VICTORIA DAWSON

CORONAL RESTORATION IN ROOT-FILLED AND NON ROOT-FILLED TEETH

Studies on periapical status, subsequent treatments
and treatment decisions

**CORONAL RESTORATION IN ROOT-FILLED AND
NON ROOT-FILLED TEETH**

Malmö University, Faculty of Odontology
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ABSTRACT

The overall aim of this thesis was to study the following aspects of direct and indirect coronal restoration, primarily of root-filled teeth, with special reference to:

- periapical health
- the natural course of root-filled teeth, particularly further clinical intervention
- the dentist's decision-making process for root-filled teeth.

The aims of coronal restoration are to restore the function and aesthetics of the tooth, with a tight marginal seal as protection from microbial leakage. A coronal restoration may be either direct, i.e. a direct chairside composite or amalgam filling, or indirect, whereby the restoration, ceramic or a combination of metal and ceramic, is fabricated in a laboratory and then permanently cemented. For the root-filled tooth, a coronal restoration of adequate quality is an important factor for a successful outcome of the endodontic treatment, in terms of periapical status. While indirect restoration is often advocated as the treatment of choice for a root-filled tooth, the procedure is nevertheless more time-consuming and 3 – 4 times more expensive than a direct restoration. In Sweden, composite is the predominant material for direct restoration and the majority of root-filled teeth are directly restored. However, some reports suggest an association between composite restoration and an increased risk of periapical disease. In terms of tooth survival, there are also reports of less favorable endodontic treatment outcomes for teeth with direct restorations than for those with indirect restorations.

In Studies I and II clinical and radiographic examinations were undertaken in a random sample of 440 subjects, living in the county of

Skåne, Sweden. No association was disclosed between apical periodontitis (AP) and direct composite restorations. In non root-filled teeth, a relationship was found between the type of restoration and AP. Those restored with direct restoration by both composite and amalgam combined, and indirect restoration were associated with increased risk of AP, indicating that the extent of tooth substance removal rather than the type or material of the restoration, was an important factor of influence on periapical status. For root-filled teeth, however, the quality of the restoration and of the root-filling was more important to periapical health than the type or material used for the coronal restoration. In Study III, data from the Swedish Social Insurance Agency on dental treatments were analyzed. Only minor differences in the frequency of additional endodontic treatment for root-filled teeth restored with direct versus indirect restoration was disclosed. The indirectly restored teeth also had a more favorable natural course during the 5-year follow-up period. In comparison, teeth restored with direct restorations required further clinical intervention (nonsurgical retreatment, extraction and additional restorations) significantly more frequently.

In Study IV, in-depth semi-structured interviews were conducted with general dental practitioners. Data from 14 interviews were analyzed by Qualitative Content Analysis. Study IV revealed that dentists' decision-making process underlying the choice of coronal restoration for a root-filled tooth, was based not only on clinical factors; contextual factors and patient's views, if in conflict, were decisive. Thus, despite the indications for an indirect restoration, a direct restoration was occasionally chosen. Accordingly, the context in which the dentist makes decisions may be a factor influencing the fate of the root-filled tooth.

It is concluded that concerns that composite restoration poses a risk for periapical disease are not supported clinically, i.e. the use of composite seems to be safe. While in non root-filled teeth, AP tended to be associated with extensive restorations, in root-filled teeth the type of restoration was not an important factor of periapical health. For teeth directly restored after root canal treatment, further clinical interventions may be expected, especially for restorative failures. This may be attributable in part to the dentist's decision-making process with respect to the choice of coronal restoration.

POPULÄRVETENSKAPLIG SAMMANFATTNING (SUMMARY IN SWEDISH)

Det övergripande målet med avhandlingen var att jämföra två metoder, direkt och indirekt koronal restaurering, för ersättning av förlorad tandsubstans, med avseende på:

- hälsotillståndet vid rotfyllda och ej rotfyllda tänder rotspets
- naturalförloppet hos rotfyllda tänder med fokus på ytterligare behandling
- tandläkarens beslutsprocess för rotfyllda tänder.

En koronal restaurering syftar till att återställa tandens funktion och estetik samtidigt som den också hindrar bakterier att ta sig in i tanden. Ersättning av förlorad tandsubstans kan utföras antingen direkt eller indirekt. Vid direkt restaurering förses tanden med ett fyllningsmaterial, vanligen komposit, som färdigställs genom härdning direkt i munnen. Vid indirekt restaurering tas ett avtryck av den tand som ska återställas, varefter en tandersättning bestående av ett keramiskt material eller en kombination av metall och keramik framställs i ett tandtekniskt laboratorium. Studier har visat att en koronal restaurering av god kvalitet, som sluter tätt mot tanden, är viktigt för att en rotbehandling ska lyckas. I Sverige är komposit det vanligaste materialet för direkt restaurering och det är också så som majoriteten av rotfyllda tänder restaureras. En indirekt restaurering är mer tidskrävande och ett cirka 3 – 4 gånger dyrare alternativ jämfört med en direkt restaurering. Studier antyder att komposit skulle kunna utgöra en möjlig risk för hälsotillståndet vid tandens rotspets. Det har dessutom rapporterats att

tänder som blev direkt restaurerade efter rotbehandling oftare avlägsnades, jämfört med tänder som blev indirekt restaurerade.

I delarbete I och II utfördes klinisk och röntgenologisk undersökning av 440 slumpmässigt utvalda individer i Skåne, Sverige. Inget samband sågs mellan inflammation vid tandens rotspets och kompositfyllningar. En högre risk för inflammation vid rotspetsen sågs däremot för tänder som inte var rotfyllda och som hade en direkt restaurering av både komposit och amalgam i kombination eller var indirekt restaurerade. Fyndet tyder på att omfattningen av förlorad tandsubstans snarare än restaureringstypen i sig var av betydelse för hälsotillståndet vid tandens rotspets. För rotfyllda tänder var kvaliteten på restaurering och rotfyllning viktigare för tillståndet vid tandens rotspets än om restaureringen var utförd direkt eller indirekt.

I delarbete III analyserades data från Försäkringskassans databas med avseende på utförda tandbehandlingar. Enbart små skillnader sågs i hur ofta ytterligare rotbehandling utfördes i rotfyllda tänder med direkt jämfört med indirekt restaurering. Tänder som hade blivit indirekt restaurerade efter rotbehandlingen hade ett mer gynnsamt förlopp under de 5 följande åren. Ytterligare behandlingar, som att rotbehandlingen eller restaureringen gjordes om, eller att tanden avlägsnades, förekom mindre frekvent.

I delarbete IV utfördes semi-strukturerade djupintervjuer med allmäntandläkare. Data från 14 intervjuer analyserades med Kvalitativ innehållsanalys och visade att tandläkarens beslut om direkt och indirekt koronal restaurering baserades på olika kliniska faktorer och speciellt mängden kvarvarande tandsubstans. Avgörande för beslutet var dock det sammanhang beslutet fattades i och patientens egen uppfattning vägde många gånger tungt. Det innebar att i vissa fall valdes direkt restaurering, trots att en indirekt bedömdes som lämpligare. Det skulle delvis kunna förklara varför ytterligare behandlingar var vanligare i tänder som fick en direkt restaurering efter rotbehandlingen.

Sammanfattningsvis verkade komposit inte utgöra någon risk för hälsotillståndet vid tandens rotspets. Typ av restaurering hade mindre betydelse medan omfattande restaureringar kunde kopplas till rotspetsinflammation vid ej rotfyllda tänder. För tänder som fick en direkt restaurering efter rotbehandlingen observerades fler ytterligare behandlingar, speciellt omgörning av restaureringen. Det skulle delvis kunna förklaras av hur tandläkaren fattar beslut om restaurering, där sammanhanget ofta var en avgörande faktor.

PREFACE

This thesis is based on the following articles, which are referred to in the text by their Roman numerals.

- I Dawson V, Petersson K, Wolf E, Åkerman S. Periapical status of non-root-filled teeth with resin composite, amalgam, or full crown restorations: a cross-sectional study of a Swedish adult population. J Endod 2014; 40: 1303-1308.
- II Dawson VS, Petersson K, Wolf E, Åkerman S. Periapical Status of Root-filled Teeth Restored with Composite, Amalgam, or Full Crown Restorations: A Cross-sectional Study of a Swedish Adult Population. J Endod 2016; 42: 1326-1333.
- III Dawson VS, Isberg PE, Kvist T, EndoReCo, Fransson H. Further Treatments of Root-filled Teeth in the Swedish Adult Population: A Comparison of Teeth Restored with Direct and Indirect Coronal Restorations. J Endod 2017; 43: 1428-1432.
- IV Dawson VS, Fransson H, Wolf E. Coronal restoration of the root-filled tooth – a qualitative analysis of the dentist’s decision-making process. To be submitted.

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THESIS AT A GLANCE

Study	Objectives	Methods	Illustrations	Main findings/Conclusions
(I) Periapical status of non root-filled teeth with resin composite, amalgam, or full crown restorations: a cross-sectional study of a Swedish adult population	To compare the periapical status of root-filled teeth restored with resin composite, amalgam or laboratory-fabricated crowns	Clinical records and radiographs of a random sample of 440 subjects were used. For all non root-filled teeth the following variables were recorded: periapical status, caries and marginal bone loss type, material and quality of the coronal restorations.		No significant difference in frequency of AP* between teeth restored with resin composite (1.3%) or amalgam (1.1%) but a higher frequency of AP was found in teeth with crown restorations (6.3%). A significant negative association between AP and crowns was disclosed but no association with composite. The risk of damage to the pulp-dentin complex from resin composite as shown in experimental studies was not reflected in the clinical setting.
(II) Periapical status of root-filled teeth restored with composite, amalgam, or full crown restorations: a cross-sectional study of a Swedish adult population	To compare the periapical status of root-filled teeth restored with resin composite, amalgam or laboratory-fabricated crowns	Study II was based on the same sample as in study I. For all root-filled teeth, the same variables as in study I were recorded. In addition, the quality of the root-filling and the type of post were also registered.		No significant difference in frequency of AP of crown and crown restorations, provided that the quality was adequate.
(III) Further treatments of root-filled teeth in the Swedish adult population: a comparison of teeth restored with direct and indirect coronal restorations	To evaluate the frequencies of nonsurgical retreatment, root-end surgery, extraction and further restoration in relation to a direct versus an indirect restoration during a 5-year follow-up period of teeth root-filled and restored within a 6-month period	Data from the SSIA† database on dental treatments were analyzed. The frequencies of further treatments were calculated for all teeth reported as root-filled during 2009 and restored with a direct or an indirect restoration within 6 months of completed root-filling.		Low frequencies of nonsurgical retreatment (2.2%) and root-end surgery (1.0%) were reported 5 years after root-filling, whereas extraction was more common (9.2%). Fewer additional treatment procedures were registered for teeth with indirect restorations than for those with direct restorations. Of the directly restored teeth, 30.3% had ≥1 further direct restoration whilst corresponding figure for indirectly restored teeth was 6.4%.
(IV) Coronal restoration of the root-filled tooth – a qualitative analysis of the dentist's decision-making process	To describe the decision-making process of the general dental practitioner underlying the choice of coronal restoration for a root-filled tooth	In-depth, semi-structured interviews were conducted with GPs** about their personal experience when deciding how to restore a root-filled tooth. Data from 14 interviews were analyzed by Qualitative Content Analysis.	Transcribed in interviews	In the dentist's decision process, clinical factors were considered important but were overruled by context and patient opinions, if in conflict. The dentist's decision process was in each case characterized by an assessment of clinical factors for which, in certain cases, contextual factors were weighted and occasionally modified the choice, however the patient's views was decisive for the decision about coronal restoration.

* Apical periodontitis

† Swedish Social Insurance Agency

** General Dental Practitioners

ABBREVIATIONS / VOCABULARY

AP	Apical Periodontitis
GDP	General Dental Practitioner
OR	Odds Ratio
PAI	Periapical Index
PDHS	Public Dental Health Service
PP	Private Practice
SPAR	The Swedish National Person Address Register, referred to in the text by the Swedish abbreviation SPAR (Statens personadressregister)
SSIA	Swedish Social Insurance Agency (Försäkringskassan)

Dental care for health A dental insurance offered by the public dental health service. It includes basic dental care at a fixed fee, based on assessment of the risk for future disease and need for dental care.

Direct restoration Filling of composite or amalgam

Indirect restoration Full-crown, inlay or onlay fabricated in a laboratory. In this thesis indirect restoration refers to a full-crown restoration.

INTRODUCTION

Coronal restoration

Coronal restoration of root-filled and non root-filled teeth may be either direct or indirect. The aim is to restore the function and aesthetics of the tooth and to ensure a tight marginal seal to prevent the ingress of oral microorganisms. A direct restoration, i. e. a build-up of composite or amalgam, is a chairside procedure, whereas an indirect restoration is fabricated in a laboratory before being permanently placed.

It is estimated that globally the annual number of direct restorations is of the order of 500 million (1). Since the early 1990s, amalgam, the major filling material for more than 150 years (2), has been successively replaced by composite, which is now the predominant material for direct restoration (1). Sweden and Norway have banned the use of amalgam on environmental grounds and composite is among the few materials available for direct restoration. However, there are considerable regional differences and in many countries the use of amalgam is still high (3). Apart from environmental issues and concerns about mercury in amalgam, the increased use of composite may also be attributable to better aesthetic properties and more conservative tooth preparation; less removal of tooth structure is required for retention, as composite bonds to the tooth structure. However, despite these advantages, there are concerns about composite material. For example, contact with skin may result in contact dermatitis and eczema (4), the rates of restorative failures are higher than for amalgam (5) and shrinkage during polymerization (6), may result in microbial leakage (7). Moreover, experimental studies have shown untoward reactions of dental pulp cells to composite material (8, 9).

Indirect restorations are most common in cases of fractures of tooth substance and failed restorations (10). Depending on the extent of the damaged tooth structure, the restoration may be in the form of a full crown, an onlay or an inlay. Various materials are available: metal, ceramic or a combination of both. Metal-ceramic indirect restorations have been widely used for more than 150 years (11), and because of the predictable clinical performance, with high expected survival rates (12) they are still commonly used. However, over time aesthetic issues may arise, especially in the anterior region (11), where gingival recession may expose the metal framework along the cervical margins. During the last 15 years, ceramic materials for indirect restoration have been introduced, offering better aesthetics (11). Their use is increasing (13), but concerns have been expressed about possible adverse outcomes, such as failure of the restoration (11). To date, however, there is insufficient evidence of their effectiveness in comparison with metal-ceramic restorations (11).

For the patient, the fee for an indirect restoration is approximately 3-4 times greater than for a direct restoration (14) and is also a more time-consuming procedure. Moreover, compared with a direct restoration, preparation for the indirect restoration (crown) requires removal of more tooth structure (15).

Non root-filled teeth

Endodontic complications after restorative treatment

Coronal restoration of a vital tooth may be necessary due to caries or tooth fracture. For a favorable prognosis, the choice of a direct or an indirect restoration should be determined by the condition of the remaining tooth structure (5). Although intended to benefit the patient, the restorative procedure is not entirely without risk of compromising the vitality of the dental pulp, such as trauma during preparation, the potential toxicity of restorative materials and microbial leakage along the margins (7). Among endodontic complications reported after direct and indirect restorative treatment are pulpal necrosis, apical periodontitis (AP) and the need for endodontic treatment.

In clinical studies of non root-filled teeth restored with direct restorations (composite or amalgam), 2–12% were reported to require endodontic treatment within 12 years of restoration (16-20).

However, whether a vital tooth restored with composite is at higher risk of pulpal complications than teeth restored with other materials has yet to be determined. A recent systematic review concluded that there is insufficient scientific evidence to answer this question (21). Contradictory results are reported from the few available studies on this topic. Although some studies report no differences in the frequency of endodontic complications between teeth restored with composite or amalgam (16,18), others report less favorable outcomes for teeth restored with composite. Whitworth et al. found that after a follow-up period of 36 months, there were more pulpal breakdowns in teeth restored with composite (22) and Kwang et al. reported a significant association between composite restorations and subsequent endodontic treatment (23). However, there are also studies in which no endodontic complications at all have been found in teeth restored with composite (24,25).

Endodontic complications after indirect restoration have been reported. In clinical studies of non root-filled teeth restored with single crown or bridge restorations, necrosis of the pulp was diagnosed in 3–15% of teeth over a follow-up period of 2–25 years (26-29).

Periapical status

Epidemiological studies report that the most important risk factor for development of AP, besides caries, is a coronal restoration, especially of inadequate quality (30). The type of restoration is also of significance; teeth with crown restorations have more than twice the risk of developing AP as those restored with fillings (30).

To date, there are no investigations of the possible association between AP and the material used for the direct restoration, composite or amalgam. Given the disadvantages of composite material such as polymerization shrinkage, with possible marginal leakage as a consequence, and the reports from experimental studies of untoward reactions of dental pulp cells to composite material (8,9), it is reasonable to assume that compared to teeth restored with amalgam, the frequency of AP may be higher in those restored with composite. However, the results of the few available clinical studies are contradictory and it remains unclear whether there is any difference in the frequency of AP between non root-filled teeth restored with composite, amalgam and crown restorations.

Root-filled teeth

Root canal treatment is mainly undertaken in teeth with deep carious lesions or in teeth with deep fillings or crowns, resulting in pulpal inflammation or necrosis of the pulp with infection of the root canal and AP as a consequence (31). Accordingly, root canal treatment may be described as a procedure intended to prevent or eliminate infection within the root canal. This is achieved by chemo-mechanical removal of infected material and the damaged pulp tissue, followed by a well-condensed obturation of the root canal system; with healthy periapical tissues as the expected outcome. Cohort studies of patients treated by specialists in endodontics have reported success rates of 80% to >90% (32, 33).

Restoration of root-filled teeth

Completion of the root canal treatment is followed by permanent direct or indirect coronal restoration, preferably as soon as possible after completion of the root canal treatment in order to avoid microbial leakage of the temporary restoration, which may occur within a couple of weeks (34).

The restoration of a root-filled tooth is usually somewhat different from that of a vital tooth. Apart from the access cavity preparation, root-filled teeth have often previously been heavily restored due to caries, tooth substance fractures or trauma, resulting in extensive loss of tooth structure. Furthermore, loss of the vital pulp functions may affect the perception of loading, so that root-filled teeth may be subjected to higher loads than vital teeth, before the patient becomes aware of discomfort (35). Although it has been suggested that root-filled teeth may be more brittle, there is no supportive evidence. There is however, a widespread clinical impression that root-filled teeth are more susceptible to fracture (36).

There has been extensive debate over how the root-filled tooth should be restored, by direct or indirect restoration (37, 38). Several guidelines are available, based on reviews of the available literature and expert opinion (39-44). While some authors have proposed different restorative strategies, depending on the amount of residual tooth structure (38, 39, 44) and the functional load (38, 44), there are also recommendations that root-filled posterior teeth should be restored with a full-crown restoration or an onlay (for cuspal coverage), regardless of the amount

of residual tooth structure (41). Accordingly, there is no consensus with respect to the restoration of choice for root-filled teeth.

Periapical status

Besides restoring the function and aesthetics of the root-filled tooth, another aim of the coronal restoration is to provide the tooth with a tight marginal seal as protection from microbial leakage. A coronal restoration of adequate quality is of decisive importance for the successful outcome of the endodontic treatment (32, 45).

As composite material is subject to polymerization shrinkage, hypothetically a crown would offer a better seal for the root-filled tooth, preventing invasion of the oral microorganisms into the root canal. The result should be a higher frequency of healthy periapical tissue in root-filled teeth restored with crowns. However, in follow-up studies, no differences in success rates, in terms of periapical health, have been found with respect to composite, amalgam and crown restorations (32, 46, 47). On the other hand, one cross-sectional study disclosed a higher frequency of AP in root-filled teeth restored with composite than in those restored with crowns (55.7% and 34.3%, respectively) (48). With respect to material used for direct restoration, composite has been reported to be predictive of AP (49), in accordance with Homme et al. reporting that AP was more common in teeth restored with composite than with amalgam (50). Extrapolating these findings to Swedish conditions, where most root-filled teeth are restored directly with composite (51, 52), a higher frequency of AP would be expected in such teeth than in those restored with other types or materials. This would be of great concern for Swedish dentistry.

However, as the results of the few available studies are inconsistent, it is largely unknown whether there is any difference in the frequency of AP in root-filled teeth in relation to the type and material used for coronal restoration.

Natural course of root-filled and restored teeth

After root canal treatment and coronal restoration, a healthy periapical condition is the expected outcome. However, from the patient's perspective, a successful treatment outcome may be defined as retaining the tooth, regardless of whether AP is present or not, as long as it is asymptomatic (53). Another desirable outcome from the patient's perspective might be an uneventful natural course of the tooth after root canal treatment and coronal restoration. When further intervention is necessary the patient may not perceive the treatment outcome to be successful, especially if the further intervention is required soon after completion of treatment. Further intervention is associated with additional costs – for both the patient and society.

Reports from several studies show that 2–10 years after root canal treatment, 74–96.1% of the teeth had an uneventful natural course, without the need for extraction, nonsurgical retreatment or root-end surgery or (54–58).

Further clinical interventions

Extraction

Although root canal treatments are undertaken in order to retain a tooth, inevitably some teeth will be extracted over time. Longitudinal studies have shown that over a period of 8–11 years, 7–12% of root-filled teeth were extracted, indicating clinical failures (59, 60). In data from a systematic review and from studies in Germany, England and Wales, the proportion of surviving teeth was reported to be 74–94%, 2–10 years after completion of the root canal treatment (57, 58, 61). Over time, more teeth are extracted. Twenty years after root-filling, 65–79% of the teeth had survived (47, 62, 63). However, the reasons for extraction may not always be related to failure of root canal treatment: the decision to extract is reported to be based mainly on other factors (47, 64, 65).

The conclusion of the meta-analysis in the systematic review was that among factors significantly associated with an improved survival rate of root-filled teeth, a crown restoration after root canal treatment was the factor with the greatest influence on tooth survival (61). The same results have been reported in more recent studies (65, 66).

Nonsurgical retreatment and root-end surgery

Some teeth will require further intervention following failure of root canal treatment. Besides extraction, possible treatment options are nonsurgical retreatment or root-end surgery. From registers of insurance companies in the United States, Taiwan and Germany, nonsurgical retreatments were reported for 0.4%–3.2% of teeth that had been root-filled 2-8 years earlier and root-end surgery in 0.6%–3.7% (54-56, 58).

