Direct composite versus glass-ceramic endocrowns for mechanically compromised molar teeth

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General discussion and conclusions
1. GENERAL DISCUSSION

In the series of studies in this thesis, several restorative aspects related to endodontically treated severely mechanically compromised molars were evaluated. Although adhesive restoration of endodontically treated teeth is common practice, clinical evidence comparing both direct composite and indirect adhesive restoration is scarce.\textsuperscript{2,3} In the systematic review (chapter 2), all indirect restorations focused on full contour crowns that were often fabricated from porcelain-fused-to-metal and cemented using a glass ionomer or zinc phosphate cement. Furthermore, different direct (adhesive and non-adhesive) restorative materials and tooth types were clustered. Thus, the included studies lacked a description or had a clear difference in indication for an (i)direct restoration based on residual tooth structure or tooth prognosis. This was the foremost confounding factor that hindered comparison of the two treatment modalities based on the current evidence. Hence, more research relevant to the direct adhesive and indirect restoration types for endodontically treated molars was deemed necessary.

1.1. Parameters influencing tooth survival

When teeth need to be restored with an adhesive restoration, adequate endodontic treatment is essential. Especially in the posterior teeth, the anatomy of root canals is often complex, rendering the endodontic treatment challenging. When treated by endodontic specialists under magnification, preservation of such molar teeth can have a good outcome (chapter 4). Cumulative survival of endodontically treated molars with complex endodontic treatment was 91.7% [95% CI: 86.8%-94.9%] after 89 months, which can be considered satisfactory when compared to pooled cumulative survival rates for all tooth types.\textsuperscript{7} The relevant predictors for tooth survival were the presence of adjacent teeth and no deviance in root canal morphology, while the predictors for endodontic success were an adequate coronal seal and an endodontic treatment that followed root canal morphology.

Endodontically treated molar teeth are more prone to complications as compared to other teeth.\textsuperscript{4,5} In chapter 4, the focus was on endodontically treated molars receiving complex endodontic (re)treatment in a specialist clinic, where standardized endodontic treatment protocols are followed. Information on tooth survival in these cases is important for both the clinician and the patient in order to reach a well informed decision to retain or extract the tooth. Endodontic (re)treatment requires investment of time and means and therefore, depending on the case, other treatment options for replacement should be considered. Even though survival of endodontically treated molars seemed satisfactory, cumulative endodontic success was lower (51.1% [95% CI: 20.2%-75.4%] up to 89 months) as compared to data from a previous systematic review.\textsuperscript{6} Pooled endodontic success rates for retreatments on all tooth types in another systematic review ranged from 76.7% [95% CI: 73.6%-89.6%] to 77.2% [95% CI: 61.1%-88.1%] after a follow-up period of at least 4 years.\textsuperscript{7} One reason for this difference could be the large amount of loss to follow-up regarding endodontic success, another reason could be that in the meta-analysis all tooth types were pooled, as opposed to the study in chapter 4.

An important limitation of the retrospective study in chapter 4 was that the required sample size (362) was not reached due to a 22% loss to follow-up after 89 months. This hindered a general statement concerning the survival of all endodontically treated molar teeth. However, the cumulative survival rate was considered a good reflection of the actual survival rate of such molars treated in the specialists’ setting.

Another difficulty was the interpretation of endodontic success, since the patients did not attend regular recall follow-ups after one year. A recent radiograph was not always present and this resulted in a loss to follow-up of 25% for the outcome ‘endodontic success’. The substantial confidence interval (51.1% [95% CI: 20.2%-75.4%] up to 89 months) is also a reflection of this and therefore the presented results on endodontic success rate should be interpreted with caution. In order to gain more valid insight into endodontic success, a prospective clinical trial with scheduled recall visits and radiographs would be more suitable.

Likewise, the low number of failures resulting in tooth loss was a limitation as far as identifying relevant predictors for tooth survival. In that regard, a multicenter study is advisable to collect sufficient number of events.

