1992). Evaluating more explanted specimens would allow a better understanding of the material’s interaction with the human tissues and could shed some light as to whether there are really differences in behaviour between in vivo and
laboratory conditions and to which extent. The current laboratory settings used for testing the bioactivity potential of endodontic materials may indeed be unrepresentative of the *in vivo* conditions. The simulating body fluids used *in vitro* are supersaturated metastable systems that tend to precipitate apatite crystals in order to reach thermodynamic stability (Bohner & Lemaitre 2009) and may thus overestimate the materials’ ability to exert biological activity when placed against osseous tissues *in vivo*. Current studies evaluating the bioactivity of endodontic materials are often conducted by simply immersing them in simulated body fluids. It is therefore necessary to improve the current methodology in order to improve our understanding of the mineral interactions between calcium silicate filling materials and dental-osseous tissues.

Currently, clinicians can choose from a wide range of root canal filling materials and techniques, some of which have been evaluated in this thesis.

Methacrylate resin-based sealers suffer from polymerization shrinkage stresses. This limitation may partly be overcome by a two-step cementation procedure. This alternative placement technique results in an increase and homogenization of the adhesion of the material to intraradicular dentin. Subsequent research should aim at developing sealers with shorter setting times for clinical implementation and confirm the present proof of concept.

It remains to be proven whether an increase in adhesion could be considered as a surrogate for improved sealing ability. With the used methodology, we could not demonstrate any association between the sealing ability and the adhesiveness of an adhesive root canal filling material.
Using the low surface tension fluid transport method, the sealing ability of the single-cone technique, after post space preparation, was found to be material dependent, with the epoxy and methacrylate resins providing a better seal than the calcium silicate-based sealer.

Roots canals filled with a single-cone technique using gutta percha and a calcium silicate-based root canal sealer were less porous than root canals filled with lateral compaction of gutta percha and the same sealer.

Delamination and tearing defects could be observed in root canals filled with hydrogel-coated hygro-expandable cones and a calcium silicate-based sealer. Hydrogels are smart materials that may currently be inadequate for endodontic use with calcium silicate sealers.

The use of simulated body fluids for testing the bioactive potential of calcium silicate-based fillings leads to the deposition calcium phosphate. This phenomenon may however be simply reflecting a thermodynamic process rather than expressing bioactivity potential. An explanted specimen revealed the formation of calcium carbonate (calcite) and the absence of calcium phosphate on its surface.
Chapter 8

References