While extractions are more frequent in root-filled teeth with direct restorations, the question of whether the same applies to nonsurgical retreatment and root-end surgery has not been investigated. Possibly, an indirect restoration may provide the root-filled tooth with a better seal against microbial leakage than a direct composite restoration. Consequently, more failures of root canal treatments would be expected in teeth restored with direct restorations, with more re-interventions of the root canal treatment as a result. However, this has yet to be verified.

Further restorative treatment

In a different scenario failure of the coronal restoration may necessitate further intervention. If restorable, the root-filled tooth may be subjected to further restorative procedures. If not, extraction is the preferred treatment. Restorative failure might be more likely to occur in root-filled teeth restored with composite, especially in cases of extensive restorations. There are few available studies of the need for further restorative procedures in root-filled teeth in relation to direct or indirect coronal restoration and the results are contradictory. One study reported more restorative failures in root-filled teeth with direct restorations (67), but no such difference has been reported in other studies (68, 69).

The natural course of root-filled teeth treated in general practice has been reported in previous studies (54-58, 67), but not in the Swedish context. Nor has it been established that there is any difference in the frequency of further clinical interventions in root-filled teeth, in relation to the type of coronal restoration.

Evidence of an association between type of coronal restoration and tooth survival

It has been claimed that there is abundant evidence favoring cast restorations on root-filled posterior teeth (42). Most studies on tooth survival after root canal treatment have reported a higher survival rate for teeth restored with indirect restorations than for those with direct restorations (61, 65, 66, 70). However, systematic reviews of the literature have concluded that the evidence is insufficient to assess the relative effects of crowns vs direct restoration (71), and that there is a lack of scientific evidence to determine whether indirect restorations maintain the longevity of a root-filled tooth better than direct restorations (72).

Although the previous studies on tooth survival may represent the current best available evidence, this does not necessarily imply that crowns are in every case the preferred restoration for root-filled teeth; there are limitations. Previous studies of tooth survival (61, 65, 66, 70) are not prospective, randomized controlled studies, and the rationale for the choice of a direct or an indirect restoration is unknown. Accordingly, the possibility of selection bias cannot be excluded, and systematic differences may have arisen between the groups of teeth restored by direct and indirect restoration, affecting the comparability of the groups. Perhaps root-filled teeth with a good prognosis are more likely to be restored with an indirect restoration. In a study by Chugal et al., it was found that teeth without preoperative AP were significantly more likely to be restored with a crown restoration than teeth with AP (46).

There is insufficient evidence (71, 72) to determine with certainty whether the better survival rate associated with the indirect restoration is attributable to better marginal seal and protection of the root-filled tooth, or if it is a result of the dentists' decision-making process. Accordingly, it has been concluded that the decision about the choice of coronal restoration of a root-filled tooth should preferably be based on the dentist's own clinical experience, whilst also taking into account the patient's preferences and his/her individual circumstances (71).

Clinical decision-making

In general

The theory of decision-making involves three different aspects: the normative, i.e. how decisions should be made and the descriptive, i.e. how decisions are actually made. The third aspect, prescriptive decision theory, is how decision-making can be improved (73). Clinical decision-making may be defined as a complex process, where data comprising clinical findings and medical history are collected and evaluated, after which a decision is formulated (74), in order to treat the patient adequately. Although it is invisible, the process of reasoning and decision-making is an everyday activity in clinical practice and one of the clinician's most important skills (75).

At its simplest, the decision-making process can be described as involving five sequential steps: 1) collection of data by clinical examination, including the patient's medical history and appropriate diagnostic tests. 2) The collected data are evaluated and the patient's clinical picture is related to the care provider's knowledge about different diseases and, 3) a diagnosis is established. 4) The clinician should then, while taking the prognosis into account, make a decision about the most appropriate treatment for the patient. 5) Finally, the treatment outcome is registered (76). The decision involves different components that are taken into account. Important components include not only the clinician's theoretical knowledge and clinical experience with respect to diagnosis and treatment options, but also patient-related aspects such as empathy and ethics – to act in accordance with the patient's best interests (76).

According to the dual process theory, decision-making involves intuitive and analytical reasoning – two different ways of thinking (77). While the intuitive approach uses inductive logic, pattern recognition, and is fast and effortless, it is prone to errors (75, 77). In contrast, the analytical approach is characterized by deductive reasoning, critical thinking and is logical. The analytical decision-making process is slow, but more reliable (75, 77). The approach used in a clinician's decision-making process depends largely on the actual situation: when a situation is recognizable it will primarily engage intuitive thinking, while in the case of an unfamiliar pattern analytical reasoning will be applied (77).

In dentistry

In daily practice, dentists encounter many situations which involve decision-making, from determining a diagnosis to decisions about selection of appropriate treatment. Although the status of the dentition serves as a basis for treatment planning, the dentists' clinical decision-making processes are usually more complex, with several other factors also to be taken into account. Kay and Nuttall (78) have suggested the following factors which may influence dentists' treatment decisions, in general:

- the dentist-patient relationship
- dentist's and patient's preferences for dental care
- patient attendance
- patient's financial circumstances
- the probability of successful treatment
- risk/benefit ratio
 - whether benefits of treatment outweigh risks
 - patient's and dentist's attitude to risk
- dentist's personal treatment threshold.

However, the authors did not address the question of whether some of these factors are more important than others. Variations in dentists' decision-making mean that different decisions may be made for patients presenting with similar problems and dental status. Perceptual variation occurs when dentists disagree about the condition they are looking at – examining the same tooth but perceiving different levels of disease. In cases of judgmental variation, the dentists agree about the level of disease, but opinions about treatment differ (79).

The choice of coronal restoration for a root-filled tooth

In Sweden, almost a quarter of million teeth are root-filled and restored annually (52). Thus for many practitioners, the choice of coronal restoration is a clinical decision encountered on a daily basis.

The amount and quality of residual tooth structure and the function and position of the tooth in the arch have been suggested as the most important technical factors when deciding on permanent restoration of a root-filled tooth (44).

Besides technical factors, biological and prognostic factors may also be important. Furthermore, the preferences of both the patient and the

dentist may influence the decision (78) and because of the considerable difference in cost for direct and indirect restorations, the treatment decision may also be influenced by the patient's financial circumstances (80).

Although the choice of coronal restoration is a common clinical scenario, little is known about how dentists actually make their decisions and which factors are of importance. One survey investigated the opinions and clinical routines of general dental practitioners (GDPs) about the restoration of root-filled teeth (81); however in general most questions concerned different technical aspects. If their decision-making included other factors of importance than those suggested by the authors, they may not have been disclosed.

Insight into the dentist's perspective of the decision-making process, which takes the context into account, would help to estimate the influence of other than technical/biological factors in selecting coronal restoration for a root-filled tooth. Furthermore, this may facilitate evaluation of the clinical significance of findings from longitudinal and follow-up studies on the influence of direct versus indirect restoration on periapical status and survival of root-filled teeth.

The Swedish context of dental care

Root canal treatments and coronal restoration

Dental care is provided by dentists working within the public dental health service (PDHS) or in private practice (PP). Almost all dentists are affiliated with the tax-funded Swedish Social Insurance Agency (SSIA). Accordingly, all interventions must be reported to the SSIA on completion. Thus the SSIA's database comprises data on all registered dental treatments for the whole adult population of Sweden. GDPs undertake all types of general dental treatment, but may refer difficult cases to the relevant specialists.

Root canal treatments and coronal restorations are undertaken mainly by GDPs (52).

Patient fees and payment models

In Sweden, dental care is free of charge for patients until the age of 23 years. Patients ≥ 24 years old are insured by the SSIA, including a general dental care allowance of 300–600 Swedish crowns (SEK) (28 – 56 Euro, based on an exchange rate €1= 10.82 SEK, on October 16, 2019) a year, depending on the patient's age. In addition, there is step-wise, high-cost protection, which applies once the fees for dental treatment exceed a certain threshold. Accordingly, since the latest reform in 2008, a patient pays 100% of the fees up to 3 000 SEK (€ 277) and thereafter 50% of costs exceeding 3 000 SEK (€ 277) and 15% of costs exceeding 15 000 SEK (€ 1 386). Most items of treatment, including endodontics and restorations, but also fixed prosthodontics and implants, are covered by the SSIA, provided that certain criteria are met. For example, for the cost of a crown restoration to be covered by high-cost protection, the tooth must have an extensive defect, that is 4 out of 5 surfaces missing on premolars/molars and 3 out of 4 surfaces on incisors/canines (82). Besides this fee-for-service system, patients have the option of dental insurance (Dental Care for Health) offered by the PDHS (83), covering basic dental care, including root canal treatments and restorations (composite, single crowns). The patients pay a fixed fee for this insurance, based on risk assessment of future disease and dental treatment need. The dental clinic receives fixed reimbursement for every patient.

Some groups of patients are covered by other regulations (84), such as those with an increased dental treatment need associated with certain diseases. They are entitled to dental care at a significantly reduced fee, with, however considerable restrictions. For example, fixed prosthodontics is usually not included. Patients unable to afford dental care can apply for financial aid from the Social Services. If approved, extensive restrictions apply.

Research methods based on analysis of quantitative and qualitative data

Research paradigms

A research paradigm may be defined as a set of common beliefs that researchers share, representing a worldview about how answers to research questions should be sought. It includes beliefs about epistemology, ontology and methodology (85).

Epistemology is the study of knowledge. It concerns what can be known, and the relationship between the researcher and the participant (85). Ontology refers to study of the nature of reality (86) while methodology describes the different approaches which may be used to acquire scientific knowledge (87). Although several paradigms have been described (88), two predominate (89), on which quantitative and qualitative research traditions are based, with different assumptions about epistemology, ontology, and methodology (85). While the quantitative research approach is based on positivism (90, 91) the qualitative approach originates from interpretivism (90).

The epistemological perspective underlying quantitative research is that the reality can be directly measured and knowledge is acquired through sense experience (86). The researcher does not influence data from the participant and it is considered possible to conduct research that is objective, without impact of the researcher's values (92). In qualitative research, even though the investigator aims to be as neutral as possible, it is inevitable that the researcher and the participant will influence each other. It is therefore not possible to achieve the same objectivity as for research methods based on quantitative data (92). It may however, be argued that quantitative research is not entirely objective. The choice of the topic to be studied may be influenced not only by the researcher's interests, but also those granting research funds and by society (93). Furthermore, the researcher may influence interpretation of the results and refrain from publishing any undesirable results. The journal editors also determine what will be published.

The ontology underlying quantitative research is that an objective reality exists independently of human beliefs and interpretation (positivism) (90, 92), and there is only one truth (90). In contrast, according to the ontology underlying qualitative research, there is an independent reality but it can be accessed only through human

interpretation; thus several perspectives are possible (interpretivism) (92).

Methodologies for quantitative research are experimental and quasi-experimental, using mainly deductive logic (94), whereas the qualitative approach involves observations or interviews for which an inductive approach predominates (89), even though both induction and deduction may be used alternately (92).

Quantitative versus qualitative research approaches

Although both approaches involve a systematic collection, organization and analysis of data they differ in several aspects, because of the different underlying philosophies described above (90). The type of data acquired through quantitative and qualitative research approaches also differs (92). Quantitative research aims at quantification, measurement and verification of hypotheses (95); in contrast, the aim of a qualitative approach is to understand and explore, rather than explain and predict (96).

Within medical research there is still a commonly held view that the quantitative research approach is the best way to acquire scientific knowledge (96); qualitative research has been criticized as being subjective (97), with an absence of facts (98). On the other hand, quantitative research has been criticized as unable to provide an in-depth view of human behavior, feelings, perceptions and attitudes (91). However, the approaches may be regarded as complementary (99) rather than competitive, as they are able to address different research questions. Methods based on quantitative data are well-suited for addressing such questions as 'how much', 'how many', 'is there a statistically significant difference between...' (92). In contrast, methods based on qualitative data are better suited to answer such questions as 'what', 'how' and 'why' (92), for exploration of experiences, meanings, thoughts, expectations, motives and attitudes (96). Accordingly, the choice of a quantitative or qualitative strategy should be based on the approach considered most appropriate for addressing the particular research question (96).

The trustworthiness of research

There are different views as to whether research methods based on quantitative and qualitative data should be evaluated according to the same quality criteria (100). One view is that concepts from the quantitative tradition, validity, reliability and generalizability may be used, implying the same meaning for qualitative research (101). However, application of the concepts credibility, dependability, conformability and transferability is another way of describing different aspects of trustworthiness in qualitative research (101, 102).

Credibility

Credibility refers to the truth value of the findings (95), how well data and analysis address the research question, and is comparable to internal validity within quantitative research. Different measures may be taken to enhance credibility, including the selection of suitable participants, the volume of data and how it is collected and aspects related to the analysis process, such as selecting the most suitable meaning unit (101). It has been suggested that credibility could be improved by presenting representative quotations from the interviews and seeking consensus among experts, participants and co-researchers (101).

Dependability

Dependability, comparable to reliability in quantitative research (95), refers to the consistency of data collection and analysis during the research process, i.e. whether the results would be the same if the study was replicated using the same or similar participants in the same context (86). On the other hand, it has also been suggested that repeatability is rarely a strict requirement in qualitative research, as different interpretations may be considered valid (98).

Transferability

Transferability, comparable to generalizability in quantitative studies, relates to the extent to which the findings also apply to other settings or groups (95). Transferability may be facilitated by clear information about the context, sampling procedure, characteristics of participants, data collection and analysis. Presenting appropriate quotations to illustrate the findings will also increase transferability (101). Authors

may suggest a degree of transferability, but it is up to the reader to decide (101).

Conformability

Conformability, corresponding to objectivity, means that the data accurately represent the information provided by the study participants; that interpretation of these data is not fabricated by the investigator (86). It has been suggested that conformability or credibility could be indicated by the participants' recognition of the results (101). On the other hand, there are suggestions that this strategy should be avoided because it may have a negative influence on validity (103). According to Pyett (104), researchers are better equipped to understand the actions and motives of the participants, than the participants themselves. To avoid subjectivity, it is important to take into account all the effects the researcher might have on the different steps of the research process (98).

AIMS

The general aims of this thesis were to investigate direct and indirect coronal restorations with reference to:

- periapical health
- the natural course of root-filled teeth, especially further clinical interventions
- the dentists' decision-making process for root-filled teeth.

The specific aims were:

- to compare the periapical status of
 - non root-filled teeth (Study I)
 - root-filled teeth (Study II)restored with resin composite, amalgam or laboratory-fabricated crowns in an adult Swedish population
- to evaluate the frequencies of nonsurgical retreatment, root-end surgery, extraction and further restoration in relation to a direct versus an indirect restoration during a 5-year follow-up period of teeth root-filled and restored within 6 months in Sweden in 2009 (Study III)
- to describe the general dental practitioner's decision-making process underlying the choice of coronal restoration for a root-filled tooth (Study IV).

HYPOTHESES

The following hypotheses were tested:

- Non root-filled teeth restored with composite have higher frequencies of apical periodontitis than teeth restored with amalgam (Study I).
- Root-filled teeth restored with composite have higher frequencies of apical periodontitis than those restored with amalgam or laboratory-fabricated crowns (Study II).
- Further clinical interventions after root canal treatment are more frequent in root-filled teeth restored with a direct than an indirect restoration (Study III).

Hypotheses were generated about the dentists' decision-making process underlying the choice of coronal restoration, to be tested in quantitative models (Study IV).

MATERIALS AND METHODS

Cross-sectional studies (I, II)

Studies I and II were based on data from a previous clinical study of oral health in the adult population of Skåne (105).

Subjects

The subjects were a random sample of 1 000 adults, registered as residents of Skåne, a county in the southern part of Sweden, in 2007. The subjects, aged 20 – 89 years, were invited to participate in a clinical study of oral health (105). The sample was retrieved from the Swedish National Person Address Register (SPAR) and included the background variables sex, address, and age in 5-year intervals. The process of random sampling for the study sample and reasons for exclusion are presented in Fig. 1.

Figure 1. Flow chart: from random sample to study sample.

In total, 451 subjects participated in the clinical study: 232 (51%) women and 219 (49%) men. The sex and age distribution did not differ between participants and non-participants except for the oldest age group, in which subjects 80 – 89 years were less likely to participate (105). The subjects were informed about the study and provided written consent.

Clinical examination

The examinations were conducted from March 2007 – November 2008 at the Faculty of Odontology at Malmö University, Sweden, and at 3 public dental clinics in the county of Skåne. The clinical examinations were carried out by 8 dentists, all of them employed at the Department of Oral Diagnostics, Faculty of Odontology, Malmö University. Prior to the examinations they were calibrated with respect to the diagnostic criteria, through comprehensive written instructions, practice and discussion of clinical cases. 90.5% of the examinations were conducted by 4 of the 8 dentists (105). Caries lesions were determined by the use of standardized clinical criteria aided by mirror, probe (EXD57; Hu Friedy, Chicago, IL, USA) and bitewing radiographs. Manifest caries was defined as a cavitated lesion extending into the dentin (D₃) (106). Five intraoral clinical photographs were taken; frontal, right and left views, all in intercuspal position, and occlusal views of the teeth in the maxilla and mandible. Further details about the clinical examination are described in Lundegren et al. (105).

Radiographic examination

Digital panoramic radiographs and bitewings, showing the distal surface of the canine to the mesial surface of the last molar, were exposed. In general, four bitewings were exposed. The available radiographic equipment at each clinic was used. At the Faculty of Odontology at Malmö University, the machine used for panoramic radiographs was Siemens Orthophos (Erlangen, Germany).

Data collection

For studies I and II, data were collected from the intraoral clinical photographs and radiographic images (bitewing and panoramic radiographs). The notations from the clinical examination protocol were also used.

The radiographs were available in the digital record system (Romexis 2.8.1.R; Planmeca, Helsinki, Finland) and interpreted on a 19-inch liquid crystal display monitor (Olorin; Kungsbacka, Sweden, VCD 190D; resolution: 1280 X 1024 32-bit color; graphic card: HD Graphic; Intel, Santa Clara, CA, USA) in a room with adjusted ambient light.

Four observers (VD, EW, KP, SÅ) underwent a calibration process for the three criteria periapical status, root-filling quality and marginal bone loss, through discussion and interpretation of panoramic images from 20 randomly selected study subjects. Another 20 panoramic images were then randomly chosen and independently evaluated by 3 observers (VD, EW, KP) in order to assess the interobserver agreement on periapical status, root-filling quality and marginal bone loss, by calculating Cohen's kappa (κ). Following discussion of the results and a second calibration process, the remaining 400 panoramic images were randomly distributed among the 3 observers for interpretation; each observer scored one third of the material. When required, image processing was done, by adjusting contrast, brightness and magnification of the panoramic radiograph.

Coronal restorations and caries

Using the information from the clinical examination protocol, intraoral clinical photographs and radiographic images (bitewing and panoramic radiographs), two observers (VD, SÅ) together scored the following variables for all permanent teeth, including third molars: type (crown and/or filling), material and quality of coronal restorations, and manifest caries (Table 1). When more than one filling material was detected in a tooth, the material judged to have the greatest impact on periapical status was scored. For example, in the case of a tooth with both a small amalgam filling and an extensive temporary filling, the latter was scored.

Table 1. Parameters scored for coronal restorations and caries, according to clinical examination protocol, intraoral clinical photographs and radiographs (bitewings and panoramic radiographs)

Coronal restoration
Crown
<ul style="list-style-type: none"> • Laboratory-fabricated • Amalgam • Composite • Temporary
Filling
<ul style="list-style-type: none"> • Amalgam • Composite • Composite and amalgam • Ceramic inlay • Other (eg, gold inlay, temporary, dislodged)
Quality of coronal restoration
<ul style="list-style-type: none"> • Adequate (restoration margins not defective) • Inadequate (defective restoration margins)
Caries
<ul style="list-style-type: none"> • Manifest caries (cavitated lesion extending into the dentin)

Periapical status, marginal bone loss, root-filling quality and type of post

In the panoramic images, periapical status and marginal bone loss were assessed for all teeth. In the endodontically treated teeth root-filling quality and any type of post were evaluated. The criteria for periapical status, marginal bone loss and root-filling quality scored from the panoramic radiographs are presented in Table 2. Posts were classified as cast, prefabricated, parapulpal, screw post or other.

Table 2. Criteria for periapical status, marginal bone loss and root-filling quality scored from panoramic radiographs

Periapical status

- Normal periapical conditions: normal periapical structures or widening of the apical periodontal ligament space not exceeding twice the width of other parts of the root
- AP: apical periodontal ligament space exceeding twice the width of other parts of the root or periapical radiolucency observed
- Not assessable: periapical structures not discernible (overlapping anatomic structures, inadequate image quality)

Marginal bone loss

- No marginal bone loss or $\leq 1/3$ of the root length
- Marginal bone loss $> 1/3$ and $\leq 1/2$ of the root length
- Marginal bone loss $> 1/2$ of the root length

Root-filling quality

- Amputated: radiopaque material in the pulp chamber
 - Adequate: ending 0-2 mm from the radiographic apex and without visible voids
 - Inadequate: root-filling ending > 2 mm or extending beyond the radiographic apex, signs of voids, fractured instrument in a canal, perforation, or untreated canal
 - Retrograde filling: radiographic sign of retrograde filling material
 - Not assessable
-

If there was any doubt as to the presence of AP, periapical conditions were registered as normal (107). For multirooted teeth periapical status, marginal bone loss and root-filling quality were classified according to the root presenting the worst score for these variables. The variable marginal bone loss was dichotomized during the statistical calculations: 1) no marginal bone loss, or loss $\leq 1/3$ of the root length or 2) marginal bone loss $> 1/3$ of the root length.

The following interobserver agreement was achieved for the 3 observers:

periapical status: 516/539 (95.7%), $\kappa = 0.56$

marginal bone loss: 514/539 (95.3%), $\kappa = 0.47$

root-filling quality (adequate/inadequate): 528/539 (98.0%), $\kappa = 0.5$.

Registry-based cohort study (III)

Subjects

The study population comprised all adults in Sweden who were registered in the SSIA database as having a root-filling completed during 2009. There were 217 047 in all (49.8% women and 50.2% men), aged 20 – 102 years, with an average age of 55 years at the time of root-filling. In total, 248 299 teeth had been root filled during 2009.

Data collection

Root-filled teeth

Data were obtained from the SSIA database (see “The Swedish context of dental care”, page 24-25). By searching for treatment codes corresponding to root-filling of 1 – 4 root canals (items 501 – 504), teeth registered as root filled between 1 January and 31 December 2009 were identified. The specific tooth as well as the specific individual were identifiable in the database. These teeth were followed for a period of 5 years after registration of the root-filling, up until 31 December 2014.