As this was not a prospective clinical, the referring dentist was responsible for the restoration of the endodontically (re)treated teeth. Hence, there was a lack of standardization. In the study described in chapter 4, the majority of the post-endodontic direct restorations were made of direct composite resin (99.2%). Of these direct restorations, 56% of the teeth had two or more remaining walls. Of the endodontically treated molar teeth that were restored with a direct restoration, only 22.6% received full cusp coverage. In contrast, in 100% of the indirectly restored molar teeth, all cusps were covered and 99% were restored with full contour crowns. This might be an indication that the choice for a direct or indirect restoration is strongly dictated by the amount of residual coronal tooth tissue. It was however not possible to retrieve the rationale for the decision for the type of restoration or cusp coverage.

1.2. Restorative decision-making

Since clinical trials require much effort and time to conduct, the implementation of restorative techniques often rely on the preference of the clinician and on the results from laboratory studies. It was therefore of interest to investigate which parameters influence clinical decision-making in general practice. One probable determinant for the preference for a direct or indirect restoration would be the amount of remaining coronal tooth structure.\textsuperscript{7} However, to what extent the type of restoration influences the decision of a clinician to use a post or cover the cusps was unknown.
1.2.1. Parameters in clinical practice

A survey among Dutch dentists was conducted. The most important parameter that influenced the decision of general dentists in the Netherlands between a direct resin composite resin or an indirect restoration, was the amount of residual tooth structure (chapter 3). Eight clinical cases with 4 premolars and 4 molars, with a varying number of walls were presented: two walls, one supporting or non-supporting wall and no walls. In order to focus on adhesive restoration of endodontically treated posterior teeth, the outline of all presented cases finished in enamel and the wall thickness was set at 2mm. The median preference of the respondents leaned towards a direct restoration in case of a two-walled defect, but this shifted towards an indirect restoration when only one wall remained. The tooth type (premolar/molar) did not influence the preference for a direct or indirect restoration.

When a clinician opted for an indirect restoration, cusp coverage was more often indicated than for a direct restoration, while a post was preferred less. This was corroborated by the results of the retrospective study in chapter 4, where only a small portion (27.4%) of the three- to four-surface direct restorations received full cusp coverage.

Direct composite resins have a lower flexural strength than glass-ceramics which might be insufficient to protect the tooth from flexural deformation when both marginal ridges are absent. An in vitro study showed a higher fracture strength after cusp coverage for direct composite restorations in MOD-cavities on endodontically treated teeth. Hence, cusp coverage during the fabrication of a direct or an indirect bonded restoration should be taken into account in future trials.

Of the 383 general dentists, approximately half choose a partial preparation over a full contour crown for endodontically treated single-walled (pre)molars. Interestingly, dentists who graduated after 2010 opted significantly more often for a partial preparation for single-walled teeth. This shows a tendency that indirect partial restorations are considered a viable treatment option for endodontically treated posterior teeth by Dutch dentists. This view was however not reflected in teeth that were reviewed in the retrospective study, where 99% of the indirect restorations were full contour crowns and only one adhesive partial indirect restoration was fabricated. This discrepancy might be explained by a difference in the graduation dates and experience with adhesive partial indirect restorations of the referring dentists in the retrospective study.

One limitation of the survey was that it was limited to and hence specific for general dental practices in the Netherlands. Restorative decision-making might vary between different countries. However, sample size based on restorative preference was met. Therefore, the conclusions from this study can be regarded as valid and a reflection of the decision-making among Dutch dentists. Another limitation was that possible other motives for restorative decisions and the influence of the outline were not investigated.

In fact, an outline situated in dentin has been shown to decrease the survival rate for both direct and indirect bonded restorations. This would have resulted in a too extensive survey, rendering the risk of a low response rate too high.

1.3. In vitro studies

Adhesive rehabilitation of severely compromised endodontically treated molars, be it direct or indirect, resulted in a tooth-restoration complex that could withstand the mean masticatory force in man (chapters 5a and 5b). All specimens survived $1.2 \times 10^7$ cycles of thermomechanical aging, which is considered to be comparable to 5 years of clinical function. Direct microhybrid composite resin restorations performed similarly in terms of fracture strength as compared to lithium disilicate endocrowns. The extension of lithium disilicate in the pulp chamber and the outline did not influence the fracture strength significantly (chapter 5b).