Coronal restoration

The type of coronal restoration registered within 6 months of completion of the root-filling was identified by searching for the treatment codes corresponding to direct and indirect restorations. Depending on the treatment code registered, the root-filled teeth were grouped as follows:

- direct restoration (codes 701 – 707; a direct resin composite restoration of 1 – 5 surfaces)
- indirect restoration (codes 801, 805 – 809; inlay, onlay or a full-crown restoration fabricated in a laboratory)
- unknown (no registration of restorative treatment codes within 6 months of the root-filling).

In case of registration of both a direct and an indirect restoration within 6 months after the root-filling the tooth was classified as indirectly restored.

Further clinical interventions

To identify further clinical interventions undergone within 5 years of the root-filling, the data were searched for treatment codes allotted to the root-filled teeth, either directly or indirectly restored, with reference to:

- extraction (codes 401 – 404; extraction of a tooth, the level of difficulty ranging from uncomplicated to surgical removal)
- nonsurgical retreatment (501 – 504; nonsurgical retreatment of 1 – 4 root canals)
- root-end surgery (codes 541 – 542; root-end surgery of 1 or more teeth at the same appointment)
- direct restoration (codes 701 – 707; a direct resin composite restoration of 1 – 5 surfaces)
- indirect restoration (codes 801, 805 – 809; inlay, onlay or a full-crown restoration fabricated in a laboratory).

In cases of obviously erroneous information, data reported to the SSIA on extractions, nonsurgical retreatment and root-end surgery were excluded. For example: the tooth number was not specified, a specific treatment was registered more than once for the same tooth and day, and extraction was registered more than once. Data on restorative procedures were excluded in cases where the information was inadequate, that is when tooth number was not specified.

In-depth interviews (IV)

To gain a deeper understanding of the decision-making process, from the perspective of the dentist, preceding the choice of coronal restoration for the root-filled teeth, a qualitative research approach was considered suitable. The specific method for analysis used was Qualitative Content Analysis, according to the approach described by Graneheim & Lundman (101).

Research team and reflexivity

The three authors VD, EW and HF are specialists in Endodontics, working at a faculty of odontology. EW has previous experience, while VD and HF have limited experience of qualitative research. Our preconceptions included selection bias, which may partly explain the

better survival rates for root-filled teeth restored by indirect restoration. A tooth with a good prognosis is more likely to be restored with a crown. Factors of importance for the dentist's decision-making process leading to the choice of coronal restoration may be technical and biological factors, the patient's financial circumstances and the dentist's and the patient's preferences.

Subjects

The study population comprised 14 GDPs practicing in Sweden. The following two absolute inclusion criteria had to be met:

- recent experience of making decisions about coronal restorations for root-filled teeth
- ability to express themselves in Swedish, to allow in depth narration during the interview.

In order to achieve variation in perspectives on the topic, the informants were strategically selected with respect to gender (female or male), age (years), undergraduate dental education (Stockholm, Gothenburg, Malmö or Umeå), service affiliation (PDHS or PP), and length of professional experience (years). The informants were 8 men and 6 women, aged 27 – 64 years (mean age 46 years), three from Stockholm, Gothenburg and Malmö and five from Umeå, 9 working within the PDHS and 5 within a PP, with professional experience ranging from 2 – 40 years (mean 20 years).

Through personal contacts, the informants were successively recruited and interviewed until saturation had been achieved. In total, 35 GDPs were contacted either by telephone or e-mail, whereby they received information about the study and were invited to participate. The reasons for non-participation among the 35 GDPs who were contacted are presented in Table 3. Two of the participants each recruited a colleague to participate in the study. Finally, in all 15 GDPs were interviewed. One interview was excluded because the informant described cases dealing with restorative aspects other than those covered by the aim of the study, thus interviews from 14 informants were included in the analysis.

Table 3. Reasons for non-participation of the GDPs invited to the study.

35 GDPs invited by telephone or e-mail		
Did not answer n=11	Declined to participate n=5	Excluded n=6
11 unknown reason	1 unknown reason	2 did not fulfill the inclusion criteria
	1 living abroad	1 was not reachable
	2 lack of time	1 responded late to the invitation
	1 did not fulfill the inclusion criteria	1 had to cancel
		1 did not provide variation (same dental school and length of work experience as another informant)

Prior to the interviews the following information was given to the informants:

- the focus of the interview would be the informants' personal experience of the four latest occasions on which they decided on the type of restoration for a root-filled tooth; the 2 latest occasions when composite and laboratory-fabricated crowns respectively, were selected
- the cases were to include teeth root-filled by the GDPs themselves and which had not previously been restored with a laboratory fabricated crown
- anonymized records, radiographs and plaster study models could be brought to the interview, if the informant considered it might facilitate narration.

Data collection

Pilot study and test interviews

A pilot study, including 3 interviews, was conducted by two dental students. These interviews were not included in the analysis of the present study. The pilot study disclosed a tendency by the informants to describe their decision-making process in more general terms, rather than recounting, in their authentic cases, the reasoning they actually used in order to arrive at a decision on restoration by a composite filling or a crown respectively. Based on the pilot study, a decision was made to provide the informants with more comprehensive information before

the interviews – to focus on personal experience of their cases rather than their general opinions about coronal restoration.

Before study start, VD conducted two test interviews, with transcriptions. Feed-back on the interview technique was provided by EW. The test interviews were not included in the analysis.

Interviews

In-depth, semi-structured interviews were conducted, focusing on the informants' personal experience of deciding on the type of permanent restoration of a root-filled tooth. The interviewer invited the informants to express themselves freely on the topic by asking them to describe:

- the latest two occasions on which the informant's choice for permanent restoration of a tooth after root-filling was a direct composite restoration
- the latest two occasions on which the informant's choice for permanent restoration of a tooth after root-filling was a laboratory-fabricated crown.

During the narration the interviewer asked questions intended to encourage the informant to develop, specify, deepen and reflect on the narration: *can you tell me more about....?*, *can you develop what you mean by....?*, *you said a large amount of residual tooth structure, what does large amount mean to you?*.

In cases where the informants tended to talk in more general terms about restoration of root-filled teeth, questions were asked in order to redirect the focus to the specific cases. Before ending the interviews, the informants were asked if they wanted to add anything not mentioned earlier.

The interviews were conducted from October 2017 – October 2018, at the GDP's clinic (n=14). The interviews were digitally recorded, the duration ranging from 15 – 40 minutes.

The text preparation process

Fourteen interviews were transcribed verbatim by a contracted secretary, and then checked and complemented for non-verbal expressions by VD. The transcripts were then read several times to get an overall impression of the material. Thereafter, each interview was separated into meaning

units. When a change of meaning occurred in the informant's narrative, a mark was made in the text. By removing the excess words, each text unit was condensed into a shorter formulation which still preserved the meaning (Table 4). The text preparation process for the first interview was undertaken by VD and EW together and the remainder by VD.

Data analysis

Meaning units, relating to the decision-making process applied in the informants' own authentic cases to arrive at a decision on permanent restoration of a root-filled tooth, were identified and selected for analysis as follows:

1. through abstraction, the condensed meaning units were each given a code, reflecting the possible inherent meaning of the content
2. after completion of the coding process, the emergent patterns (codes sharing a commonality), were grouped into categories and sub-categories illustrating the manifest level of content (the visible, obvious components)
3. a theme was identified, illustrating the latent level of content (interpretation of the underlying meaning).

The first part of one interview was coded together by VD and EW. The remainder of the first interview and a further two interviews were then coded separately by VD, EW and HF. The codes were compared and discussed until consensus was reached and the remaining interviews were then coded by VD. Together, VD, EW and HF identified sub-categories, categories and theme, reaching consensus by discussion. Examples of the text preparation process and analysis are presented in Table 4.

Statistical analysis (I – III)

The statistical calculations were conducted using the Statistical Package for the Social Sciences (SPSS 22 for Windows; SPSS Inc, Chicago, IL). The analyses were conducted separately for non root-filled (I) and root-filled teeth (II) from the same sample. Differences were considered to be significant at a 5% level (I, II) and 0.1% level (III).

Chi-square test was used to detect any significant differences in:

- periapical status in relation to the type (filling and/or crown), material and quality of the coronal restorations, caries (I, II) and quality of the root-filling (II)
- frequency of further clinical interventions in relation to the type of coronal restoration within 6 months of root-filling (III).

Descriptive statistics were used to describe the frequencies of initial nonsurgical retreatment, initial root-end surgery, extraction and further restorative procedures for all teeth registered as root-filled in 2009 with an indirect, direct or unknown coronal restoration (III).

Kappa statistics were used to assess interobserver agreement for periapical status, marginal bone loss and root-filling quality (I, II).

Logistic regression analysis was used to describe AP according to the following explanatory variables:

- type (filling or crown) and material of the coronal restoration, caries and marginal bone loss (I, II)
- the quality of the coronal restoration (I, II) and the root-filling (II)
- the type of post (II).

Ethics (I-IV)

The Regional Ethics Review Board at Lund University approved Studies I-II (Dnr 2006/513), Study III (Dnr 2011/800) and Study IV (Dnr 2016/547). In Studies I, II and IV the subjects received verbal and written information about the study and they provided written consent. For the registry-based Study (III), informed consent was not considered necessary because the data retrieved from the Swedish Social Insurance Agency were anonymized. This was approved by the Ethical Review Board.

Table 4. The text preparation process. Examples of meaning units with its corresponding condensed meaning unit, code, sub-category and category.

Ex	Meaning unit	Condensed meaning unit	Code	Sub-category	Category
1	No, but I really think there was so much tooth substance missing so to do a composite filling on that tooth would not have been an alternative. I just don't even think it would have been an alternative really, on that tooth. V: How much tooth substance <i>had</i> been lost, when you say a lot? Yes, well there was in any case ... I mean, it... It was in fact ..., first there were big, on the mesial such enormous fillings there. So there was very little. And then he got ..., and then one was supposed to ... And then he got toothache in that tooth as well. So then there was in fact like nothing ..., nothing ... So then I had to take away all of the palatal. And then there was like no tooth substance left.	I really think there was so much tooth substance missing, a composite filling would not have been an alternative. There were enormous mesial fillings. Then he got toothache in that tooth, I had to take away all the palatal. There was no tooth substance left.	Obvious decision in favor of a crown because of the amount of tooth substance lost	Dental status	Clinical factors
2	And then I considered his bite a little too, because his 2 nd and 3 rd molar are missing, so that it ... it will be under heavy loading. ... So just from the point of view of longevity so then we thought that the only reasonable thing was ... to put a crown on it. And ... the patient thought so too. Yes. And this is in fact ... Erm ... I try the whole time to talk about the prognosis and that when one in any case when one is going to do endodontic treatment on an important tooth then one should in fact try to make it last as long as possible So ... Yes.	I considered his bite, his 2 nd and 3 rd molar are missing, it will be under heavy loading. Of longevity we thought a crown was the only reasonable thing, the patient too. I try to talk about prognosis when one is to do endodontic treatment on an important tooth, one should try to make it last as long as possible.	Longevity assessment and communication, basis for decision	Longevity assessment	

Ex	Meaning unit	Condensed meaning unit	Code	Sub-category	Category
3	Moreover she doesn't <i>really</i> like going to the dentist. She thinks it's a bit unpleasant. So that I ... I thought she did really well to tolerate two root fillings, considering. She didn't think so at first when she started coming here. But it's good that ... She thought it went really well.	Moreover she doesn't like going to the dentist. I thought she did well, tolerate two root fillings. She didn't think so at first, she thought it went really well.	Dental fear obviously supports choice of composite	Patient-related factors	Contextual factors
4	Otherwise I could easily have maybe just done a new filling there too. That wasn't such a bad idea there. But my frame of mind that day was ... * Laugh * My choice that day was ..., a crown. He had in fact ..., he had very little ... He had remaining teeth then. He had only a 34 there and then nothing behind that. But in his upper jaw he had a longer ... He had more teeth on the left ..., on the left side of ..., of his upper jaw. So that... .. But he thought that it functioned so that... on the right side ... in fact I don't remember what his bite was like on the right side ... But it was an ordinary normal bite. There was nothing complicated or so about the bite.	Otherwise I could have just done a new filling. But my frame of mind that day...my choice was a crown. He had remaining teeth, only a 34 there, had more teeth on the left side of his upper jaw. He thought it functioned, I don't remember his bite on the right side. Ordinary normal bite, nothing complicated.	Dentist's frame of mind influences decision	Dentist-related factors	
5	However, if she breaks off a cusp, then I can do a crown later. But at present it feels as if it ... And here it's also not ... Erm..., nor is it reimbursable from Försäkringskassan when there are only three ... surfaces. So that can also have some little influence. But as I said I didn't think I felt like doing the preparation on it.	If a cusp breaks off, then I can do a crown. Nor is it reimbursable from FK*, there are only three surfaces. That can have some influence. I didn't think I felt like doing the preparation.	Choice of composite supported by FK's regulations	External circumstances	

*FK: Försäkringskassan (Swedish Social Insurance Agency)

Ex	Meaning unit	Condensed meaning unit	Code	Sub-category	Category
6	<p>And ... And we discussed either that one ... Because he himself was a bit inclined to extract the tooth. Erm ... Because it was in fact rather knocked about, and it was there on its own, he thought.</p> <p>And then ... in fact I recommended that we should root-fill it and put ..., put a crown on it. Just so that he could keep some support on that side. Yes he was in full agreement with that. Mm. When I explained my reasoning what I thought and so on.</p>	<p>We discussed, he was inclined to extract. It was knocked about, there on its own, he thought I recommended we root-fill and put a crown on it. To keep some support on that side. He was in full agreement. When I explained what I thought.</p>	<p>Dentist's advice (preserve molar support) led to change of patient's opinion</p>	<p>Mutual decision</p>	<p>Patient's views</p>
7	<p>... .. Otherwise then... of course in her..., her case then I would have recommended real crowns. Or rather I did that but she could not afford it.</p> <p>V: Do you remember how ..., what the patient said about that?</p> <p>... Erm..., no, it was finances that ... Yes, she knows in fact that it isn't as durable as real crowns.</p> <p>V: Mm. ... So it was composites instead.</p> <p>Yes, composite crowns then. Mm. Mm.</p>	<p>In her case I would have recommended real crowns. I did but she could not afford. She knows it isn't as durable as real crowns.</p>	<p>Financial circumstances dictate composites. Patient understands prognosis</p>	<p>Compromise decision</p>	

RESULTS

Periapical status of teeth restored with composite, amalgam or laboratory-fabricated crowns (I, II)

Individual level

In the 440 subjects (49% women and 51% men), the number of teeth examined was 11 876. The mean number of remaining teeth and intact teeth per individual was 27 (3 – 32) and 14 (0 – 32), respectively. The mean number of root-filled teeth per individual was 1.5 (0 – 11).

In the study population, the overall prevalence of individuals with AP was 42.3%: the prevalence of individuals with AP in non root-filled teeth was 24.5% and of those with AP in root-filled teeth was 36.3%; 52.3% of the subjects had at least one root-filled tooth.

Tooth level

Non root-filled teeth

The number of non root-filled teeth was 11 198. Caries was detected in 326 (2.9%) teeth. In total, 4 902 teeth were restored: 4 333 with fillings and 569 with crowns. In 192 teeth (1.7%) the periapical status could not be assessed.

AP was detected in 140 (1.3%) of the non root-filled teeth. There was no difference in the frequency of AP between teeth restored with composite (1.3%) or amalgam (1.1%). The frequency was higher in teeth restored with a laboratory-fabricated crown and in those restored with both composite and amalgam (6.3% and 4.0%, respectively), compared to those restored with either material (composite or amalgam), $P < 0.001$ (Table 5). Analysis of the subgroup of teeth with

coronal restorations of adequate quality revealed the same relationships between the frequency of AP and the type/material of restoration (Table 5).

AP was detected in a significantly higher proportion of teeth with restorations of inadequate quality than in those with restorations of adequate quality (9.0% and 1.9% respectively), $P < 0.001$ (Table 5). Teeth with caries also had a significantly higher frequency of AP than those without caries (10.7% and 1% respectively), $P < 0.001$.

Logistic regression analysis disclosed no association between AP and teeth restored with either composite or amalgam. AP was significantly associated with the following variables:

- type of restoration
 - laboratory-fabricated crown (OR 5.7; confidence interval [CI], 3.27–9.93) $P < 0.001$
 - laboratory-fabricated crown in combination with a filling (OR 6.98; CI, 2.23–21.83) $P = 0.001$
 - a combination of composite and amalgam (OR 3.53; CI, 1.96–6.35) $P < 0.001$
- inadequate quality of coronal restoration (OR 3.76; CI, 1.83–7.74) $P < 0.001$
- manifest caries (OR 7.99; CI, 2.45–26.01) $P = 0.001$
- marginal bone loss $> 1/3$ of the root length (OR 3.57; CI, 2.31–5.52) $P < 0.001$.

Table 5. Type (filling and/or crown), material and quality of the restorations in relation to apical periodontitis (AP) in non root-filled (n= 4 471 *) and root-filled teeth (n= 546*)

Restoration group	Non root-filled teeth						Root-filled teeth					
	All qualities		Adequate quality		Inadequate quality		All qualities		Adequate quality		Inadequate quality	
	Total	AP, n (%)	Total	AP, n (%)	Total	AP, n (%)	Total	AP, n (%)	Total	AP, n (%)	Total	AP, n (%)
Composite (crown, filling)	1 748	22 (1.3)	1 705	22 (1.3)	43	0 (0.0)	143	44 (30.8)	128	38 (29.7)	15	6 (40.0)
Amalgam (crown, filling)	1 766	20 (1.1)	1 732	15 (0.9)	34	5 (14.7)	58	27 (46.6)	51	22 (43.1)	7	5 (71.4)
Both composite and amalgam	454	18 (4.0)	439	16 (3.6)	15	2 (13.3)	34	12 (35.3)	32	10 (31.3)	2	2 (100.0)
Laboratory-fabricated crown	474	30 (6.3)	459	28 (6.1)	15	2 (13.3)	281	72 (25.6)	275	72 (26.2)	6	0 (0.0)
Laboratory-fabricated crown repaired with filling	29	3 (10.3)	25	2 (8.0)	4	1 (25.0)	30	12 (40.0)	26	9 (34.6)	4	3 (75.0)
All restorations (5 groups)	4 471	93 (2.1)	4 360	83 (1.9)	111	10 (9.0)	546	167 (30.6)	512	151 (29.5)	34	16 (47.1)

* Teeth with other restorations, caries and periapical status not assessable were excluded.

Root-filled teeth

The number of endodontically treated teeth was 678. Twelve pulpotomized teeth and 6 with retrograde fillings were excluded, leaving 660 root-filled teeth for analysis.

Caries was detected in 7.7% of the root-filled teeth, and was more common in root-filled than in non root-filled teeth (2.9%), $P < 0.001$. Of the root-filled teeth, 231 (35%) were restored with a filling, 413 (62.6%) had a crown restoration and 16 teeth (2.4%) had no coronal restoration.

The technical quality of the root-filling was adequate in 35% of the teeth and inadequate in 65%.

Due to the quality of the radiograph or overlapping anatomic structures, periapical status could not be assessed in 40 root-filled teeth. In another two teeth, the quality of the root-filling could not be assessed.

Of the 620 root-filled teeth with assessable periapical status, 546 teeth without caries belonged to one of the five restoration groups of interest for this study (Table 5). AP was detected in 167 (30.6%) of these teeth. There was no significant difference in the frequency of AP between teeth restored with composite and those restored with a laboratory-fabricated crown (30.8% and 25.6% respectively). The frequency of AP was significantly higher in teeth with amalgam (46.6%) than in those restored with composite (30.8%), $P < 0.05$, and those with a laboratory-fabricated crown (25.6%), $P < 0.01$. In the subgroup of teeth with coronal restorations of adequate quality, there were no statistically significant differences in the frequency of AP among the 5 restoration groups (Table 5). A significantly higher frequency of AP was detected in teeth with restorations (crown or filling) of inadequate quality than in those with restorations of adequate quality (47.1% and 29.5% respectively), $P < 0.05$.

AP was more frequent in teeth with inadequate root-filling quality 171/400 than in those with adequate quality 32/218 (42.8% and 14.7% respectively), $P < 0.001$. The lowest frequency of AP was found in teeth in which both the coronal restoration and the root-filling were of adequate quality (12.9%). A significantly higher frequency of AP was found in teeth with a root-filling of inadequate quality (39.2%), $P < 0.001$, or with both the root-filling and coronal restoration of inadequate quality (60.0%), $P < 0.001$. Root-filled teeth with caries had also a significantly higher frequency of AP than those without caries (45.8% and 31.6% respectively), $P < 0.05$.

Logistic regression analysis disclosed no association between AP and the type of coronal restoration. However, AP was significantly associated with the following variables:

- inadequate root-filling quality (OR 4.02; CI, 2.54–6.36) $P < 0.001$
- marginal bone loss $> 1/3$ of the root length (OR 2.00; CI, 1.24–3.24) $P = 0.005$.

Further clinical interventions in root-filled teeth with direct and indirect restorations (III)

In the 217 047 individuals, a total of 248 299 teeth were registered as root filled in Sweden during 2009. The mean number of root-fillings was 1.14 (1 – 15). Most subjects had one tooth root-filled (88.9%) during 2009, whereas 8.9% had two and 2.2% had three or more (52). Within 6 months of completion of the root-filling, the teeth were registered to be restored as follows:

- direct restoration: $n = 143\,295$ (57.7%)
- indirect restoration: $n = 55\,974$ (22.5%)
 - of which 74.7% were registered with a post and core, fabricated either directly or indirectly
- restoration unknown: $n = 49\,030$ (19.7%).

Further clinical interventions on root-filled teeth

Nonsurgical retreatment, root-end surgery and extraction

In total, 29 943 (12%) of all teeth reported as root-filled during 2009 were registered as undergoing one or more further clinical interventions (nonsurgical retreatment, root-end surgery or extraction) during the 5-year follow-up period (Fig 2).

Nonsurgical retreatment was registered in 5 546 (2.2%) of the teeth and was more frequent in directly restored than indirectly restored teeth (2.4% and 1.2% respectively).

Root-end surgery was registered in 2 433 (1.0%) of the root filled teeth and was less frequent in directly restored than indirectly restored teeth (0.8% and 1.1%, respectively).

Extraction was registered for 22 939 (9.2%) teeth. The proportion of directly restored teeth subsequently extracted was higher than indirectly restored teeth (9.5% and 5.0% respectively).

Further clinical interventions were most common in teeth for which the type of coronal restoration was unknown (nonsurgical retreatment 2.8%; root-end surgery: 1.3%; extraction 13.2%). All the intergroup differences (direct, indirect, and unknown coronal restoration) were statistically significant ($P < 0.001$), with respect to nonsurgical retreatment, root-end surgery and extraction.

Figure 2. Further clinical interventions (nonsurgical retreatment, root-end surgery and extraction) in teeth registered as root-filled and restored in Sweden during 2009

* Teeth were excluded (n= 31) when data on further intervention reported to the Swedish Social Insurance Agency were inadequate (tooth number was not specified, a specific treatment was registered more than once on the same tooth and day, or extraction registered more than once), leaving 248 268 root-filled teeth in the analysis.

** 952 teeth had more than one further intervention.

Restorative treatment

In the group of directly restored root-filled teeth, 43 363 (30.3%) were reported as having at least one further direct restoration (ranging from 1 – 17) and 11 919 (8.3%) were reported as indirectly restored during the 5-year follow-up period.

In the group of indirectly restored root-filled teeth, the number undergoing further direct restorations was 3 594 (6.4%), ranging from 1 – 6 per tooth, and the number of indirect restorations was 2 175 (3.9%). The difference in frequency of further restorations, between teeth registered as restored by direct or indirect restoration within 6 months of the root-filling, was statistically significant ($P < 0.001$).

The dentists’ decision-making process about coronal restoration of the root-filled tooth (IV)

A theme covering the latent content was identified: *Clinical factors considered important but overruled by context and patient opinions, if in conflict.* The decision-making process of the GDPs was in each case characterized by an assessment of clinical factors for which, in certain cases, contextual factors were weighted and occasionally modified the choice. However the patient’s views were decisive for the choice of coronal restoration (Fig. 3).

Figure 3. The dentist’s decision-making process was based on clinical factors (blue arrows). In certain cases contextual factors were also weighted and occasionally modified the choice (green arrow), but the patient’s view was decisive in either approving (arrows unchanged) or modifying (purple arrow) the dentist’s decision

Three main categories, including 7 sub-categories covering the manifest content were found (Table 6).

Table 6. The theme, the categories and the sub-categories

Theme	Clinical factors considered important but overruled by context and patient opinions, if in conflict		
Category	Clinical factors	Contextual factors	Patient's views
Sub-category	Dental status Assessment of longevity	Patient-related Dentist-related External circumstances	Mutual decision Compromise

Categories

Clinical factors

In each case, clinical factors constituted the basis for the GDPs' decision about coronal restoration: dental status in general and the predicted longevity of the restoration were taken into account. Sometimes one clinical factor was decisive, whereas in other cases several factors, in combination, contributed to the decision. The amount of residual tooth structure was mentioned by all informants as a factor influencing the decision as to how to restore a root-filled tooth (Table 4, Ex 1). In cases where the amount of residual tooth structure was considered substantial, according to the GDP's view, a composite restoration was chosen. When a crack was detected, the decision was often directed towards a crown:

"When I see that there's a crack. Then..., then I say: either take it out or ream out the root canal and root fill it and then put a crown on it. Because I ... Then I don't think there's any point in doing a root canal treatment and then just a filling because then I think that it will break down in the near future in any case."

Some informants expressed prognostic aspects to be of importance. Situations were described where the prognosis was assessed as poor, due

to active caries, persistent symptoms and marginal bone loss, directing the decision towards a composite filling. Furthermore, such factors as a root-filling of inadequate quality and an uncertain prognosis for endodontic retreatment also contributed to the choice of composite. On the other hand, a root-filling of adequate quality supported the choice of a crown restoration. In all cases where the root canal treatment had been performed by a colleague, the quality of the root-filling was commented on, but there was little mention of the informant's own root-fillings.

Several other aspects relating to dental status were also taken into account. The status of the surrounding dentition was mentioned, situations where the root-filled tooth was restored with a crown restoration, as part of a fixed partial denture, the clinical status of neighboring teeth and esthetic aspects:

"And then to do prosthetic therapy on one front tooth when there are two front teeth ... Then the esthetics comes into it. [...] in this case I chose ..., ... or I am going to choose a filling."

Tooth type (molars) directed the decision towards a crown, whereas in cases with high caries activity, composite was selected. The estimated longevity of the intended restoration was another clinical factor mentioned as important: when considering a composite restoration, the decision was preceded by an assessment of the predicted survival:

"It's good if you do a filling, isn't it. [...] Yes, I didn't consider that it would break up here, or has. It should hold up, I think."

When composite was not expected to last, the dentist would suggest a crown (Table 4, Ex 2).

Contextual factors

In certain cases, the decision was influenced by contextual factors, which could either support the GDPs' proposal for restoration, resulting in a decision, or could modify the proposal, in which case, although the indications were for a crown, the GDP would decide in favor of composite.

Dental fear was a patient-related factor described as having an impact, directing the decision towards a composite filling (Table 4, Ex 3). Along

with clinical factors, patients' desires, needs and motivation were important. When a crown restoration was indicated on the basis of clinical factors, the decision could be supported by consideration of such factors as a highly motivated patient with an interest in his/her oral health. In contrast, low motivation in patients would support the choice of composite. In some cases the GDP's awareness of the particular patient's financial circumstances was decisive:

"An upper first molar [...] Yes, there was not much ..., very much left of that tooth, but I still decided to do a filling, because his economy is not all that good."

The age of the patient was described as important. In a relatively young patient a decision in support of crown therapy was based on awareness that the tooth would likely be in function for a long time. The dentist-patient relationship also influenced the decision, as exemplified by a situation in which the informant perceived the patient as suspicious, blaming her former dentist for causing her pain. This directed the informant's decision towards a composite filling, in order not to undertake "too much" treatment.

Even though the decision about coronal restoration was always based primarily on clinical factors, the decision process was also influenced by factors related to the dentist, such as opinions and preferences. The informants expressed a desire to preserve sound tooth structure: removal of healthy tooth structure for a crown restoration was regarded as overtreatment:

"And that is in fact very obvious, I think, how much tooth structure remains then. Then of course you don't do a crown preparation and grind away tooth structure and fiddle about when it's not necessary."

Other opinions expressed by some informants were a preference for crown restorations:

"And I recommended a crown [...] there is evidence to show that you should put a crown on a tooth that is root-filled."

The informant's current frame of mind was also mentioned as decisive for a situation (Table 4, Ex 4).

External circumstances were of importance for certain cases. Although clinical factors constituted the basis for the decision, the particular payment model and accompanying rules were often mentioned in conjunction with the informants' decision. The SSIA's regulations, although not decisive, were often kept in mind as a guideline for the choice of restoration. When a composite was chosen, the GDPs often mentioned that SSIA's rules did not support a crown restoration (Table 4, Ex 5), but when a decision was made in favor of a crown, they commented that SSIA's criteria had been met when a decision to make a crown was made. Some informants commented that their decision in favor of a crown was facilitated when the level had been reached for the high-cost protection to apply:

” [...] qualifies for high-cost protection. [...] So then it won't be so big, to pay the cost of a full crown. Instead it ..., I also think it... has..., ... has influenced... the decision to in fact give this tooth the very best.”

In situations where patients' costs were covered by other regulations than the SSIA, these were often decisive for the choice of coronal restoration, regardless of the amount of remaining tooth structure:

”Yes, it can be filled and so on but a lot was for financial reasons. [...] she gets support from Social Services. Mm. And then ..., so then it's a matter of doing just the least possible ... treatment. And then it will be a root canal treatment and a filling. Mm. No crowns or such.”

Lack of time available for performing the preferred treatment, a crown restoration, was another external circumstance decisive for the choice of composite.

Patient's views

The GDP's decision, the fee for the suggested and possible treatment options were presented to the patient. The motive for choosing a certain restoration including prognostic information was also given, when considered necessary. The dentist's recommendation was often decisive for the patients' decision; there was often not much of a discussion as

the patient accepted and agreed readily, without any objections; accordingly a mutual decision was achieved. Trust and a good dentist-patient relationship were expressed as contributing factors for a mutual decision. If the GDP found the patient's wishes unacceptable, the dentist initiated an extended discussion, including a thorough explanation. This often resulted in the patients changing their opinions (Table 4, Ex 6) and so a mutual decision was achieved. Some informants mentioned that patients covered by the payment model Dental Care for Health readily agreed to the dentist's suggestion of restorative treatment, because financial aspects did not need to be considered:

"And the patient was quite in agreement with that, because he was moreover insured under Dental Care for Health. [...] So this crown, post and all, was covered by Dental Care for Health."

Occasionally, apart from a fixed partial denture (crown restoration), an implant and removable partial denture were also possible treatment options for replacement of a missing tooth, whereas for some teeth composite and crowns were both suitable options. These were presented to the patient, who then decided on a treatment, whereby a mutual decision was achieved.

However, the patient's views were decisive: when the patient did not agree with the GDP's treatment recommendation, the dentist took the patient's views into account and modified the decision accordingly – provided that the GDP found it acceptable. Such a situation arose when a crown was considered the best treatment option, but composite was chosen instead. Economic factors (Table 4, Ex 7) and patient's opinions were described as reasons.

However, the informants did not accept a compromise decision without reflection. When agreeing to composite instead of a crown restoration, this was preceded by assessment to predict the longevity of composite in the particular case: that a composite restoration was expected to be durable, at least in the short-term.

DISCUSSION

Main findings

The main findings of Studies I and II were that no association between AP and direct composite restorations was disclosed. Furthermore, Study I revealed the same low frequency of AP in non-root-filled teeth directly restored with different materials (composite or amalgam). The frequency of AP in teeth with indirect restorations was higher. In Study II, no significant difference in frequency of AP was found in root-filled teeth restored with direct or indirect restorations, provided that the quality of the coronal restoration was adequate. Moreover, in Study III, only minor differences were associated with direct versus indirect restoration in terms of frequency of further endodontic treatment.

However, the main finding in Study III was that during the 5-year follow-up period, all further clinical interventions taken together, (extraction, nonsurgical retreatment and further restorative treatment), were significantly more frequent in directly than in indirectly restored teeth.

The main finding of Study IV was that the dentist's decision-making process underlying the choice of coronal restoration for a root-filled tooth was based not only on clinical factors: contextual factors and the patient's view, if in conflict, were decisive. Consequently, a direct restoration was occasionally selected despite the indications for an indirect restoration. Thus the context in which the dentist makes decisions may be a factor influencing the fate of the root-filled tooth.

Methodological considerations

Studies based on quantitative data (I – III)

Aspects of validity and reliability

Studies I – III aimed to investigate the type of coronal restoration in relation to periapical health and the natural course of root-filled teeth, especially with reference to further clinical interventions after root canal treatment and restoration. Studies I and II were cross-sectional studies, based on data from a previous investigation of oral health in the adult population of Skåne (105) and Study III was a registry-based cohort study.

A strength of Study III, using the SSIA's data base of dental treatments, was that data were available for the entire adult population of Sweden; thus, a large number of root-filled teeth could be included. However, a limitation was the lack of patient records and radiographs. Thus the clinical status of the root-filled teeth, such as preoperative status of the pulp and periapical tissues, periodontal status, residual tooth structure and quality of restorations and of root-fillings was unknown.

The type of coronal restorations was recorded in Studies I – III. In Study I and II the type and material were recorded from both clinical and radiographic examination. This was considered a strength, providing a comprehensive basis for evaluation of the type and quality of the coronal restorations. Evaluation of restoration quality from radiographs alone may underestimate the frequency of inadequate restorations (50). In Study III, the type of restoration, was classified according to the treatment codes registered, which may involve some uncertainties. Although the codes 701 – 707 most likely represent a direct composite restoration, it is possible that some teeth were restored with other materials. The treatment codes 801, 805 – 809 represent indirect restoration, but it is not possible to differentiate inlays, onlays or full-crown restorations. Although code 701 corresponds to a direct one-surface restoration, the amount of residual tooth structure was unknown, thus the tooth may have been previously restored. As the amount of residual tooth structure is a factor associated with both survival of the restoration (108) and of the root-filled tooth (109), it would have been valuable to take into account this information, and the extent of the restoration, in the analyses. In Study III, the root-filled teeth were

classified as directly or indirectly restored, based on the treatment code registered within 6 months of completion of the root-filling. The time limit chosen is likely to influence the results. If a shorter time span had been used, fewer teeth might have been classified as indirectly restored (110). However, the same time limit has been applied in a similar study (69). Six months was also considered a reasonable length of time for the root-filled teeth to have been permanently restored, as permanent restoration should preferably be undertaken as soon as possible after root-filling (111, 112).

In Studies I – II, radiographs were used for the evaluation of periapical health and in Study III, further endodontic treatments (nonsurgical retreatment and root-end surgery) registered during the 5-year follow-up period was considered to indicate periapical disease, most likely with symptoms. However, the true periapical status of the root-filled teeth was unknown. Although radiography is more valid for the evaluation of the periapical conditions, the use of panoramic radiography in Studies I and II may not be optimal; thus the frequency of AP may have been underestimated (113-116). Nor is panoramic radiography optimal for the evaluation of root-filling quality, thus there is a risk that in Study II the frequency of inadequate root-fillings may have been underestimated. Despite these reservations, however, the results of Study II, with respect to quality of root-filling and periapical status, are in accordance with previous studies using periapical radiographs (117, 118). Studies I and II were preceded by a comprehensive investigation of oral health in Skåne (105), in which panoramic radiography and bitewings were the radiographic methods applied. Given the good oral status of many of the subjects, full-mouth radiographic examination would have been unethical because of the higher radiation doses compared with panoramic radiography (119). An alternative approach applied in some studies, but not in the present study (120, 121), is to supplement panoramic radiography with periapical radiographs.

In Study III, the data in the SSIA's register are based on the treatment codes reported by the dentists, after completion of an intervention. This is a prerequisite for reimbursement of dentists from the SSIA. However, the possibility cannot be excluded that for various reasons some interventions were not reported. To date, there is no estimation of how well interventions are reported by the dentists to the SSIA (122).

However, The National Board of Health and Welfare has conducted a validation of the reporting of the number of remaining and intact teeth: 92% and 88% respectively corresponded with the information in the records (122). Furthermore, it is possible that extractions and further restorative treatment were undertaken abroad, and therefore not noted in the SSIA's register.

The results of Studies I – III can be considered as representative of general dentistry in Sweden. An advantage of a cross-sectional study is the high external validity (123): the root-fillings and coronal restorations in Studies I and II are considered to be the work of GDPs, because there are few endodontists in Sweden (124). The treatment outcomes in terms of further clinical interventions in Study III, are likewise representative of general dentistry in Sweden.

In Studies I and II, AP was registered when a radiolucency was detected around the root apex, exceeding at least twice the width of the periodontal ligament space in other parts of the root (125). Although the periapical index (PAI) (126) has been widely used for evaluation of periapical status, it was not considered appropriate for Studies I and II, PAI is based on periapical radiographs of maxillary incisors (126, 127) in which the appearance of anatomic and bone structure is different from panoramic radiography.

Three observers each assessed one third of the material, to compensate for individual observer characteristics in the assessment of AP (128). After a calibration process, a high percentage of agreement was achieved for the three observers with respect to registrations of periapical status (95.7%) and root-filling quality (98.0%). The corresponding Cohen kappa value was moderate (129): 0.56 and 0.5, respectively. The discrepancy between the high percentual agreement and the moderate Cohen kappa value for periapical status may be attributable to the high frequency of teeth with normal periapical conditions on which the observers agreed.

Study based on qualitative data (IV)

Aspects of credibility

The aim of Study IV was to describe the decision-making of Swedish GDPs underlying the choice of coronal restoration for a root-filled tooth. This question is largely unexplored. Interviews were conducted with

GDPs who had recent experience of choosing the type of coronal restoration for a root-filled tooth. In order to ensure a variety of perspectives, the GDPs were purposively selected, using the maximum variation sampling strategy (92).

Based on the pilot study, the context in which the GDPs' decisions were made was reinforced during the interviews and this was considered to strengthen credibility. Prior to the interviews the GDPs were more thoroughly informed about the aim of the study, and the interviewer was better prepared to guide the narration to focus on the GDPs' own cases rather than their general opinions about coronal restoration.

Despite the information given prior to the interview, the informants' cases may possibly not have been the most recent ones. Some GDPs mentioned that they had included a case because it was interesting but it is not known whether it was the most recent case. Although a few cases had been root-filled by a colleague, they were included in the analysis, because it was the informants who made the decision about the type of permanent restoration of the tooth.

The use of semi-structured interviews, comprising mainly open questions, invited the informants to express themselves freely on the topic, using their own authentic cases as a basis for the narration. This was considered to strengthen credibility, as it was possible to study the GDP's decisions in context.

The informants' narration may be influenced by the conditions under which the interview is conducted (130). Having a relaxed informant is considered to improve the chances of obtaining more valuable data during an interview (131). The informants themselves chose the location for the interview, so that the interviews could be conducted in an environment that was comfortable for them. However, during interviews there is always some power play (132). This may influence the narration and it may also shift between the interviewer and the informant (133). In Study IV, the interviewer, a specialist in endodontics working at a faculty of odontology, might have been regarded by some informants as an 'authority' who might test their knowledge. Thus, some informants may possibly have modified their narration to please the interviewer. To minimize that risk, prior to the interviews, all informants were informed about the lack of knowledge on the topic and it was emphasized that their personal experience would contribute valuable information.

The number of informants required in a study using a qualitative approach depends on the quality of the data obtained and the complexity of the area of interest (101). In Study IV, data from 14 informants was considered sufficient to address the research question – saturation had been achieved. To increase credibility, examples of the text preparation process were illustrated in Table 4 and quotations from the interviews were presented in the Results section, to demonstrate the identified patterns.

Dependability

The research process was considered to be reasonably consistent with respect to data collection and the analysis process. During the collection of data, all informants were requested to describe the same topics. Depending on how the interview developed, different follow-up questions were asked. However, it is possible that after some interviews, the interviewer was more attentive to asking follow-up questions about specific factors.

The coding for 3 interviews was done separately by the authors and then discussed. Although some codes were not labelled in exactly the same way, the same meaning was expressed in different words. Following the good agreement among the authors, the remaining interviews were coded by the first author.

Transferability

As the selected informants reflected a diversity of GDPs working in Sweden, with respect to gender, age, length of professional experience, service affiliation and dental school attended for undergraduate education, the results may be considered valid for Swedish GDPs. To facilitate the readers' assessment of transferability, the characteristics of the informants have been described ("In-depth interviews", page 39).

Conformability

The authors' preconceptions about the GDPs' decision-making process about the choice of coronal restoration for a root-filled tooth were accounted for in the Material & methods section. To increase conformability, the preconceptions of the authors were bracketed during the data collection and the analysis. No questions were asked about specific factors that might influence the decision, unless mentioned by

the informants themselves. Semi-structured interviews with mainly open questions were used, allowing the interviewer to ask follow-up questions in order to obtain a more detailed and clarified response (131). Accordingly, the GDPs were allowed to narrate from their perspective, disclosing the factors which were decisive when selecting the appropriate coronal restoration, while the interviewer's influence was kept to a minimum.

The results were largely in accordance with the authors' preconceptions. In addition, some factors were more crucial to the decision than others.

Results

Periapical health of teeth with direct versus indirect restoration

Concerns have been expressed that composite material (5-9) may imply a risk for periapical health. Composite is the predominant material for direct restoration and its use continues to increase as amalgam is phased out (134). It was considered important to explore any possible negative impact on periapical health of teeth restored with composite, compared to other types of restorations and materials. The main findings of Studies I and II were that teeth with direct composite restorations were not associated with an increased risk of periapical disease. However, Study III disclosed that over the 5-year follow-up period, the frequency of endodontic retreatment (nonsurgical retreatment and root-end surgery) was significantly higher for root-filled teeth with direct composite restorations than for those with indirect restorations (3.2% and 2.2% respectively). Although the small difference was statistically significant, because of the large number of teeth included (135), it was not considered to be clinically relevant. Nor can it be excluded that the results of Study III may be attributable, at least in part, to selection bias. Study IV indicated that in cases of unfavorable prognosis of the endodontic treatment, the dentists recommended direct composite restoration, which is in accordance with the findings of previous studies (46, 110). In case of AP, extraction is also a possible treatment option. Although in Study III the reasons for extraction were unknown, previous studies report that root-filled teeth were extracted mainly on indications

other than endodontic failure, such as being unrestorable due to caries and fractures, and also due to periodontal disease (47, 64, 65).

The findings of Studies I – III about the influence of the type of restoration on periapical status are in accordance with some studies (16, 18), but in contrast to others (22, 23, 49, 50). The discrepancy may be attributable to the different methods applied and the sample studied (49).

In Study I a significant difference in periapical health was disclosed between non-root-filled teeth restored with direct and indirect restorations. The same low frequencies of AP were found in teeth restored with composite (1.3%) and amalgam (1.1%), but the frequencies were significantly higher in teeth with indirect restorations (6.3%) and those restored with both composite and amalgam (4.0%). These results are in agreement with a previous study (30) and may be explained by pulpal damage, due to earlier caries and/or fractures, in combination with the invasiveness of the crown preparation procedure (26-29). Moreover, one study reported that compared to teeth restored with composite or amalgam, those with extensive restorations (five-surface and crowns) required further intervention sooner, due to pulpal pathology (136).

In contrast, in Study II no significant difference in periapical health was disclosed between root-filled teeth with direct or indirect restorations, provided that the quality of the restorations was adequate. Although a significantly higher frequency of further endodontic treatment was found for directly restored teeth in Study III, the difference was not considered to be clinically relevant – the frequency was low and very similar to those with indirect restorations.

The importance of an adequate coronal restoration for periapical health was also found in Studies I and II and is in accordance with previous studies (30, 32, 48, 137). Moreover, adequate quality of the root-filling was also associated with periapical health in root-filled teeth, Study II, while the most favorable periapical conditions were found in teeth where both the root-filling and the coronal restoration were of adequate quality. This is in accordance with the conclusion of a systematic review (137).

Thus, the concerns that composite poses a risk for periapical health and further endodontic treatment were not confirmed in Studies I – III: composite appeared safe for direct restoration, provided the clinical conditions were suitable, ensuring an adequate seal.