Since the publication of the study in chapter 5a, one additional study compared direct nanohybrid composite resin with lithium disilicate endocrowns on endodontically treated molars using stepwise fatigue testing. They found no significant difference in survival probability when mean number of cycles until failure and fatigue failure load were considered. There was also no significant difference in the incidence of catastrophic failures between both restoration types. However, lithium disilicate endocrowns presented higher mechanical reliability when compared to composite resin restorations. In addition, finite element analysis showed a higher stress concentration in tooth tissue for the direct composite resin endocrowns as compared to the indirect ones, but this was not reflected in a significant difference in failure types. Whether or not this will eventually lead to a difference in clinical performance, can only be validated in a clinical trial.

The use of a post on the other hand, did not contribute to a higher mean fracture strength. This finding was corroborated by both in vitro and in vivo studies. In the case of molar teeth, the pulp chamber provides ample space to increase the surface area for bonding. This also seems to be the opinion of Dutch dentists, as reflected in the survey study, where single-walled premolar teeth received a post more often than single-walled molar teeth (chapter 3).

A limitation of these in vitro studies was that the specimens were loaded until failure under continuous force. Typically, dental restorations are subjected to fatigue loading. Furthermore, it is unlikely that molar teeth are subjected to lateral forces at an angle of 45 degrees to the occlusal table in a clinical situation, as was done in chapter 5b. It could be expected that the fracture strength values would be higher when loaded in an axial direction (chapter 5a).
1.4. Adhesion
When a lithium disilicate endocrown was bonded in conjunction with an Immediate Dentin Sealing (IDS) procedure, an outline in dentin did not negatively affect the mechanical behavior after cyclic loading and load to failure (chapter 5b). In clinical studies however, an outline in dentin was shown to decrease the survival rate for both direct and indirect restorations.

Dentin bonding still remains a challenge due to the presence of moisture in the dentinal tubules and the activation of matrix metalloproteinases (MMPs) after acid etching, which negatively affects the collagen fiber network. Additionally, adhesion to the dentin of the pulp chamber can be negatively influenced by endodontic sealer remnants, size of dentinal tubuli, moisture and structural changes in the dentin due to endodontic irrigation protocols. Intertubular dentin is especially important for hybrid layer formation. Due to wider diameter of the dentinal tubuli in the dentin close to the pulp chamber, there is less intertubular dentin available as compared to coronally located dentin, which might compromise the formation of a stable hybrid layer formation.

Although in vitro studies have shown that the Immediate Dentin Sealing (IDS) procedure result in higher bond8,12 and fracture strengths, a three-year randomized split-mouth clinical trial did not show a difference in survival or success rates for glass-ceramic posterior restorations. Possible explanation was the limited follow-up time (3 years) and that it concerned minimal preparations, with a varying amount of enamel on the outline. However, when comparing ceramic laminate veneers with 50% dentin exposure, IDS resulted in higher restorative success as compared to laminate veneers bonded to dentin without IDS. This might be an indication that in case of the presence of a large dentin surface and little enamel to bond to, adhesive ceramic restorations may benefit from IDS on the long-term. However, this needs to be verified with further studies if this is also the case for indirect adhesive restorations on endodontically treated molar teeth.

1.5. Material type
In this thesis, material choice for the fabrication of the direct and indirect endocrowns was limited to microhybrid composite resin and lithium disilicate. Both materials have shown good clinical performance in stress-bearing cavities in the posterior dentition up to 5 years. However, a plethora of direct and indirect restorative materials are available for the clinicians to use in the restoration of endodontically treated molars. Depending on the manufacturer, a number of ‘hybrid’ materials could be used for adhesively bonded restorations in the posterior dentition.