In the clinical setting, dental pulp cells of vital teeth are usually not directly exposed to composite, as they are separated by a layer of dentin which acts as a protective barrier against the material and possible microbial leakage due to polymerization shrinkage (138). Although polymerization shrinkage may lead to poor marginal adaptation and recurrent caries (6), this may not always be the case. In Studies I and II, the frequency of inadequate composite restorations was low (3.0%), similar to that of amalgam (2.2%). To reduce polymerization shrinkage various filling techniques have been proposed, such as the incremental technique, and different curing methods involving the use of low-light energy have been recommended (139). However, to date no method completely eliminates it (140). In non root-filled teeth, periapical disease was more frequent in those directly restored with both composite and amalgam, and those indirectly restored, indicating that the extent of the restoration rather than the type or material per se is of significance for periapical status. In root-filled teeth, the quality of the restoration and also of the root-filling, were found to be of greater importance to periapical health than the type or material of the coronal restoration. Thus both direct and indirect restorations appear able to provide the root-filled tooth with a tight marginal seal against microbial leakage.

Natural course of teeth after root canal treatment: comparison of directly and indirectly restored teeth

The main finding of Study III was the significant difference in the natural course of events after root canal treatment, in relation to the type of restoration. Over the five year follow-up period, further clinical interventions such as extraction, nonsurgical retreatment and further restorative treatment, were significantly more frequent in teeth restored with direct restorations.

The higher extraction rate of teeth restored by direct restoration (9.5%, compared to 5.0% for indirectly restored teeth) was not an unexpected finding, and is in accordance with previous studies (61, 65, 66, 70), although the reasons for extraction are unspecified. That the survival rate might be better in indirectly restored teeth was expressed by some informants in Study IV. Some regarded an indirect restoration as the ideal restorative treatment for a root-filled tooth. This was based

not only on previous studies, but also on their own clinical experience. However, the statistically significant difference of 4.5% in extraction rates, disclosed in Study III, may not be considered clinically relevant. In contrast, other studies have reported more pronounced differences between the survival rates of root-filled teeth with direct or indirect restorations. In a systematic review, the survival rate for directly restored root-filled teeth was reported to be 63%, compared with 81% for indirectly restored teeth (15). Similar results are reported in more recent studies (65, 66, 111). This might be attributable to the longer follow-up time of 10 years (15, 65, 111). On the other hand, a high survival rate for premolars restored with composite – comparable to crowns, has also been reported, in cases with considerable residual tooth structure (66).

Although nonsurgical retreatment was significantly more frequent in teeth with direct than indirect restorations (2.4% and 1.2% respectively), this minor difference was not considered to be clinically relevant. Given the higher fee for an indirect restoration, it is reasonable to assume, from the patients' perspective, that a difference of 1.2% may not be perceived as meaningful. Furthermore, the difference in the frequency of nonsurgical retreatment between direct and indirect restorations may be attributed to factors other than the type of restoration. However, the low frequencies reported for endodontic retreatments are in accordance with previous studies (54-56, 58). As there is so little information available, the results warrant further exploration.

Restorative failures were considerably more frequent in root-filled teeth restored by direct than by indirect restoration. The results are consistent with a previous study (67) but different from those of other studies (68, 69). Study IV disclosed that the choice of coronal restoration for a root-filled tooth was often preceded by an assessment of the potential longevity of the intended restoration. Although in cases with little residual tooth structure a composite restoration was expected to have limited longevity, it was evident that such teeth were occasionally restored with composite, when contextual factors and the patient's views were taken into account. This may partly explain why 30.3% of the directly restored teeth required at least one further direct restoration during the 5-year follow-up. The amount of residual tooth structure is reported to be a factor that may influence the failure rates of restorations (108).

In Study III it was disclosed that further clinical interventions were more frequent in directly restored teeth, but did not explain the reason. An indirect restoration may provide a better marginal seal and protection for the root-filled tooth. However, the possibility cannot be excluded that selection bias is accountable for the findings, at least in part. In Study IV, it was obvious that some teeth were less likely to be restored with a crown after root-filling, despite the clinical indications. There were various reasons: poor prognosis of the tooth, contextual factors and the patient's views. As found in Study III, teeth restored with composite when the indications in fact favored a crown, may be more likely to be vulnerable to restorative failures and to require extraction or nonsurgical retreatments. Although the above-mentioned results of Study III mentioned above were in favor of indirect restoration, they may not be clinically relevant with respect to nonsurgical retreatment and extractions. In addition, in the absence of clinical records and radiographs, it is not possible to make recommendations about the choice of restoration for root-filled teeth. Further randomized prospective studies are required, taking clinical and radiographic status into account, in order to determine whether an indirect restoration results in a better long-term outcome of the endodontic treatment, in terms of periapical health and tooth survival.

However, Study III provided an overview of the outcome of teeth root-filled and restored in Swedish general dentistry, with respect to further clinical interventions, implying additional costs, for both the patient and society. The finding of a recent study, based on the same sample as Study III (141) over a 5 – 6 year perspective, was that the overall mean fees were significantly lower for direct than indirect restoration after root canal treatment, despite the additional clinical interventions in teeth with direct restorations. Whether this is the case in the longer term warrants further exploration. Furthermore, the cost to society is not known.

Study III also disclosed how root-filled teeth are restored in Swedish dental practice. Within 6 months of completed root canal treatment, most teeth (57.7%) were directly restored and only 22.5% were indirectly restored. Study IV disclosed that the dentists' decision as how to restore a root-filled tooth was influenced by other than just clinical factors. The SSIA's regulations were suggested as having an indirect impact on the decision, serving as an underlying guideline for

indications for a crown. In contrast, only 35% of the root-filled teeth were restored with fillings in Study II, whereas the percentage of teeth with crown restorations was 62.6%. The data for Study II were collected in 2007 and at that time SSIA had different regulations and this may be one reason for the higher frequency of indirect restorations. It is also possible that time had passed since the root canal treatment and even though some teeth may initially have been restored with a direct restoration some teeth certainly received an indirect restoration over time, following failure of the direct restoration. After the follow-up time of 5 years (Study III), 8.3% of the directly restored teeth had undergone indirect restoration. A recent study also reported that teeth with direct restorations were indirectly restored over time: 8 – 19 years later, 53% of the directly restored teeth had been indirectly restored (47).

The dental reimbursement system in Sweden is currently under review, to be completed in March 2020.

The dentists' decision-making process in the choice of coronal restoration of root-filled teeth

Study IV accounted for the descriptive aspect of decision-making – exploring how decisions are actually made (73) about how to restore a root-filled tooth. The main finding of Study IV was that the GDPs' decision-making process is complex, involving clinical and occasionally contextual factors and the patient's views. If in conflict, contextual factors and the patient's views overruled clinical factors.

After a dialogue with the patient and a clinical examination, data comprising medical history and clinical findings were evaluated, followed by the GDP's decision as to how to restore the root-filled tooth. Several clinical factors were mentioned as influencing the decision and this is in accordance with the relevant descriptions in textbooks (36) and clinical guidelines (44). All informants mentioned the influence of the amount of residual tooth structure on the decision; when substantial the choice of composite was obvious, while a crown was preferred in cases of limited residual tooth structure. The SSIA's regulations served as underlying guideline indications for a crown. However, in cases which met the criteria for an indirect restoration, this was not always the treatment chosen. Even though the findings in Study IV suggests that the technical quality of the root-filling may influence

the decision, it was not mentioned to any great extent, a somewhat unexpected finding, as it is a factor of importance for the outcome of root canal treatment, in terms of periapical health (45). Inadequate root-filling quality may also increase the risk of extraction, although to a lesser extent (142). If root-filling quality was mentioned, in most cases it was in relation to colleagues' root-fillings rather than the GDPs' own. The reason why root-filling quality was not mentioned more frequently is unknown and needs to be further explored.

The importance of the context in which the decision about coronal restoration was made, was a significant finding. Although clinical factors always constituted the basis for GDPs' decision, they were not decisive in every case. Factors related to the patient and external circumstances, such as dental fear and payment model, are examples of contextual factors that overruled clinical factors, as well as the patient's views, causing the GDP to choose a composite restoration despite the more favorable prognosis of a crown. The GDP's current frame of mind was also mentioned as influencing the decision. That the emotional state of the provider may influence the clinical decision-making process has been reported previously (143). Furthermore, in accordance with previous studies (144, 145), some informants expressed a preference for indirect restoration of a root-filled tooth. There may be a difference between how dentists think decisions should be made and how decisions are actually made, but this has not yet been explored. The results of Study IV, disclosing other than just clinical factors to be of importance for the decision as to how to restore a root-filled tooth, is largely in accordance with a previous study (146), reporting for instance that the dentists' personal views, the patients' preferences and professional fees/time have an impact on restorative treatment decisions for non-root-filled teeth. Furthermore, the factors suggested by Kay and Nuttall (78) (see "Clinical decision-making", page 23) as influencing the decision were all mentioned in the interviews in Study IV. In addition, this study also disclosed that the impact of the specific factors, contextual factors and patient's views were decisive. As this is an almost unexplored area, few previous results are available. Dentists' decision-making processes have been investigated within other areas, but most of these studies have used predetermined cases as a basis for exploring the decision-making process, disclosing different decisions for the same cases (147, 148). In contrast, the present study was based on the GDPs' actual decisions,

revealing the different contexts in which they occurred. Apart from one previous study (149), little is known about the impact of the context on the decisions.

Although not directly explored in Study IV, it is reasonable to assume that both intuitive and analytical reasoning were used to reach a decision, depending on the perceived complexity of the individual case.

The findings of Study IV, describing the decision-making process of Swedish GDPs, may facilitate our understanding of the results in Study III regarding the frequency of further clinical interventions in teeth root-filled and restored by GDPs in Sweden. Although teeth with direct composite restorations required further clinical interventions significantly more often, Study IV revealed several situations in which, despite indications for a crown, the tooth was more likely to be restored with composite, such as: teeth with poor prognosis, poorly motivated patients with little interest in their oral health, dental fear, an extensive need for dental care and/or poor financial circumstances. Certain payment models, which did not allow crown restorations, and lack of time were also decisive for the choice of composite, despite indications for a crown. These findings are in accordance with those of a previous study (145). Accordingly, the results of Study IV indicate that in previous studies selection bias cannot be excluded (61, 65, 66, 70). Thus, the favorable results for indirect restorations may, at least in part, be explained by the dentist's decision-making process leading to the choice of coronal restoration for the root-filled tooth, but to what extent is unknown.

CONCLUSIONS

- Teeth restored with composite were not associated with periapical disease or the need for further endodontic treatment, thus concerns that composite material may be a potential risk to periapical health were not reflected in the clinical setting.
- While the type of coronal restoration was found to be indicative of periapical disease in non root-filled teeth, this was not the case for root-filled teeth:
 - non root-filled teeth, directly restored with fillings of both composite and amalgam, and those with indirect restorations, were at an increased risk of having AP, indicating that the extent of the restoration rather than the type or material is of importance for periapical disease
 - in root-filled teeth, the quality of the restoration, and of the root-filling, were of greater importance for periapical status, than the type or material of the coronal restorations.
- Teeth restored with indirect restoration after root canal treatment had a more favorable natural course during the 5-year follow-up period. Further clinical interventions, such as nonsurgical retreatment, extraction and further restorative treatment, were significantly more frequent in teeth restored by direct than indirect restoration. There is a need for further prospective studies to evaluate the effect of the type of restoration, direct versus indirect, on the endodontic treatment outcome.
- The GDPs' decision-making process leading to the choice of coronal restoration is based on clinical and occasionally contextual factors, but the patient's views are decisive. If in conflict, contextual factors and patient's views overruled clinical factors.

Accordingly, in this context the dentists' decision-making process may be a factor influencing the fate of the root-filled tooth, but the extent is unknown.

Clinical implications and suggestions for future studies

In this thesis it was found that composite was safe as a direct restorative material, in terms of periapical health and the need for further endodontic treatment, provided the marginal seal was adequate. This finding is considered significant, because composite is the predominant material used for direct restorations and in Sweden most root-filled teeth are directly restored with composite.

Extensively restored non root-filled teeth and root-filled teeth in which the restoration and the root-filling were of inadequate quality were at higher risk of AP, in accordance with a previous study (150). The results may aid dentists to identify teeth at increased risk of AP.

In Study I, the indirect restorations were mainly metal-ceramic, only a few were all-ceramic. The use of all-ceramic indirect restorations is increasing (13), and certainly today more teeth are restored with all-ceramic crowns than in 2007. As the preparation technique is reported to be less invasive than for metal-ceramic crowns (151, 152) there may be a difference in the periapical status of non root-filled teeth with different types of indirect restorations. This may be investigated in future studies.

For root-filled teeth, it was found that the type of coronal restoration was not predictive of periapical disease. Both direct and indirect restorations seemed to be able to provide a marginal seal against microbial leakage, provided that the quality was adequate. However, compared to indirectly restored teeth, those restored directly are more likely to require further clinical intervention over the following 5 years, especially for restorative failures. Before making any treatment recommendations, further prospective clinical studies are needed, preferably long-term, to estimate the impact of direct versus indirect restoration on the outcome of root canal treatment, in terms of periapical status, tooth survival and the need for further clinical interventions, to be followed by an estimation of the cost-effectiveness. Future studies might also evaluate the outcome of the root canal treatment from the patients' perspective. Although a root-filled tooth has survived, it may not

necessarily be perceived as successful by the patient, given that additional events may occur, necessitating more dental appointments and additional costs. Although a high rate of patient satisfaction has been reported for root canal treatment (153) and the potential improvement in the patients' quality of life, in cases of preoperative pain (154), it is unknown how further clinical interventions may affect the patient's perception of the endodontic treatment outcome. Fewer clinical interventions may be expected for indirectly restored teeth, but over a 5-year perspective the cost will be higher than for a direct restoration (141). It is not known whether there is any difference in patient satisfaction with respect to direct or indirect restoration after root canal treatment.

Although the findings in Study IV may not have direct clinical implications, they contribute to an understanding of the dentists' decision-making process in the choice of coronal restoration and this process may be a factor influencing the fate of the root-filled tooth.

The following hypotheses, generated during Study IV, may be tested in quantitative models:

- root-filled teeth are more likely to be restored directly rather than indirectly if the prognosis is poor, because of clinical factors such as periapical disease, inadequate quality of the root-filling, and marginal periodontitis, and patient-related factors
- the quality of the root-filling may be important for the dentists' decision in choosing the coronal restoration, but it is not a decisive factor
- although an indirect restoration is the preferred restoration in a particular situation, for various reasons composite is frequently chosen instead.

Furthermore, Study IV provided the descriptive aspect of the dentists' decision-making process underlying the choice of coronal restoration for a root-filled tooth, i.e. how the decision is actually made. It is not known whether this coincides with the normative aspect, i.e. how dentists think the decision should be made. This issue warrants further investigation through in-depth interviews.

Authors' contribution to the studies, according to International Committee of Medical Journal Editors (ICMJE) requirements for authorship

Study	Design	Acquisition of data	Analysis and interpretation of data	Drafting the article	Revising the article
(I) Periapical status of non – root-filled teeth with resin composite, amalgam, or full crown restorations: a cross-sectional study of a Swedish adult population	Victoria Dawson Kerstin Petersson Eva Wolf Sigvard Åkerman	Victoria Dawson Kerstin Petersson Eva Wolf Sigvard Åkerman	Victoria Dawson Kerstin Petersson Eva Wolf Sigvard Åkerman	Victoria Dawson	Kerstin Petersson Eva Wolf Sigvard Åkerman
(II) Periapical status of root-filled teeth restored with composite, amalgam, or full crown restorations: a cross-sectional study of a Swedish adult population	Victoria Dawson Kerstin Petersson Eva Wolf Sigvard Åkerman	Victoria Dawson Kerstin Petersson Eva Wolf Sigvard Åkerman	Victoria Dawson Kerstin Petersson Eva Wolf Sigvard Åkerman	Victoria Dawson	Kerstin Petersson Eva Wolf Sigvard Åkerman
(III) Further treatments of root-filled teeth in the Swedish adult population: a comparison of teeth restored with direct and indirect coronal restorations	Victoria Dawson Thomas Kvist Helena Fransson	Victoria Dawson Helena Fransson	Victoria Dawson Per-Erik Isberg Helena Fransson	Victoria Dawson	Per-Erik Isberg Thomas Kvist Helena Fransson
(IV) Coronal restoration of the root-filled tooth – a qualitative analysis of the dentist's decision-making process	Victoria Dawson Helena Fransson Eva Wolf	Victoria Dawson	Victoria Dawson Helena Fransson Eva Wolf	Victoria Dawson	Helena Fransson Eva Wolf

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I

Periapical Status of Non-root-filled Teeth with Resin Composite, Amalgam, or Full Crown Restorations: A Cross-sectional Study of a Swedish Adult Population

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Abstract

Introduction: Experimental studies show that dental pulp cells respond unfavorably to contact with resin composite restorative material. Hypothetically, in a random population, the frequency of apical periodontitis should be higher for teeth restored with resin composite than with amalgam. Therefore, the aim was to compare the periapical status of non-root-filled teeth restored with resin composite, amalgam, or laboratory-fabricated crowns in an adult Swedish population. **Methods:** The subjects comprised 440 individuals from a randomly selected sample of 1,000 adult residents of a Swedish county. The type, material, and quality of the restorations were recorded for all non-root-filled teeth by clinical examination and intraoral clinical photographs. Periapical status was evaluated on panoramic radiographs. The association between periapical status and type, material, and quality of the restorations was analyzed using the chi-square test and logistic regression analysis. **Results:** There was no significant difference in the frequency of apical periodontitis (AP) between teeth restored with resin composite or amalgam (1.3% and 1.1%, respectively). The frequency of AP for teeth restored with laboratory-fabricated crowns was significantly higher (6.3%). Regression analysis showed no association between AP and resin composite restorations but a significant association with laboratory-fabricated crowns. **Conclusions:** The results indicate that the risk of damage to the pulp-dentin complex from exposure to resin composite material and dentin bonding agents shown in experimental studies is not reflected in the clinical setting. However, in the study sample, AP was diagnosed in a significantly higher proportion of teeth restored with laboratory-fabricated crowns. (*J Endod* 2014;40:1303–1308)

Key Words

Apical periodontitis, cross-sectional study, crowns, dental amalgam, dental pulp, epidemiology, periapical status, resin composite

In June 2009, further use of amalgam was prohibited in Sweden on environmental grounds. However, resin composite has been the predominant restorative material since the 1990s; the major advantages over amalgam are superior aesthetics and less invasive cavity preparation. Experimental research has shown shrinkage of resin composite during the polymerization process, implying a risk of microbial leakage, leading to pulpal inflammation, with subsequent pulp necrosis and the development of apical periodontitis (AP) (1–3). Other complications frequently associated with polymerization shrinkage stress are secondary caries and postoperative sensitivity and pain although there is limited clinical supportive evidence (4). In experimental studies, adverse cellular responses to resin composite material and dentin bonding agents have been observed in dental pulp cells (5, 6).

There are few clinical studies of the association between endodontic complications and resin composite restorations. In 1 such study, vital teeth were restored with amalgam ($n = 377$) or resin composite ($n = 225$); after a follow-up period of 36 months, pulpal breakdown was more frequently associated with the resin composite than the amalgam restorations (7). In contrast, 2 other studies reported no significant difference in pulpal complications in teeth restored with resin composite or amalgam in terms of subsequent endodontic treatment over follow-up periods of 5–12 years (8, 9). In 2 further studies, all teeth restored with a class I or II resin composite restoration remained vital as tested by electrical and/or cold stimuli after 4–11 years (10, 11). Although there does not seem to be any obvious difference in pulpal status or pulpal complications between teeth restored with resin composite and amalgam, periapical status was not evaluated in the previously mentioned studies. Thus, no conclusions can be drawn from the literature with respect to changes in periapical status after restoration with resin composite or amalgam.

There are several follow-up studies of the periapical status of non-root-filled teeth with full crown restorations, primarily as abutments for fixed partial dentures. The reported frequencies of AP vary, from 3%–15% for observation times from 2–25 years (12–15). In a cross-sectional study, Saunders and Saunders (16) reported AP on 19% of non-root-filled teeth restored with crowns. Although some variations in results may be attributable to differences in study design, observation time, criteria, and methods of assessing periapical status, all studies indicated an increased frequency of AP on teeth with full crown restorations.

In longitudinal epidemiologic studies, non-root-filled teeth with periapical pathology have been associated with carious lesions or the presence of a coronal restoration of poor quality (17). Experimental studies indicate adverse effects of resin composite materials on the dental pulp as well as a risk of shrinkage of the filling material, with microbial leakage as a consequence. Extrapolating these findings to the current clinical

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Clinical Research

setting, the widespread use of resin composite materials may lead to an increased frequency of AP in the population. To date, there are no studies at population level investigating the relative frequency of AP associated with resin composite and amalgam restorations.

The hypothesis for the present study of a random population was that the frequency of AP was higher for teeth restored with resin composite than those restored with amalgam. The aim was to compare the periapical status of non-root-filled teeth restored with either resin composite, amalgam, or laboratory-fabricated crowns in an adult Swedish population.

Materials and Methods

A randomly selected sample of 1,000 adults living in the county of Skåne, Sweden, was invited to participate in a clinical study of oral health. The individuals were 20–89 years old and registered as residents of Skåne in the year 2007. The sample was obtained from SPAR (the Government's Person Address Register in Sweden) and included background variables such as sex, address, and age in 5-year intervals. Of the original sample, 11 individuals had moved from the region, the addresses of 14 were unknown, and 9 were deceased, thus leaving 966 individuals as the final sample. In total, 451 subjects (47% of the final sample) underwent clinical examination (Fig. 1). The remaining 515 individuals (53%) did not participate because of poor health and/or old age or because they could not be contacted or declined to participate. The study design was approved by the Regional Ethical Review Board at the University of Lund, Sweden (Dnr 513/2006).

Clinical Examination

The clinical examinations were conducted from March 2007–November 2008 at the Faculty of Odontology at Malmö University, Sweden, and at 3 public dental clinics in Skåne County. Patients were informed about the survey and provided written consent. For detailed information about the clinical examination, see Lundegren et al (18). Five intraoral clinical photographs were taken: the frontal view in the intercuspal position, the right and left views in the intercuspal position, and the occlusal views of the maxilla and mandible. Radiographic examination comprised digital bitewings, showing the distal surface of the canine to the mesial surface of the last molar (in general 4 bitewings) and panoramic radiographs. Caries lesions were determined using standardized clinical criteria aided by a mirror, probe (EXD57; Hu-Friedy, Chicago, IL) and bitewing radiographs. Cavitated lesions extending into the dentin were registered as manifest caries.

Radiographic Examination

Eleven subjects were excluded: 3 were edentulous, panoramic radiographs were unavailable at examination for 7 subjects, and in 1 subject the panoramic radiograph was of inadequate quality. Thus, the final sample for the study comprised 440 subjects (Fig. 1).

The radiographic images were available in the digital record system (Romexis 2.8.1.R; Planmeca, Helsinki, Finland) and interpreted separately on a 19-inch liquid crystal display monitor (Olorin, Kungsbäcka, Sweden, VCD 190D; resolution: 1,280 × 1,024 32-bit color; graphic card: HD Graphic; Intel, Santa Clara, CA) in a room with adjusted ambient light.

Initially, data for 20 subjects were collected and discussed by all 4 observers in order to calibrate for radiographic evaluation of periapical status and marginal bone loss. Another 20 panoramic images were then randomly selected and evaluated independently by 3 observers to assess interobserver agreement for periapical status and marginal bone loss by computing Cohen kappa. Once good agreement was reached, the re-

Figure 1. Flow chart from original sample to study sample.

maining subjects were randomly assigned to 1 of 3 groups; each observer was allotted the radiographs of 1 group for interpretation. Image processing and changing contrast, brightness, and magnification of the image were done when needed.

Evaluation of Caries and Restorations

Using the notations in the clinical examination protocol, intraoral clinical photographs, and the registrations from the interpretations of radiographic images (bitewing and panoramic radiographs), 2 observers recorded the following data for all permanent teeth including third molars: type (filling and/or crown), material and quality of restoration, and manifest caries (Table 1).

Evaluation of Periapical Status and Marginal Bone Loss

In the panoramic radiographs, periapical status and marginal bone loss were evaluated for all teeth. The 678 teeth with radiopaque material in the pulp chamber or in 1 or more root canals were considered to have undergone endodontic treatment and were excluded from further analysis in this article. Periapical status was registered as normal, AP, or not assessable (Table 1). In cases of doubt about the presence of AP, the status was classified as normal. Multirrooted teeth were classified according to the root exhibiting the worst score for the previously mentioned criteria. Marginal bone loss was classified as more or less than one third of the root length (Table 1).

All 3 observers agreed on 516 of 539 (95.7%) of the periapical status registrations, with a Cohen kappa value of 0.56 for interobserver agreement. For marginal bone loss, the observers agreed on 514 of 539 (95.3%) of the registrations with a Cohen kappa value of 0.47.

Statistical Methods

Chi-square tests were applied to detect any significant differences in periapical status associated with caries, type (filling and/or crown), material, and quality of the coronal restorations. Logistic regression analysis was used to describe AP by explanatory variables (type of

TABLE 1. Parameters Scored from Examination Protocol, Intraoral Clinical Photographs, and Radiographs (bitewing and panoramic radiographs)

Filling
Amalgam
Resin composite
Both resin composite and amalgam
Ceramic inlay
Other (gold inlay and so on)
Temporary material (including glass ionomer)
Dislodged filling (partial or complete)
Crown
Laboratory-fabricated crown (gold/cast, metal ceramic, gold onlay, porcelain, porcelain onlay)
Amalgam (5 surfaces)
Resin composite (5 surfaces)
Temporary
Quality of restoration
Adequate (no defective restoration margins)
Inadequate (defective restoration margins)
Caries
Manifest caries (cavitated lesion extending into the dentin)
Periapical status
Normal periapical conditions: normal periapical structures or widening of the apical periodontal ligament space (PDL) not exceeding twice the width of other parts of the root
Apical periodontitis: apical PDL exceeding twice the width of other parts of the root or periapical radiolucency observed
Periapical status not assessable: periapical structures not discernible (overlapping anatomical structures, inadequate image quality)
Marginal bone loss
No marginal bone loss or $\leq 1/3$ of the root length
Marginal bone loss $>1/3$ of the root length

restoration; material; and quality of restoration, manifest caries, and periodontal status).

Results

Individual Level

Four hundred forty individuals, 215 men (49%) and 225 women (51%), were examined. The study disclosed no differences in registrations between men and women; hence, sex distribution is not presented. The ages of the participants ranged from 20–89 years. The mean number of remaining teeth per individual was 27, and the mean number of intact teeth was 14. AP was diagnosed on 1 or more teeth (root filled and non–root filled) in 42.3% and on 1 or more non–root-filled teeth in 24.5% of the subjects examined (Table 2).

TABLE 2. Distribution per Age Group of All Examined Individuals, the Mean Number of Remaining Teeth and Intact Teeth, the Number and Percentage of Individuals with 1 or More Teeth with Apical Periodontitis (root-filled and non–root-filled), and the Number and Percentage of Individuals with 1 or More Non–root-filled Teeth with AP and Nonparticipants

Age	Examined individuals, <i>n</i>	Remaining teeth (mean)	Intact teeth (mean)	Individuals with 1 or more teeth with AP, <i>n</i> (%)	Individuals with 1 or more non–root-filled teeth with AP, <i>n</i> (%)	Nonparticipants, <i>n</i>
20–29	71	29.2	23.5	11 (15.5)	8 (11.3)	91
30–39	81	29.4	21.9	13 (16.0)	8 (9.9)	86
40–49	80	28.5	15.9	25 (31.3)	12 (15.0)	88
50–59	76	27.1	9.9	47 (61.8)	27 (35.5)	84
60–69	81	24.9	6.2	52 (64.2)	28 (34.6)	72
70–79	41	21.1	5.2	33 (80.5)	22 (53.7)	56
80–89	10	21.4	4.9	5 (50.0)	3 (30.0)	49
Total	440	27	14	186 (42.3)	108 (24.5)	526

AP, apical periodontitis.

The percentages are calculated out of examined patients in each age group.

Tooth Level

In the 440 subjects, the total number of teeth examined was 11,876; 678 (5.7%) were recorded as root filled and excluded from the study. Thus, the results are based on a sample of 11,198 non–root-filled teeth (94.3%).

Caries

Manifest caries was detected in 326 (3%) of the 11,198 teeth; 92 (1%) were primary lesions (ie, caries on unrestored surfaces).

Restorations (Fillings and Crowns)

For the distribution of different materials and types of restoration, see Table 3. Teeth with temporary restorations, teeth restored with other materials, teeth with secondary caries, and those with non-assessable periapical status were excluded from the analysis of the quality of the restorations, leaving 4,471 teeth to be evaluated. The quality of the restorations was assessed as adequate in 98% and inadequate in 2% (Table 4).

AP

AP was detected in 140 (1.3%) of the 11,198 teeth included in the study. Periapical status could not be assessed in 192 teeth (1.7%). The frequency of AP was higher for the 326 teeth with caries (35 teeth, 10.7%) than for the 10,872 teeth without caries (105 teeth, 1%) ($P < .001$).

The frequency of AP on the 4,471 noncarious teeth in relation to the material and type of restoration are presented in Table 4. There was no difference in the frequency of AP between teeth restored with resin composite or amalgam, but teeth restored with both resin composite and amalgam had a higher frequency of AP than those restored with either material ($P < .001$). AP was more common in teeth restored with laboratory-fabricated crowns and those restored with laboratory-fabricated crowns and repaired with filling material than in those restored with either resin composite or amalgam ($P < .001$) (Table 4).

Analysis of the subgroup of teeth in which the quality of the restoration was recorded as adequate disclosed the same relationships between the different restoration groups with respect to the frequency of AP (Table 4). Comparison of periapical status of the 4,360 teeth with adequate restorations and the 111 teeth with inadequate restorations disclosed that AP was more common on teeth with restorations of inadequate quality (9% vs 1.9%) ($P < .001$) (Table 4).

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TABLE 3. Distribution of Coronal Restorations in the 4,902 Restored Teeth

Fillings	
Resin composite	1,890 (16.9)
Amalgam	1,819 (16.2)
Both resin composite and amalgam*	500 (4.5)
Ceramic inlay	19 (0.2)
Temporary	75 (0.7)
Other	30 (0.3)
Total	4,333 (38.7)
Crowns	
Laboratory-fabricated	507 (4.5)
Laboratory-fabricated repaired with filling material	37 (0.3)
Resin composite	15 (0.1)
Amalgam†	5 (0.04)
Amalgam repaired with a resin composite filling‡	1 (0.009)
Temporary	4 (0.04)
Total	569 (5.1)

The percentages are calculated from the total number of teeth (N = 11,198).

*Both resin composite and amalgam fillings in 1 and the same tooth.

†Restorations including 5 surfaces were classified as crowns.

Logistic Regression Analysis

The variables (ie, type of restoration, quality of restoration, caries, and marginal bone loss) were analyzed by logistic regression to study their association with AP (Table 5).

Discussion

There was no significant difference in periapical status between teeth restored with resin composite and those restored with amalgam. However, AP was registered on a significantly higher proportion of teeth restored with laboratory-fabricated crowns or both resin composite and amalgam. Logistic regression analysis also disclosed a significant association between AP and teeth restored with laboratory-fabricated crowns or both resin composite and amalgam.

The subjects of this study constituted a random sample of adults living in Skåne in the year 2007, providing an overview of the standard of restorative treatment in the context of routine primary dental care in Sweden. Because the participation rate (47%) was low, it is important to address the question of whether the population examined represents the target population. The sample examined matched the overall population of Skåne in the year 2007, with respect to age and sex, with the exception of a smaller proportion of participants in the 80- to 89-year age group (18). However, because the aim of the study was to relate periapical status and restorative materials and not to describe the oral health of the residents of the county, the high nonparticipation

rate was not considered to have a decisive influence on the results. The advantage of a cross-sectional population study is the high external validity; hence, the restorations were considered to be representative of primary dental care provided by general practitioners (19).

The participants underwent both clinical and radiographic examination. Several studies of the quality of coronal restorations and the periapical status of endodontically treated teeth have been based only on the interpretation of radiographic images (20–22). In 1 study using both clinical and radiographic examination (23), the quality of the coronal restoration was assessed as adequate in 78.1% when scored on periapical radiographs but only 67.4% when scored on combined clinical and radiographic criteria. In the present study, the clinical and radiographic data together provided a comprehensive basis for assessment of the quality of the coronal restorations.

The present study was preceded by a comprehensive investigation of oral health in Skåne (18), applying panoramic radiography and bite-wings as the radiographic examination of choice. It has been shown that the image of AP on panoramic radiographs may result in underestimation compared with periapical radiographs (24–27). Consequently, a limitation in the present study might be a relative underestimation of AP, as evidenced by the high frequency of nonassessable periapical structures, mainly because of overlapping of anatomic structures in the anterior region. However, because a mean of 14 teeth per individual was classified as intact, mainly anterior teeth, the frequency of anterior restorations was low, and the influence on the results should be limited. One advantage of panoramic radiography is the lower radiation dose compared with a complete full mouth survey (28). The oral health status of most of the study participants was good, with few or no restorations, and periapical radiographs were not indicated. Thus, for many of the participants, taking periapical radiographs and unnecessarily exposing the participants to radiation would have been unethical.

The criterion for diagnosing AP in this study was radiolucency around the root apex, exceeding at least twice the width of the periodontal ligament space in other parts of the root (29). The periapical index (30) has been extensively applied for registration of periapical status in endodontic studies. Based on criteria derived from reference periapical radiographs of teeth with verified histologic diagnoses, it is intended to improve diagnostic conformity among different research groups. However, the periapical index is based on periapical radiographic images of maxillary incisors (30, 31) and is therefore not appropriate for the present study, which is based on the interpretation of panoramic radiographs in which the appearance of anatomic and bone structures is different from periapical radiographs.

To compensate for individual observer characteristics in the assessment of AP and the marginal bone score, each of the observers

TABLE 4. Type (filling and/or crown), Material, and Quality of the Restorations in Relation to Apical Periodontitis (N = 4,471)

AP in relation to restoration			AP in relation to restoration quality			
Type/material of restoration	Total	AP, n (%)	Adequate quality		Inadequate quality	
			Total	AP, n (%)	Total	AP, n (%)
Resin composite (crown, filling)	1,748	22 (1.3)	1,705	22 (1.3)	43	0 (0.0)
Amalgam (crown, filling)	1,766	20 (1.1)	1,732	15 (0.9)	34	5 (14.7)
Both resin composite and amalgam	454	18 (4.0)	439	16 (3.6)	15	2 (13.3)
Laboratory-fabricated crown	474	30 (6.3)	459	28 (6.1)	15	2 (13.3)
Laboratory-fabricated crown repaired with filling material	29	3 (10.3)	25	2 (8.0)	4	1 (25.0)
All restorations (5 groups)	4,471	93 (2.1)	4,360	83 (1.9)	111	10 (9.0)

AP, apical periodontitis.

Teeth with caries, other restorations and periapical status not assessable were excluded.

TABLE 5. Logistic Regression Analysis of Tooth-related Factors in Relation to Apical Periodontitis in Restored Teeth

Variables	Total	Odds ratio	95% CI (P value)
Type of restoration			
Amalgam (crown, filling)	1,813	1	Reference
Resin composite (crown, filling)	1,852	1.23	0.70–2.15 (.48)
Both resin composite and amalgam	493	3.53	1.96–6.35 (<.001)
Laboratory-fabricated crown	488	5.70	3.27–9.93 (<.001)
Laboratory-fabricated crown in combination with filling	34	6.98	2.23–21.83 (.001)
Ceramic inlay, temporary material, dislodged filling	154	7.08	2.98–16.84 (<.001)
Quality of restoration in teeth without caries (all permanent restorations included)			
Adequate quality	4,406	1	Reference
Inadequate quality	111	3.76	1.83–7.74 (<.001)
Other	317	0.81	0.24–2.68 (.72)
Manifest caries			
No	4,603	1	Reference
Yes	231	7.99	2.45–26.01 (.001)
Marginal bone loss			
≤1/3 of the root length	4,443	1	Reference
>1/3 of the root length	391	3.57	2.31–5.52 (<.001)

CI, confidence interval.

assessed one third of the material (32). With respect to observer variation, the high percentage of agreement compared with the agreement expressed by the Cohen kappa value can be attributed to the very high frequency of teeth with normal periapical and marginal conditions on which the observers agreed. In case of uncertainty, the periapical condition was considered to be normal, and the lower marginal bone score was applied. This approach minimizes the proportion of false-positive registrations, which are more detrimental to the results when the prevalence of the disease is low (33).

This study failed to disclose any significant differences in the frequency of AP associated with teeth restored with resin composite or amalgam. Although experimental studies have shown that resin composite material is harmful to the dental pulp cells (5, 6), this does not seem to be the case when it is used for restoration in general dentistry. In the present study, a large number of the teeth examined had only 1 restored surface. However, the extent of the restorations varied from 1–5 surfaces. In contrast to the direct contact in experimental studies on resin composite and pulpal cells, under clinical conditions the restorative material is separated from the pulp by a layer of dentin, which may act as a protective barrier. A dentin barrier might also be a good defense against microbial leakage caused by polymerization shrinkage (34). In a study with a follow-up period of 36 months, Whitworth et al (7) concluded that pulpal breakdown was associated more frequently with resin composite than amalgam restorations. In their study, some pulp exposures occurred during cavity preparation, and this may have influenced the results.

Because resin composite has been the primary material for direct restoration in Sweden since the 1990s, the amalgam restorations are likely to be older than the resin composite fillings. However, an equal proportion of resin composite and amalgam restorations were judged to be of inadequate quality. The significantly higher frequency of AP recorded on teeth restored with both resin composite and amalgam than

those restored with only resin composite or amalgam is probably attributable to the damaging effect of repeated operative procedures on these teeth.

A significantly higher frequency of AP was observed on teeth restored with laboratory-fabricated crowns (alone or repaired with filling material) than those restored with either resin composite or amalgam. These results are in agreement with Kirkevåg et al (17). Several follow-up studies of teeth with full crown restorations have reported the development of AP on 3%–15% during the observation period (12–15). The development of AP on teeth with full crown restorations is generally attributed to underlying severe damage to the dentin-pulp complex by deep caries. Further factors contributing to pulpal breakdown have been proposed, such as iatrogenic damage caused by excessive removal of dentin and other treatment procedures in preparation for full crowns (35).

The association between inadequate restoration quality and AP has been established in population studies (17). In the present study, such teeth were excluded from the evaluations; a separate analysis was undertaken of teeth with restorations of adequate quality. The same relationship with respect to frequency of AP was disclosed as when restorations of adequate and inadequate quality were evaluated together, giving no indication that adequate resin composite restoration has adverse effects on the dentin-pulp complex. The proportion of teeth with inadequate restorations was small (ie, only 2%). As in the previously cited Danish population study (17), caries and marginal bone loss were also associated with AP in the present study.

In conclusion, the results do not support the hypothesis that in a random population, the frequency of AP is greater for teeth restored with resin composite than amalgam; no difference in the frequency of AP was disclosed between non-root-filled teeth restored with either resin composite or amalgam. Furthermore, logistic regression analysis disclosed no association between resin composite restorations and AP. This indicates that the risk of damage to the dentin-pulp complex by resin composite material and dentin bonding agents shown in experimental studies is not reflected in the clinical context. However, AP was observed on a significantly higher proportion of teeth restored with laboratory-fabricated crowns, and regression analysis disclosed a significant association with AP. This is probably attributable to pulpal insult by a combination of pre-existing conditions necessitating full crown coverage, such as extensive caries or trauma, and the invasiveness of the crown preparation procedures.

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The authors deny any conflicts of interest related to this study.

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II

Periapical Status of Root-filled Teeth Restored with Composite, Amalgam, or Full Crown Restorations: A Cross-sectional Study of a Swedish Adult Population

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Abstract

Introduction: The aim was to compare the periapical status of root-filled teeth restored with resin composite, laboratory-fabricated crowns, or amalgam in a Swedish adult population. **Methods:** The subjects consisted of 440 individuals from a randomly selected sample of 1000 adult residents of a Swedish county. The type, material, and quality of the restorations were recorded for all root-filled teeth by using clinical examination and intraoral clinical photographs. Periapical status, root-filling quality, and marginal bone loss were evaluated on panoramic radiographs. The association between periapical status and type, material, and quality of the restorations was analyzed by using the χ^2 test and logistic regression. **Results:** No difference in the frequency of apical periodontitis (AP) between teeth restored with resin composite, laboratory-fabricated crowns, or amalgam (29.7%, 26.2%, and 43.1%, respectively) of adequate quality was found. No association between AP and resin composite restorations was disclosed; however, there was an association between AP and inadequate root-filling quality and marginal bone loss >1/3 of the root length. **Conclusions:** The results did not indicate any association between AP and resin composite restorations. Neither the type nor the material of the restoration was of significance for periapical status as long as the quality was adequate. (*J Endod* 2016;42:1326–1333)

Key Words

Apical periodontitis, cross-sectional study, crowns, dental amalgam, endodontics, resin composite

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The quality of the coronal restoration of a root-filled tooth has been found to be important for periapical health in various studies. In a longitudinal epidemiologic study, inadequate restorations have been found to be among the most important risk factors for the development of apical periodontitis (AP) in root-filled teeth (1). Similarly, in a prospective follow-up study from a specialist clinic, satisfactory coronal restorations were significantly associated with periapical health (2). In a systematic review and meta-analysis that were based on 9 studies, Gillen et al (3) concluded that the odds for healing of AP increased with both adequate restorative treatment and adequate root canal treatment.

A few studies have focused on the type of restoration in relation to the periapical status; for example, both Safavi et al (4) and Stassen et al (5) have found a lower frequency of AP in root-filled teeth restored with laboratory-fabricated crowns compared with teeth restored with direct restorations. However, other studies found no statistically significant difference in the frequency of AP in teeth restored with laboratory-fabricated crowns compared with teeth restored with direct restorations (6–8). Differences in root-filling quality in teeth restored with crowns or fillings as well as small numbers of teeth in the studied groups may contribute to the variation of the findings. In some studies, the quality of the coronal restorations was not evaluated (4, 6, 8).

Regarding the material for direct restoration of the root-filled teeth and its relation to periapical status, the literature is sparse. In a cross-sectional study of an adult Swedish population, Frisk et al (9) found composite fillings to be predictive of AP in root-filled teeth, and Hommez et al (7) detected more AP in root-filled teeth restored with composite material compared with amalgam. However, Stassen et al (5) did not find any statistically significant difference in the periapical status of root-filled teeth restored with amalgam compared with composite, but a significant difference was found between restorations of adequate and inadequate quality. In Sweden, resin composite has been the predominant restorative material since the 1990s, and since the ban of amalgam in 2009, it has been the only material available for direct restorations. Because 80% (2002) and 85% (2005) of the root-filled teeth in a Swedish adult population were restored with direct composite restorations (10), it seems important to continue the study of possible differences in periapical status between root-filled teeth restored with different materials.

The hypothesis for this study was that the frequency of AP was higher for teeth restored with composite compared with teeth restored with other types of restorations. The aim of the study was to compare periapical status of root-filled teeth restored with resin composite, laboratory-fabricated crowns, or amalgam in a Swedish adult population.

Significance

This study did not indicate any association between apical periodontitis and resin composite restorations in root-filled teeth. If the quality of the coronal restoration is adequate, neither the type nor the material seems to be of significance for periapical status.

Materials and Methods

The random sample of 1000 adults comprised residents of the county of Skåne, Sweden in 2007. The individuals, aged 20–89 years, were invited to take part in a clinical study of oral health. The sample was obtained from SPAR (the government's Person Address Register in Sweden). Of the original sample of 1000 individuals, 34 were excluded for various reasons, leaving 966 available individuals (Fig. 1). In total, 451 individuals underwent clinical examination, and the remaining 515 did not participate because of poor health, old age, not being reachable, or declining to participate. The distribution regarding sex and age did not differ between participants and non-participants. Patients were informed about the study, and they provided written consent. The design of the study was approved by the Regional Ethical Review Board at the University of Lund, Sweden, Dnr 513/2006.

Clinical Examination

The clinical examinations were conducted at the Faculty of Odontology at Malmö University, Sweden or at 3 public dental clinics in the county of Skåne between March 2007 and November 2008. For details about the clinical examination, see Lundegren et al (11). Five intraoral clinical photographs were taken: frontal, right, and left views (all in intercuspal position) and occlusal views of the teeth in the upper and lower jaw. Caries lesions were determined by using standardized clinical criteria aided by mirror, probe (EXD57; Hu Friedy, Chicago, IL), and bitewing radiographs. Cavitated lesions extending into the dentin were defined as manifest caries.