The dilemma between a rigid or more flexible restoration is especially relevant in case of severely compromised endodontically treated molars. A rigid bonded restoration might aid in the adhesive splinting of the tooth structure, comparable to what is aimed at with the ferrule effect. On the other hand, failure of such restorations requires more force, which increases the risk for catastrophic tooth failure. In contrast, a more flexible restoration might act as a stress-breaker and lead to a more repairable failure. In chapter 5a, a glass fiber-reinforced composite resin was one of the tested materials. Indeed, the glass fibers deflected the fracture towards the outer portions of the tooth, resulting in more repairable failures as opposed to the microhybrid and lithium disilicate restorations. However, this might bring the risk of more reinterventions, which in turn could be a possible burden to the patient. To the author’s best knowledge, only one split-mouth randomized clinical trial investigated the survival rate of direct composite resin restorations with or without a glass fiber-reinforced composite core on endodontically treated molars. After 3 years of clinical service, out of 24 glass fiber-reinforced composite restorations, 3 failures were reported versus 1 out of 24 microhybrid restorations.

Another part of this thesis focused on the procedural aspects of bonding the indirect glass-ceramic restorations to the endodontically treated molar teeth. The advantage of using a microhybrid composite resin over a dual-polymerizing composite resin cement, is the superior mechanical properties and ease of handling. Light transmittance through the glass-ceramic is cause for concern as it may hinder the degree of conversion and therefore the mechanical properties.

A limitation of the study design was the immediate recording of the absorption spectrum and the use of an internal control specimen, which was considered to be ‘optimally’ polymerized after 9 minutes of light-curing. This resulted in higher conversion rates than those that would be reached clinically, with a range of median relative degree of conversion rates of 80.3% to 97.7% after 3x90 seconds of polymerization. Due to a decrease in monomer mobility during the polymerization process, a 100% conversion rate is not feasible and would ultimately be somewhere in the 60%-80% range. Furthermore, post-polymerization occurs over 72 hours. In future research, when a relative degree of conversion is calculated based on an internal reference (chapter 5c), this internal reference should include the post-polymerization process to better reflect the clinical conversion rate.

1.6. Clinical study
After one year of clinical service time, there was no difference in survival or patient satisfaction between direct microhybrid composite resin and lithium disilicate endocrowns bonded to severely biomechanically compromised endodontically treated molars (chapter 6). Direct composite resin endocrowns presented with less surface luster at baseline compared to lithium disilicate endocrowns. Baseline characteristics were evenly distributed over both treatment arms. This suggest a reliable comparison between the
differences in tooth and restoration survival based on the restoration type, as opposed to the current literature (chapter 2).

Yet, the management and maintenance of contact points proved to be difficult, both for direct and indirect restorations when little tooth surface remains, as in the included cases. This was observed for both terminal and non-terminal teeth in the dental arch. However, a higher number of composite resin restorations at baseline started with a weak contact point. From a clinical point of view, such large resin composite restorations require much skill of the clinician. There was also a need for the use of specific sectional matrices, both varying in height and, more importantly, curvature. When the teeth are further apart, the sectional matrix should provide more curvature in order to create an anatomically correct contact point. Thus, especially in the case of a large distance between the teeth and its neighbor, an indirect restoration may be more suitable to restore the proximal anatomy than a direct composite resin restoration.

In the current study, one shade of the microhybrid composite resin was used as opposed to different shades for the high translucent lithium disilicate endocrowns. Interestingly however, there was no significant difference in the color match. Generally, individualizing the shade of the indirect restoration would result in a better esthetic result than using the same shade for each case. Due to the minimal invasive preparation technique, if possible, the outline finished supragingivally in order to maintain as much tooth structure as possible. Since more molar teeth in the indirect treatment arm were darker than the adjacent teeth, the choice was often made to mimic the color of the adjacent teeth. This means that the shade of the indirect restoration would be too bright compared to the prepared tooth, but was in line with the adjacent teeth. Although such preparations result in maximum preservation of sound dental tissues, care must be taken when a discolored tooth needs to be treated in the esthetic zone.

In the study presented in chapter 6, no difference was noted in patient satisfaction between both restoration types. Discomfort for the patients consisted mainly of sensitivity at the gum level during and after treatment. Due to the subgingival outlines, gingivectomy was often needed to facilitate isolation under rubber dam. Since overall satisfaction remained quite stable over time, the treatment of such molar teeth can be considered as adequate care. However, it has to be noted that in the current study, the indirect restorations were offered at the same cost as a direct restoration. In standard care, the cost of the fabrication of an indirect restoration is substantially higher, which might influence patient perception on the treatment outcome, especially when an early failure occurs.