Radiographic Examination

Radiographic examination comprised panoramic radiographs and bitewings (in general 4 bitewings), which showed the distal surface of the canine to the mesial surface of the last molar.

The radiographic images were available in the digital record system (Romexis 2.8.1.R; Planmeca, Helsinki, Finland) and interpreted

separately on a 19-inch liquid crystal display monitor (Olorin; Kungsbacka, Sweden, VCD 1900; resolution: 1280 × 1024 32-bit color; graphic card: HD Graphic; Intel, Santa Clara, CA) in a room with adjusted ambient light.

Interpretable radiographs were not available for 11 individuals (3 were edentulous, 7 without panoramic radiographs, and 1 with panoramic radiograph of inadequate quality). Thus, the final sample for this study comprised 440 subjects (46%) (Fig. 1).

A calibration process for the criteria of periapical status, root-filling quality, and marginal bone loss was carried out by 4 observers through discussion and interpretation of panoramic radiographs from 20 randomly selected subjects. The panoramic images of another 20 patients were then randomly chosen and independently evaluated by 3 observers to assess the interobserver agreement for periapical status, root-filling quality, and marginal bone loss by computing Cohen's kappa. After a second calibration, the remaining subjects were randomly assigned to 1 of 3 groups, and each observer was allotted the radiographs of 1 group for interpretation. Image processing by changing contrast, brightness, and magnification of the image was done when needed.

Evaluation of Caries and Restorations

Clinical examination protocol, intraoral clinical photographs, and radiographic images were used for the following registrations: type (filling and/or crown), material and quality of restoration, and manifest caries. Two observers simultaneously recorded the data for all endodontically treated teeth including third molars (Table 1).

Evaluation of Periapical Status, Root-filling Quality, Marginal Bone Loss, and Type of Post

In the panoramic radiographs, periapical status, root-filling quality, marginal bone loss, and type of post were evaluated. The criteria for classification are presented in Table 1. In cases of doubt about the presence of AP, the status was classified as normal. At the registrations of all teeth in the 440 patients, the 3 observers agreed on 96% of the periapical status registrations with a Cohen's kappa value of 0.6. Regarding the root-filling quality (adequate and inadequate), all 3 observers agreed on 98% of the registrations with a Cohen's kappa value of 0.5, and regarding the marginal bone loss, the observers agreed on 95% of the registrations with a Cohen's kappa value of 0.5. During the statistical calculations, the variable marginal bone loss was dichotomized as follows: (1) no marginal bone loss or $\leq 1/3$ of the root length or (2) marginal bone loss $> 1/3$ of the root length.

Statistical Methods

Statistical calculations were performed with the Statistical Package for the Social Sciences (SPSS 22 for Windows; SPSS Inc, Chicago, IL). Chi-square tests were applied to detect any significant differences in periapical status associated with type (filling and/or crown), material, and quality of the coronal restorations and manifest caries and root-filling quality. Logistic regression was used to describe AP by the following explanatory variables: type (filling or crown) and material of the coronal restoration, manifest caries, root-filling quality, marginal bone loss, and type of post. Differences were considered as significant at a 5% level.

Results

Individual Level

Four hundred forty individuals, 215 men (49%) and 225 women (51%), were examined, with a mean number of 27 teeth and 2.9

Figure 1. Flow chart of original sample to final sample.

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TABLE 1. Parameters and Criteria Scored from Clinical Examination Protocol, Intraoral Clinical Photographs, and Radiographs (panoramic radiographs and bitewings)

Filling
Amalgam
Resin composite
Combination resin composite and amalgam
Ceramic inlay
Other (eg, gold inlay)
Temporary material (including glass ionomer)
Dislodged filling (partial or complete)
Crown
Laboratory-fabricated (gold/cast, metal ceramic, gold onlay, porcelain, porcelain onlay)
Amalgam (5 surfaces)
Resin composite (5 surfaces)
Temporary
Quality of coronal restoration
Adequate (no defective restoration)
Inadequate (defective restoration)
Caries
Manifest caries (cavitated lesion extending into the dentin)
Periapical status
Normal periapical conditions: normal periapical structures or widening of the apical periodontal ligament space not exceeding twice the width of other parts of the root
AP: apical periodontal ligament space exceeding twice the width of other parts of the root or periapical radiolucency observed
Periapical status not assessable: periapical structures not discernible (overlapping anatomic structures, inadequate image quality)
Root-filling quality
Amputated
Adequate (ending 0–2 mm from the radiographic apex and without visible voids)
Inadequate (root filling ending >2 mm or extending beyond the radiographic apex, signs of voids, fractured instrument in a canal, perforation, or untreated canal)
Retrograde filling (radiographic sign of retrograde filling material)
Not judgeable
Marginal bone loss
No marginal bone loss or $\leq 1/3$ of the root length
Marginal bone loss > $1/3$ and $\leq 1/2$ of the root length
Marginal bone loss > $1/2$ of the root length
Post
Screw post
Cast
Prefabricated
Parapulpal
Other

root-filled teeth per individual. Two hundred thirty of the individuals (52.3%) had at least 1 root-filled tooth (Fig. 2). For the distribution in age groups, see Table 2. The study disclosed no differences in observations between men and women; hence, sex distribution is not presented.

Tooth Level

The 440 individuals examined had 11,876 teeth, and 678 of them were endodontically treated. The object for the present study was the 660 root-filled teeth (5.6%) (12 pulpotomized teeth and 6 teeth with retrograde fillings were excluded). An analysis of the 11,198 endodontically untreated teeth has been presented previously (12).

Manifest Caries. Manifest caries was detected in 51 of the 660 root-filled teeth (7.7%) and in 326 of the 11,198 non-root-filled teeth (2.9%). The frequency of manifest caries was significantly higher in the root-filled teeth ($P < .001$).

The 40 teeth with non-assessable periapical status were excluded from the analysis of manifest caries in relation to AP, leaving 620 teeth to be evaluated (Fig. 3). The frequency of AP in root-filled teeth with manifest caries (22 of 48, 45.8%) was significantly higher compared with the 181 of 572 teeth without manifest caries (31.6%) ($P < .05$).

Restorations. Of the 660 root-filled teeth, 231 (35%) had a filling, 413 (62.6%) had some sort of crown restoration, and 16 (2.4%) had no restoration (Table 3).

Of the 620 root-filled teeth with assessable periapical status, 546 teeth without caries belonged to 1 of the following 5 restoration groups:

- 1. Laboratory-fabricated crown
- 2. Laboratory-fabricated crown in combination with filling
- 3. Amalgam (crown or filling)
- 4. Composite (crown or filling)
- 5. Combination of composite and amalgam (Table 4) (Fig. 3)

The frequency of AP was significantly higher in teeth restored with amalgam (27 of 58, 46.6%) compared with teeth restored with a laboratory-fabricated crown (72 of 281, 25.6%) ($P < .01$) and compared with teeth restored with composite (44 of 143, 30.8%) ($P < .05$). There was no significant difference in periapical status between teeth restored with a laboratory-fabricated crown and teeth restored with composite (Table 4).

Comparing the coronal restorations of adequate quality, no statistically significant difference in the frequency of AP was found between the 5 restoration groups (Table 4). However, the frequency of AP was significantly higher in the teeth with restorations (crown or filling) of inadequate quality (16 of 34, 47.1%) compared with the teeth with restorations of adequate quality (151 of 512, 29.5%) ($P < .05$).

Coronal Leakage. A risk for coronal leakage, which was defined as presence of caries, dislodged restoration, defective restoration, or restoration of temporary material registered at the clinical and

Figure 2. Distribution of individuals regarding number of root-filled teeth.

radiographic examinations and the intraoral photographs, was observed in 104 of the 620 root-filled teeth (16.8%) with assessable periapical status (Fig. 3). AP was detected in significantly more teeth (50 of 104, 48.1%) with risk for coronal leakage compared with 153 of 516 teeth without risk (29.7%) ($P < .001$).

Root-filling Quality. Of the 620 root-filled teeth with assessable periapical status, 2 teeth with non-assessable root-filling quality were excluded, leaving 618 teeth to be evaluated (Fig. 3).

AP was detected in 203 of 618 root-filled teeth (32.8%). The technical quality of the root fillings was adequate in 218 teeth (35%) and inadequate in 400 teeth (65%). The frequency of AP was significantly higher in teeth with inadequate root-filling quality, 171 of 400 (42.8%), compared with teeth with adequate root-filling quality, 32 of 218 (14.7%) ($P < .001$).

Quality of Coronal Restorations and Root Fillings. Of the 618 root-filled teeth, 544 teeth without caries and belonging to 1 of the 5 restoration groups were analyzed regarding the combined qualities (adequate/inadequate) of both the coronal restoration and the root filling (Fig. 3). A significantly lower frequency of AP was observed in teeth having both a coronal restoration

and a root filling of adequate quality (12.9%) compared with teeth having a root filling (39.2%) ($P < .001$) or both the root filling and coronal restoration (60.0%) ($P < .001$) of inadequate quality (Table 5).

Logistic Regression Analysis. The following variables were analyzed by logistic regression to study their association with AP (Table 6): type and material of restoration, manifest caries, root-filling quality, marginal bone loss, and type of post. Inadequate root-filling quality had the highest odds ratio (OR) for AP (OR, 4.02; confidence interval [CI], 2.54–6.36), followed by marginal bone loss $> 1/3$ of the root length (OR, 2.00; CI, 1.24–3.24) (Table 6).

Discussion

In this study of a general adult Swedish population, there was no significant difference in periapical status between root-filled teeth restored with laboratory-fabricated crowns and those restored with composite or amalgam, provided that the quality of the coronal restoration was adequate. When calculating adequate and non-adequate restorations together, the periapical status differed neither in root-filled

TABLE 2. Distribution Per Age Group of All 440 Examined Individuals, Mean Number of Remaining and Root-filled Teeth, Standard Deviation (SD) for Number of Root-filled Teeth, and the Number and Percentage of Individuals with ≥ 1 Root-filled Teeth

Age (y)	Individuals, <i>n</i>	Remaining teeth, <i>n</i> (mean value)	Root-filled teeth, <i>n</i> (mean value $\pm$ SD)	Individuals with 1 or more root-filled teeth, <i>n</i> (%)
20–29	71	29.2	1.8 $\pm$ 1.3	9 (13)
30–39	81	29.4	1.3 $\pm$ 0.6	16 (20)
40–49	80	28.5	1.9 $\pm$ 1.4	32 (40)
50–59	76	27.1	2.8 $\pm$ 2.0	55 (72)
60–69	81	24.9	3.2 $\pm$ 2.2	72 (89)
70–79	41	21.1	3.9 $\pm$ 2.4	3 (88)
80–89	10	21.4	3.4 $\pm$ 2.3	10 (100)
Total	440	27	2.9 $\pm$ 2.1	230 (52.3)

Figure 3. Flow chart of number of root-filled teeth included in the analyses regarding AP in relation to manifest caries, coronal leakage, restorations, root-filling quality, and quality of coronal restoration and root fillings. The number of excluded teeth and reasons for exclusion in the different analyses are specified.

teeth restored with composite nor in those with laboratory-fabricated crowns; however, both were significantly better than when restored with amalgam. Furthermore, logistic regression analysis did not indicate any significant association between composite restoration and AP.

TABLE 3. Distribution of Coronal Restorations in the 660 Root-filled Teeth

Restoration	n
Fillings	
Amalgam	42
Resin composite	135
Combination resin composite and amalgam	38
Ceramic inlay	2
Other (eg, gold inlay)	2
Temporary material	12
Total	231
Crowns	
Laboratory-fabricated	325
Laboratory-fabricated in combination with filling	34
Amalgam	24
Amalgam in combination with a resin composite	1
filling	
Resin composite	25
Temporary	4
Total	413
Missing restoration	16
Total	660

Therefore, the hypothesis that the frequency of AP was higher in teeth restored with composite could not be verified.

The subjects of this study were a randomly selected sample of adults living in the county of Skåne in 2007, and they provided an overview of the standard of restorative and endodontic treatment in the context of routine primary dental care in Sweden. Despite the low participation rate (46%), the possible influence on the results is considered to be minimal because the aim of this study was to compare the periapical status of root-filled teeth restored with different types of restorations and not to describe the oral health status in this adult Swedish population. Nevertheless, the examined sample was similar to the overall population of Skåne in 2007 regarding sex and age, with the exception of a small proportion of subjects in the age group 80–89 (11). The high external validity, which means that the root fillings and restorations are considered to be representative of primary dental care provided by general practitioners, is an advantage with a cross-sectional population study (13). However, only information from the specific moment in time when the examination was conducted is available, and no information on how and when the treatments were performed can be retrieved in a cross-sectional study.

Both clinical and radiographic examinations of the subjects were conducted. In comparison, several studies of restoration quality and periapical status in root-filled teeth have used only radiographs for the evaluation of the restoration quality (14, 15). In a study where both clinical and radiographic examinations were performed, the

TABLE 4. Type (filling and/or crown), Material, and Quality of the Coronal Restorations in Relation to AP in the 546 Root-filled Teeth with Assessable Periapical Status, without Caries, and Belonging to 1 of the 5 Restoration Groups

Type/material of restoration	Total		Adequate quality		Inadequate quality	
	n	AP, n (%)	n (%)	AP, n (%)	n (%)	AP, n (%)
Laboratory-fabricated crown	281	72 (25.6)	275 (98.0)	72 (26.2)	6 (2.0)	0 (0.0)
Laboratory-fabricated crown in combination with filling	30	12 (40.0)	26 (87.0)	9 (34.6)	4 (13.0)	3 (75.0)
Amalgam (crown, filling)	58	27 (46.6)	51 (88.0)	22 (43.1)	7 (12.0)	5 (71.4)
Resin composite (crown, filling)	143	44 (30.8)	128 (90.0)	38 (29.7)	15 (10.0)	6 (40.0)
Combination resin composite and amalgam	34	12 (35.3)	32 (94.0)	10 (31.3)	2 (6.0)	2 (100.0)
Total	546	167 (30.6)	512 (94.0)	151 (29.5)	34 (6.0)	16 (47.1)

quality of the coronal restorations was assessed as adequate in 78.1% of the cases when scored on periapical radiographs, whereas only 67.4% were adequate when evaluated by clinical and radiographic criteria (7). Thus, the data from both clinical and radiographic examinations constituted an optimal basis for assessing the quality of the coronal restorations in the present study.

Several studies have found that AP may be underestimated when using panoramic radiographs compared with periapical radiographs (16, 17), which may be a limitation of this study. However, the present study was preceded by a comprehensive survey of oral health in Skåne (11), in which panoramic radiographs and bite-wings were the radiographic examinations of choice. A significant proportion of the subjects had a good oral health status, and a full-mouth radiographic examination would thereby be unethical because of higher radiation dose than panoramic radiography (18). In some studies that used panoramic radiographs, the examination was supplemented with periapical radiographs of the root-filled teeth (19, 20), which may reduce the number of non-assessable periapical structures. Because 620 of the 660 root-filled teeth (94%) were judged to have assessable periapical structures, we considered the use of panoramic radiography to be reasonably accurate for the purpose of this study.

The criterion for AP was radiolucency around the root apex exceeding twice the width of the periodontal ligament space in other parts of the root (6). Although the periapical index (21) has been extensively used for registration of periapical status, it was not considered appropriate for the present study because the periapical index is based on periapical radiographs of maxillary incisors (21, 22), in which the appearance of anatomic and bone structures is different from panoramic radiographs.

The root filling was judged as adequate when ending 0–2 mm from the radiographic apex and without visible voids. Root fillings not fulfilling these criteria were judged as inadequate. Although panoramic radi-

ography is not the preferred method for assessment of the technical quality of the root fillings, our results concur with previous findings regarding AP and root-filling quality (15, 23) and also regarding the frequency of inadequate root fillings (9).

To compensate for individual observer characteristics in the assessment of AP and the marginal bone score, each of the observers assessed one third of the material (24). In case of uncertainty, the periapical condition was considered to be normal, and the lower marginal bone score was applied. This approach minimizes the proportion of false-positive registrations, which are more detrimental to the results when the prevalence of the disease is low (25).

In previous epidemiologic studies on AP, variables on the individual level have not or with uncertainty (smoking) been associated with AP (1, 26, 27), and socioeconomic variables predictive of AP in the previous studies were not either (26, 27). Therefore, we decided not to include variables at the individual level in the logistic regression analysis.

Our findings that resin composite restorations were not associated with AP were in contrast to the results by Frisk et al (9), who found that restorations of composite or composite and amalgam combined were associated with AP. In that study, 3 random samples of subjects from the county of Jönköping, Sweden were examined in 1983, 1993, and 2003, and the composite restorations may represent a somewhat earlier

TABLE 6. Logistic Regression Analysis of Tooth-related Factors in Relation to AP in Root-filled Teeth

Variables	Total	OR	95% CI	P value
Type of restoration				.193
Composite (crown, filling)	150	1	Reference	
Amalgam (crown, filling)	63	1.62	0.84–3.14	
Combination composite and amalgam	38	0.80	0.37–1.76	
Laboratory-fabricated crown	294	0.76	0.43–1.33	
Laboratory-fabricated crown in combination with filling	34	1.27	0.56–2.89	
Manifest caries				.199
No	542	1	Reference	
Yes	37	1.63	0.78–3.44	
Root-filling quality				<.001
Adequate	204	1	Reference	
Inadequate	375	4.02	2.54–6.36	
Marginal bone loss				.005
≤ 1/3 of the root length	485	1	Reference	
> 1/3 of the root length	94	2.00	1.24–3.24	
Type of post				.302
No post	257	1	Reference	
Screw	98	0.85	0.49–1.47	
Cast	141	0.69	0.37–1.28	
Prefabricated	83	1.26	0.68–2.33	

Nagelkerke $r^2 = 0.166$.

TABLE 5. Quality (adequate/inadequate) of the Coronal Restoration and Root Filling in Relation to AP in the Root-filled Teeth with Assessable Periapical Status, without Caries, and Belonging to 1 of the 5 Restoration Groups

Quality				
Coronal restoration	Root filling	n	AP, n (%)	Significance
Adequate	Adequate	186	24 (12.9)	* †
Adequate	Inadequate	324	127 (39.2)	
Inadequate	Adequate	9	1 (11.1)	
Inadequate	Inadequate	25	15 (60.0)	
Total		544	167 (30.7)	

Teeth with non-assessable root-filling quality were excluded ($n = 2$), leaving 544 root-filled teeth in the analysis.

* $P < .001$.

† $P < .05$.

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type compared with those in our study where the patient material was collected in 2007, possibly with a better quality of the composite restorations because of improvements in the materials, techniques, and instruments for placing the restorations (28). In the study by Frisk et al, the information about restoration quality such as underfill and overfill was lacking; therefore, evaluation of the frequency of inadequate restorations was not possible. Also in contrast to our results, Hommez et al (7) found AP in more teeth restored with composite compared with amalgam, but no differentiation was made between inadequate and adequate fillings when comparing composite with amalgam. Because 12% of the amalgam restorations in our study were inadequate, it was not possible to determine whether the higher frequency of AP observed in teeth restored with amalgam was dependent on the material or the inadequate quality of the restorations. When the inadequate restorations were excluded and only the adequate restorations were compared to analyze the possible influence of the restoration type on periapical status, no difference was found between resin composite, amalgam, and laboratory-fabricated crowns. The significantly higher frequency of AP that was found in the inadequately restored teeth has also been found and highlighted in several previous studies (1–3, 5).

There was no reason to suspect a difference between the restoration groups regarding the use of rubber dam during the endodontic treatment. Even though the information is unavailable whether a rubber dam was used during root filling of the 660 teeth in the present study, the use of a rubber dam during endodontic treatment is frequent in Sweden; in a study by Koch et al (29) more than 90% of the general practitioners reported a routine use. It can be noted that despite the assumed frequent use of rubber dam, the frequency of AP in the root-filled teeth was high. The high frequency of inadequate root fillings may be an explanation for this finding. Also, even with the use of rubber dam, deficiencies in the aseptic treatment routines can occur.

The use of panoramic radiographs for the classification of root-filling quality makes the observed low frequency of adequate root fillings (35%) in the present study somewhat uncertain but similar to the low frequency (30.5%) reported by Frisk et al (9). Furthermore, the well-known pattern with a significantly higher frequency of AP in teeth with inadequate root fillings (9, 15, 23, 30) was found also in the present study. The lowest proportion of AP (12.9%) was detected when both the root filling and coronal restoration were of adequate quality, which is in accordance with previous studies (3).

Similar to the study by Frisk et al (31), we found that manifest caries was significantly higher in the root-filled teeth compared with the non-root-filled teeth. However, the underlying reasons are not well-understood and require further exploration.

A higher frequency of AP was found in root-filled teeth with manifest caries compared with those without manifest caries by using χ^2 analysis. However, logistic regression did not disclose any significant association between caries and AP. Moreover, Frisk et al (9) found recurrent caries not to be predictive of AP in root-filled teeth; however, in a study by Kirkevang et al (32), an association between caries and AP was found, but only for primary caries.

Logistic regression analysis did not disclose any significant association between composite restoration and AP. The variable with the highest OR for AP (OR, 4.02; CI, 2.54–6.36) was inadequate quality of the root fillings. Furthermore, marginal bone loss $>1/3$ of the root length was also significantly associated with AP. The association between severe marginal bone loss and AP in root-filled teeth has been reported previously in longitudinal studies (10, 29, 33) and might be explained by the spread of microorganisms through the root dentin either from a denuded root surface to the root canal or vice versa (34) or by the progression of marginal inflammation to the apical area, inducing inflammation at the apical level.

Although teeth with coronal leakage and coronal restorations of inadequate quality had higher frequencies of AP, it was not possible to include these variables in the logistic regression because of their close relation to the variable caries.

In conclusion, the results did not support our hypothesis that the frequency of AP is higher for teeth restored with composite compared with teeth restored with other types of restorations. There was no association between the type of restoration and AP, provided that the quality of the coronal restoration was adequate.

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The authors deny any conflicts of interest related to this study.