Limitation of the available randomized clinical trial is the limited follow-up time of 1 year. A longer follow-up time is needed to distinguish between the direct and indirect restorative materials with regard to clinical performance and patient satisfaction and is ongoing. In a randomized clinical trial comparing direct and indirect composite cusp-replacing restorations on premolars, no significant difference in restoration survival was found after 5 years of clinical service. Nonetheless, patient satisfaction might change over a longer follow-up period, due to maintenance of the restorations.

1.7. Future perspectives
Even though endodontically treated teeth show an acceptable long-term prognosis, data that incorporates modern endodontic techniques is lacking. The most extensive systematic review considering tooth survival dates from 2010 and included studies published between 1993 and 2007. Future research on the survival of endodontically treated teeth should focus on a specific tooth type and incorporate operator-, patient-, tooth- and technique-related variables. Especially cusp coverage, direct or indirect, should be noted in future studies. In order to achieve this goal, a prospective multicenter cohort study is most suitable to investigate tooth survival, in an attempt to standardize restorative and endodontic protocols.

In order to control for the effect of restoration type on tooth survival, there is a need for randomized clinical trials. To date, only two randomized clinical trials comparing direct composite and porcelain-fused-to-metal crowns were conducted. Future trials should focus on the adhesive rehabilitation of endodontically treated teeth, especially considering the fact that the adhesively bonded indirect restorations were more often indicated by the new generation of dentists (chapter 3).

To optimize clinical protocols, it is necessary to investigate more on the polymerization kinetics of composite resin and composite resin cements as a function of the thickness of glass-ceramic restorations. Especially information on the length of polymerization and difference between high and low translucent glass-ceramics is of interest.

More research is needed to aid the clinicians with the indications for a direct or indirect restoration. The restored molar teeth in the randomized clinical trial described in chapter 6 will be evaluated over a longer period.

Due to the large plethora of direct and indirect restorative materials, laboratory studies still remain an important part of the research on endodontically treated teeth. Laboratory studies can be used to make a first selection between potential adequate and inadequate candidate materials for the restoration of endodontically treated teeth, which then can then be assessed in clinical situations.

1.8. Clinical implications
From a clinical point of view, the questions relevant to the patient are twofold. Is the tooth worth restoring and how long will the restoration last? Systematic reviews or prospective cohort or clinical studies on endodontically treated teeth focusing on
operator-, patient-, tooth- and technique-related parameters are of importance. To date, extensive evidence for certain restoration types on endodontically treated teeth is lacking (chapter 2). The clinician needs to assess tooth prognosis prior to the adhesive rehabilitation of the endodontically treated tooth. When considering in vivo parameters relevant for tooth and restoration survival, the presence of adjacent teeth (chapter 4), preparation outline in enamel and the amount of coronal tooth structure seem to be important determinants. In the case of endodontically treated molar teeth, the pulp chamber can aid to provide an increase in adhesive surface area (chapter 5a and 5b). Also, since restorations are subjected to fatigue loading which might challenge the adhesive interface, it seems prudent to limit the lateral forces on the restored tooth.

Evidence from randomized clinical trials regarding the added value of IDS when providing endocrown restorations is lacking too date and the procedure is time consuming compared to no IDS. Furthermore, care must be taken during impression taking since some impression materials might interact with the IDS layer as well as provisionalization due to adhesion of the temporary resin material to the free monomers in the IDS layer. There are some practical benefits of IDS, such as the ability to restore undercuts, especially in the pulp chamber, which preserves peri-cervical dentin. Furthermore, if gutta-percha is exposed during the preparation, the coronal seal is secured. Therefore, weighing the presumed pros and cons and based on phronesis, the author considers IDS prudent when contemplating to restore a mechanically compromised, endodontically treated molar with an indirect glass-ceramic endocrown restoration.

Figure 1 proposes a clinical decision tree to aid clinicians (and patients) in the assessment of prognosis and the feasibility of the adhesive rehabilitation of endodontically treated molar teeth based on findings presented in this thesis and clinical good sense. The first step would be to assess the endodontic and periodontal prognosis as to whether non-surgical or surgical endodontic retreatment would be necessary. If uncertain, a joined decision with the patient should be made as to commence with the fabrication of a coronal restoration, direct- or indirectly. When the endodontic and periodontal prognosis is deemed adequate, possibility of isolation under rubber dam should be assessed. If this is not possible, a gingivectomy or crown lengthening procedure might result in adequate isolation. Isolation under rubber dam is deemed important in order to prevent contamination of the endodontic treatment.

The location of the preparation should then be assessed. When the preparation is situated in enamel, the prognosis of a bonded restoration could be assumed favorable. When less enamel is present, the pulp chamber might provide an increased surface area for the bonded restoration. As assessed on an intraoral radiograph, a pulp chamber depth of ≥2mm is considered adequate in such situations. When no enamel is left and a pulp chamber depth of <2mm is available, other treatment options should be considered. In the case of suboptimal conditions, as depicted by the orange circle (Figure 1), the presence of adjacent teeth and limitation of lateral forces might provide a better prognosis for a bonded restoration. Furthermore, lateral forces can be limited by incorporating flat cusp inclinations or by restoring canine guidance. In such cases, adhesive restoration is still assumed to result in a satisfactory result.

Clinical success of endocrown restorations strongly depends on adhesion to dentin, which is a clinical challenge, as outlined before. There is ample and credible evidence from in vitro studies that IDS positively influences adhesion to dentin and fracture load of biomechanically compromised teeth when restored with indirect glass-ceramic restorations, without negative repercussions. Good clinical results are reported for endocrown restorations when using IDS in the short (chapter 6) and long run, but endocrown restorations without IDS also seem to do well in clinical practice.

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2. CONCLUDING REMARKS

In the following years, adhesive restoration of endodontically treated teeth can be expected to become the new gold standard. The studies undertaken as part of this thesis aimed to provide some insight in the status quo of bonded restorations to restore endodontically posterior teeth (chapter 2 and 3) and the prognosis of such teeth (chapter 4), as well as some procedural aspects (chapters 5a-c). Finally, the randomized clinical trial as described in chapter 6 will provide valuable insight on the influence of the type of coronal restoration on tooth survival of endodontically treated molar teeth in the following years, hopefully serving both clinicians and patients.

From this thesis, the following conclusions can be drawn:

1. After 2.5-3 years, low quality evidence suggests that there was no difference in the odds for tooth loss or restorative success between direct composite resin and indirect restorations on endodontically treated posterior teeth (chapter 2);
2. The amount of coronal tissues is considered decisive in the indication for a direct or indirect restoration by Dutch general dentists (chapter 3);
3. Cusp coverage was indicated to a lesser extent for direct restorations as compared to indirect ones among Dutch general practitioners (chapter 3 and 4);
4. 51-53% of the general dentists and 93-94% of the endodontists would choose a partial preparation over a full crown preparation for endodontically treated single-walled (pre)molars (chapter 3);
5. Dentists graduated between 2010-2020 opted significantly more often for a partial preparation for single-walled (pre)molars than dentists graduated before 2010 (chapter 3);
6. The survival of molar teeth in need of complex endodontic (re)treatment was 91.7% [95% CI: 86.8%-94.9%] after 89 months (chapter 4);
7. Endodontically treated molar teeth with adjacent teeth and endodontic treatment that followed the anatomy of the root seem to have a higher chance of survival after 89 months (chapter 4);
8. Large direct composite resin or lithium disilicate restorations perform similar after cyclic loading and load-to-failure, where the addition of a glass fiber-reinforced composite resin resulted in less catastrophic failures (chapter 5a);
9. There is no influence of the outline or the extension of the endocrown on the mechanical behavior of endodontically treated molars restored with adhesively bonded endocrowns in conjunction with Immediate Sealing (chapter 5b);
10. The relative degree of conversion for a microhybrid composite resin under high cyclic loading and load-to-failure, where the addition of a glass fiber-reinforced composite resin resulted in less catastrophic failures (chapter 5a);
11. The clinical performance of direct composite resin and lithium disilicate endocrowns was not significantly different after 12 months of clinical service (chapter 6).

REFERENCES