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III

Further Treatments of Root-filled Teeth in the Swedish Adult Population: A Comparison of Teeth Restored with Direct and Indirect Coronal Restorations

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Abstract

Introduction: The aim of this study was to evaluate the frequencies of nonsurgical retreatment, root-end surgery, extraction, and further restoration of root-filled teeth in Sweden in 2009 during a follow-up period of 5 years and to compare the outcomes in teeth restored with direct or indirect restorations. **Methods:** Data from the Swedish Social Insurance Agency were analyzed, and the frequencies of nonsurgical retreatment, root-end surgery, extractions, and further restoration were calculated for all teeth registered as root filled during 2009. Chi-square tests were applied to detect any significant differences in the frequency of further treatment in teeth registered as restored with either a direct or an indirect restoration within 6 months of root filling. **Results:** Of the 248,299 teeth reported root filled in Sweden in 2009, nonsurgical retreatment was registered in 2.2%, root-end surgery in 1.0%, and extractions in 9.2% during the follow-up period. Of the teeth restored with a direct restoration within 6 months after the root filling, 30.3% were registered as having undergone at least 1 further direct restoration; the corresponding percentage of teeth with indirect restorations was 6.4%. A statistically significant difference in the frequency of nonsurgical retreatment, extraction, and further restoration was found; teeth restored with an indirect restoration within 6 months of root filling had fewer of these treatments than those restored by direct restoration. **Conclusions:** Low frequencies of nonsurgical retreatment and root-end surgery were reported 5 years after root filling, whereas extraction was more common. Fewer additional treatment procedures were registered for teeth with indirect restorations than for those with direct restorations. (*J Endod* 2017;43:1428–1432)

Key Words

Apicoectomy, endodontics, epidemiology, permanent dental restoration, root canal therapy, tooth extraction

Under ideal conditions, the outcome of a root filling and permanent direct or indirect restoration should be uneventful (ie, the tooth should function without any further treatment). However, studies based on data from insurance companies in the

United States, Taiwan, and Germany report that 2 to 8 years after completion of the root filling, nonsurgical retreatment was required in 0.4%–3.2% of the teeth and root-end surgery in 0.6%–3.7% (1–4), indicating failure of the root canal treatment.

Extraction of the tooth may also be the choice in case of failed endodontic treatment; extraction rates of 6.7%–23.3% within 2 to 10 years of root canal treatment have been reported in a systematic review (5) and in recent studies from Taiwan, Germany, England, Wales, and Sweden (3, 4, 6, 7). However, in these studies, the reason underlying the decision to extract the tooth was not explored. It has been reported that the decision to extract a root-filled tooth is based primarily on factors other than failure of endodontic treatment (8, 9).

Some studies following the fate of root-filled teeth for 5 to 10 years after root canal treatment have indicated better survival of teeth restored with indirect compared with direct restorations (5, 7). Although extraction seems to be less frequent in indirectly restored teeth, it remains unclear whether the frequencies of nonsurgical retreatment and root-end surgery differ in relation to the type of coronal restoration. Root-end surgery may be the clinician's first choice in cases of endodontic failure of an indirectly restored tooth (10).

Besides failure of the root canal treatment, the coronal restoration may fail, necessitating further restorative procedures. Compared with indirectly restored teeth, those restored with a direct restoration after root filling may more frequently need total

Significance

This study showed low frequencies of nonsurgical retreatment and root-end surgery 5 years after root filling, whereas extraction and further restorations were more common. Teeth with indirect restorations had fewer additional treatment procedures than those with direct restorations.

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replacement of the restoration or supplementary restorations (eg, in case of cusp fracture). To date, few studies have addressed this issue, and the results of the available studies are contradictory. Spielman et al (11) reported a significantly higher percentage of restorative failures in root-filled teeth with direct restorations, whereas other studies have found no such difference (12, 13). Because the results of previous studies are inconsistent and based on small samples, further investigations in large populations are warranted.

To date, little is known about the natural course of root-filled teeth and how frequent further treatments are. Therefore, the present study was designed to test 2 hypotheses: first, that compared with teeth directly restored after completion of the root filling, indirectly restored teeth are less frequently extracted, less frequently undergo nonsurgical retreatment and less frequently require restoration replacement and, second, that root-end surgery is more frequently undertaken on indirectly restored root-filled teeth.

Therefore, the aim of this study was to evaluate the frequencies of nonsurgical retreatment, root-end surgery, extraction, and further restoration in relation to a direct versus an indirect restoration during a 5-year follow-up period of teeth root filled and restored within 6 months in Sweden in 2009.

Materials and Methods

In Sweden, all citizens are insured by the tax-funded Swedish Social Insurance Agency (SSIA), and, therefore, data on dental treatment are available for the whole adult population (residents 20 years and older). The SSIA database of dental treatment was described in more detail previously (7). The root-filled teeth were identified in the SSIA database by searching for treatment codes corresponding to root filling of 1–4 root canals (items 501–504) registered between January 1 and December 31, 2009. The database allows for the identification of completed root fillings in a specific tooth as well as in the specific individual. All root-filled teeth were tagged and tracked in the database for a time period of 5 years after completion of the root filling with a cutoff date of December 31, 2014. The type of coronal restoration within 6 months of completion of the root filling was based on the treatment code registered and grouped as follows:

1. Indirect restoration (items 801, 805–809: corresponding to an inlay, onlay, or a full-crown restoration fabricated in a laboratory)
2. Direct restoration (items 701–707: corresponding to a direct resin composite restoration of 1 to 5 surfaces)
3. Unknown (no registration of coronal restoration within 6 months of the root filling)

Teeth registered as having both indirect and direct restorations within 6 months of completion of the root filling were classified as indirectly restored.

To identify further treatment provided within 5 years of completion of the root filling, the database, comprising all teeth root filled during 2009 and restored with an indirect, direct, or unknown restoration, was searched for treatment codes indicating the following:

1. Extraction (items 401–404: corresponding to extraction of a tooth with the difficulty level ranging from uncomplicated to surgical removal)
2. Nonsurgical retreatment (items 501–504: corresponding to nonsurgical retreatment of 1–4 root canals)
3. Root-end surgery (items 541–542: corresponding to root-end surgery of 1 or more teeth at the same appointment)
4. Direct restoration (items 701–707: corresponding to a direct resin composite or glass ionomer restoration of 1 to 5 surfaces)

5. Indirect restoration (items 801, 805–809: corresponding to an inlay, onlay, or a full-crown restoration fabricated in a laboratory)

Of the data on extractions reported to the SSIA (items 401–404), nonsurgical retreatment (items 501–504), and root-end surgery (items 541–542), data were excluded in cases of inadequate information, that is: tooth number was not specified, a specific treatment was registered more than once for the same tooth and day, and extraction was registered more than once.

With respect to further restorative procedures reported to the SSIA (items 701–707, 801, 805–809), data were excluded in cases of inadequate data (ie, tooth number was not specified).

The frequencies of initial nonsurgical retreatment, initial root-end surgery, extraction, and further restorative procedures were calculated for all teeth root filled during 2009 with respect to the type of coronal restoration (indirect vs direct). Of special interest for this study was the first occasion after completion of the root filling on which nonsurgical retreatment and root-end surgery were undertaken; therefore, only the first registration of these treatments was included in the analysis.

IBM SPSS Statistics Version 22 (SPSS Inc, Chicago, IL) was applied for statistical analysis. Chi-square tests were applied to detect any significant differences in the frequency of further treatments associated with the type of coronal restoration within 6 months of root filling. Differences were considered as significant at $P < .001$. The study was approved by the Regional Ethical Review Board at Lund University, Lund, Sweden (Dnr 2011/800).

Results

Teeth Root Filled in 2009

In all, 248,299 teeth in 217,047 individuals (49.8% women and 50.2% men) were reported as root filled in Sweden during 2009. The average age of the individuals at the time of root filling was 55 years, ranging from 20–102 years. The survival rate has been presented in a previous study (7).

Type of Coronal Restoration

Of the 248,299 root-filled teeth, 55,974 (22.5%) were restored by indirect restoration fabricated in a laboratory and 143,295 (57.7%) were restored by direct restoration. Of the indirectly restored teeth, 41,812 (74.7%) received a post and core (fabricated either directly or indirectly). For the 49,030 (19.7%) remaining teeth, the type of coronal restoration was unknown because no treatment code for any restoration had been registered within 6 months after completion of the root filling.

Further Treatment of Root-filled Teeth during 5-year Follow-up

Excluded from the analysis of further treatment were 125 nonsurgical retreatments and 57 root-end surgeries registered more than once on the same tooth during the 5-year follow-up period. Thus, 29,943 (12%) of the teeth root filled in 2009 were registered as undergoing 1 or more further treatment procedures (nonsurgical retreatment, root-end surgery, and extraction) during the 5-year follow-up period, and 218,325 (88%) of the teeth required no further treatment (Table 1).

Nonsurgical Retreatment

Of all teeth root filled in 2009, a total of 5546 (2.2%) were registered as undergoing an initial nonsurgical retreatment during the 5-year follow-up period. Some of these nonsurgically retreated teeth also had root-end surgery ($n = 182$), were extracted

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TABLE 1. Registered Further Treatment Procedures (Nonsurgical Retreatment, Root-end Surgery, and Extraction) of Teeth Registered as Root Filled during 2009 in Sweden

Further treatment procedures	n (%)
No	218,325 (88.0)
Yes	29,943 (12.0)
Total	248,268 (100.0)
Treatment procedures registered	
Nonsurgical retreatment	
Nonsurgical retreatment, n = 4858	
Nonsurgical retreatment + extraction, n = 483	
Nonsurgical retreatment + root-end surgery, n = 182	
Nonsurgical retreatment + root-end surgery + extraction, n = 23	
Total	5546 (2.2)
Root-end surgery	
Root-end surgery, n = 1964	
Root-end surgery + extraction, n = 264	
Root-end surgery + nonsurgical retreatment, n = 182	
Root-end surgery + nonsurgical retreatment + extraction, n = 23	
Total	2433 (1.0)
Extraction	
Extraction, n = 22,169	
Extraction + nonsurgical retreatment, n = 483	
Extraction + root-end surgery, n = 264	
Extraction + root-end surgery + nonsurgical retreatment, n = 23	
Total	22,939 (9.2)

Teeth were excluded (n = 31) when data on further treatment reported to the Swedish Social Insurance Agency were inadequate (tooth number was not specified, a specific treatment was registered more than once on the same tooth and day, or extraction registered more than once), leaving 248,268 root-filled teeth in the analysis.

(n = 483), or were extracted after root-end surgery (n = 23), but for the majority no further treatment was registered (n = 4858) (Table 1).

Nonsurgical retreatment was more frequent in teeth with direct restorations (2.4%) than in those with indirect restorations (1.2%). The highest proportion was registered for the 1396 teeth (2.8%) for which the type of coronal restoration was unknown. All the intergroup differences (indirect, direct, and unknown coronal restoration) were statistically significant (P < .001) (Table 2).

Root-end Surgery

Of all the teeth root filled in 2009, a total of 2433 (1.0%) underwent root-end surgery within the follow-up period of 5 years. Of these teeth, 469 (19.3%) underwent further procedures, such as extraction

(n = 264), nonsurgical retreatment (n = 182), or nonsurgical retreatment followed by extraction (n = 23) within the 5-year follow-up period (Table 1).

The proportion of teeth undergoing root-end surgery was higher in those with indirect restorations (1.1%) than direct restorations (0.8%). The highest proportion of root-end surgery was registered for teeth with unknown coronal restorations (1.3%). The intergroup differences (indirect, direct, and unknown coronal restoration) were all statistically significant (P < .001) (Table 2).

Extraction

In total 22,939 (9.2%) of the teeth root filled in 2009 were registered as extracted by the end of the 5-year follow-up period (Table 1). The proportion of extractions was lower in teeth with indirect (5.0%) than direct restorations (9.5%). The highest proportion was registered for teeth in which the type of coronal restoration was unknown (13.2%). The intergroup differences (indirect, direct, and unknown coronal restoration) were all statistically significant (P < .001) (Table 2).

Additional Restorative Treatment

Of the 143,295 teeth restored with a direct restoration within 6 months of the completed root filling, 43,363 (30.3%) teeth were registered as receiving at least 1 further direct restoration (ranging from 1–17), and 11,919 (8.3%) were registered with an indirect restoration within the 5-year follow-up period.

Of the 55,974 teeth registered as being restored with an indirect restoration within 6 months of the root filling, the corresponding numbers were 3594 (6.4%) and 2175 (3.9%) for additional direct (ranging from 1–6) and indirect restorations, respectively. The difference in frequency of further restorations between directly and indirectly restored teeth was significant (P < .001). Detailed data are presented in Tables 3 and 4.

Discussion

In this study of the Swedish adult population, there was a low frequency of nonsurgical retreatment (2.2%) and root-end surgery (1.0%) within 5 years of completion of the root filling. However, extractions were more common; 9.2% of the teeth were registered as extracted. Our hypotheses were verified; compared with teeth directly restored within 6 months of the completed root filling, those with indirect restorations underwent fewer nonsurgical retreatments, extractions, and further restorations but more root-end surgeries during the 5-year follow-up period.

The present study is based on an extensive number of root-filled teeth; data on dental treatment were available for the whole adult population. Because the SSIA covers most dental procedures including

TABLE 2. Frequencies of Nonsurgical Retreatment, Root-end Surgery, and Extraction Registered during the Follow-up Period of 5 Years in Relation to the Type of Coronal Restoration Provided within 6 Months of Root Filling

Type of coronal restoration	Further treatment procedures		
	Nonsurgical retreatment, n (%)	Root-end surgery, n (%)	Extraction, n (%)
Indirect restoration	650 (1.2)	605 (1.1)	2786 (5.0)
Direct restoration	3500 (2.4)	1187 (0.8)	13,677 (9.5)
Unknown	1396 (2.8)	641 (1.3)	6476 (13.2)
Teeth included in the analysis	248,294 (100.0)	248,297 (100.0)	248,275 (100.0)

Of the 248,299 teeth root filled in 2009, teeth were excluded from the analysis of nonsurgical retreatment (n = 5), root-end surgery (n = 2), and extraction (n = 24) because tooth number was not specified. Therefore, the total number of teeth in each column differs. All the intergroup differences were statistically significant (indirect, direct, and unknown coronal restoration) (P < .001).

TABLE 3. Number of Further Direct Restorations Registered during the Follow-up Period of 5 Years for Teeth Restored with Indirect, Direct, or Unknown Coronal Restorations within 6 Months of Root Filling

Coronal restoration after root filling	Number of direct restorations after initial restoration					Total, <i>N</i> (%)
	0, <i>n</i> (%)	1, <i>n</i> (%)	2, <i>n</i> (%)	3, <i>n</i> (%)	≥4, <i>n</i> (%)	
Indirect	52,380 (93.6)	3264 (5.8)	269 (0.5)	51 (0.1)	10 (0.0)	55,974 (100.0)
Direct	99,932 (69.7)	30,640 (21.4)	9160 (6.4)	2496 (1.7)	1067 (0.7)	143,295 (100.0)
Unknown	37,317 (76.1)	8950 (18.3)	2088 (4.3)	501 (1.0)	174 (0.4)	49,030 (100.0)

The intergroup differences were statistically significant (indirect, direct, and unknown coronal restoration) ($P < .001$).

prosthodontics and implants, almost all dentists in Sweden are affiliated with the SSIA.

When charges for dental treatment exceed 3000 Swedish crowns (SEK) (US \$334), dental care costs are subsidized in a stepwise manner with the highest reimbursement, 85%, for fees exceeding 15,000 SEK (US \$1671) during 1 calendar year. The amounts in US \$ are based on exchange rates (US \$1 = 8.97 SEK) on October 28, 2016. All dental care provided is to be reported by dentists to the SSIA.

Despite the large number of teeth studied, there are some limitations to be considered. First, the present study is based on data received from the SSIA; patient charts and radiographs are unavailable in this study design. Thus, information such as the preoperative status of the pulp and periapical tissues is unknown nor is it possible to differentiate between primary root canal treatment and nonsurgical retreatment undertaken in 2009 because treatment codes are the same for both procedures. Furthermore, even though dentists are obliged to report all interventions to the SSIA, some procedures may not have been registered for various reasons. For example, the need for further treatment may have emerged very soon after completion of the root filling and so the dentist did not charge the patient or treatment may have been undertaken abroad. Another limitation is the lack of data for younger age groups because only individuals ≥20 years are included in the SSIA database on dental treatment.

The aim was to study the frequencies of further treatment in relation to the type of restoration; therefore, the teeth were grouped according to the type of coronal restoration registered within 6 months of the root filling. Because information about the preoperative status of the teeth was unavailable, it is unclear whether a restoration was already present at the time of root filling and how much tooth substance remained. Teeth that already had an indirect restoration at the time of the root filling and were subsequently restored with a composite restoration through the crown were thereby classified as directly restored. Consequently, the 22.5% of teeth registered as indirectly restored may be somewhat underestimated. Moreover, the treatment codes used for indirect restoration (801, 805–809) do not differentiate between an inlay, onlay, or a full-crown restoration.

If no coronal restoration was registered within 6 months, the restoration was classified as unknown. This applied to almost 20% of the teeth. An unknown restoration might imply that the tooth was restored with a direct composite, glass ionomer, or cement intended as a temporary restoration, possibly in expectancy of symptoms subsiding or signs of healing to appear. This may also explain why in this group

the frequency of root-end surgery was slightly higher (1.3%) than in indirectly and directly restored teeth.

For the majority of root-filled teeth in this study (88%), no further interventions indicating endodontic treatment failure were registered over a 5-year perspective. In Sweden, only a small percentage (0.6%) of dentists are specialists in endodontics (14); thus, the results of the present study may be considered to be representative of general dental practitioners and are comparable with those of several previous studies (2–4,6). Only 1 study (1) found an exceptionally high percentage of teeth (97%) without untoward events leading to such procedures as retreatment, root-end surgery, and extraction.

In the present study, the frequency of nonsurgical retreatment (2.2%) and root-end surgery (1.0%) was low. However compared with root-end surgery ($n = 2433$), nonsurgical retreatment was undertaken in more than twice as many teeth ($n = 5546$). The root-filled teeth were followed for 5 years, and a longer follow-up time might have yielded a higher frequency. However, 1 study (1) with a follow-up time of 8 years found that most untoward events (nonsurgical retreatment, root-end surgery, and extraction) occurred within the first 3 years of completion of the root filling. The present results are in accordance with previous studies reporting that 0.4%–3.2% of the teeth had undergone nonsurgical retreatment within 2 to 8 years (1–4) and 0.6%–3.7% had root-end surgery (1–4).

Another finding was that, compared with indirectly restored teeth, retreatment was twice as common in teeth restored by direct restoration within 6 months of the root filling. Several explanations may be possible; compared with a direct restoration, an indirect restoration may provide a better seal against oral microorganisms with fewer failures of endodontic treatment as a result although this question has not been thoroughly investigated. However, restorative failures were more frequent in the directly restored teeth as evidenced by further restorations, which could represent a potential risk for microbial leakage. On the other hand, 1 study (15) found the frequency of AP to be equal in teeth restored with laboratory-fabricated crowns and teeth restored with direct composite restorations as long as the seal was assessed as adequate.

It is also possible that dentists are less likely to advocate nonsurgical retreatment for indirectly restored teeth than for those directly restored; drilling through a crown in an extensive bridge may be considered a riskier procedure than removal of a direct composite restoration to gain access to the root canals. In a study by Wenteler et al (16), it was found that the presence of a cast post/core restoration influenced the

TABLE 4. The Number of Additional Indirect Restorations Registered during the Follow-up Period of 5 Years for Teeth Restored with Indirect, Direct, or Unknown Coronal Restorations within 6 Months of Root Filling

Coronal restoration after root filling	Number of indirect restorations after initial restoration					Total, <i>N</i> (%)
	0, <i>n</i> (%)	1, <i>n</i> (%)	2, <i>n</i> (%)	3, <i>n</i> (%)	≥4, <i>n</i> (%)	
Indirect	53,799 (96.1)	2090 (3.7)	82 (0.1)	2 (0.0)	1 (0.0)	55,974 (100.0)
Direct	131,376 (91.7)	11,661 (8.1)	253 (0.2)	5 (0.0)	0 (0.0)	143,295 (100.0)
Unknown	38,928 (79.4)	9845 (20.1)	251 (0.5)	6 (0.0)	0 (0.0)	49,030 (100.0)

The intergroup differences were statistically significant (indirect, direct, and unknown coronal restoration) ($P < .001$).

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root canal retreatment strategy; other treatment options were proposed, such as implant therapy or periapical surgery. In the present study, 74.7% of the indirectly restored teeth had a post and core, which may have influenced the treatment decision in cases of endodontic failure.

Although the frequencies of root-end surgery were very similar for teeth with indirect (1.1%) and direct restorations (0.8%), the difference was statistically significant because of the large samples involved in studies of data retrieved from a national database. The proportion of teeth receiving a post (cast post or prefabricated) in the present study was considerably higher compared with previous studies on the survival of root-filled teeth conducted in the United States and England (2, 17). Because patient charts and radiographs are unavailable, we can only speculate on the reasons why 75% of the indirectly restored teeth were registered with a post; Swedish dentists are possibly more likely to save teeth with an extensive loss of tooth substance in which a post is needed for the retention of a crown compared with dentists in other countries where other treatment options such as extraction and replacement with an implant or a fixed partial denture may be more preferable. The difference may also be because of the reimbursement system, which is likely to have an impact on the choice of therapy. Furthermore, it is possible that the assessment regarding the amount of remaining tooth substance when a post is needed differs among dentists in Sweden compared with dentists in other countries.

Of the 248,299 teeth root filled in 2009, 9.2% were extracted within 5 years. Extraction was more frequent than nonsurgical retreatment and root-end surgery. However, there could be other reasons for extraction than failed endodontic treatment. In the present study, information about the indications for extraction was unavailable; however, other studies report a relatively low percentage (6.8%–10.7%) of root-filled teeth extracted because of endodontic pathology (8, 9). More common reasons were caries, fractures, and teeth that were deemed unrestorable.

In the present study, the majority of teeth were directly restored (57.7%) within 6 months of the root filling. The percentage of teeth restored indirectly was considerably lower (22.5%). Extraction was more frequent in directly restored teeth (9.5%) compared with those indirectly restored (5.0%). The results are in accordance with previous studies (5, 17) in which a higher survival of teeth with a full-coverage restoration was found. Although it is not possible to differentiate between a full crown, inlay, or onlay in the present study, it is reasonable to assume that most of the teeth in this group were restored with a full crown providing cuspal coverage because nearly 75% were also restored with a post. Several studies (5, 17) have found restoration with a crown to be a factor associated with improved longevity of root-filled teeth; however, selection bias may also have contributed to the result. It is possible that teeth with a good prognosis were more likely to receive an indirect restoration with full cuspal coverage than those with a more questionable prognosis.

During the follow-up time of 5 years, the directly restored teeth required considerably more additional direct restorations (30.3%) than those with indirect restorations (6.4%). The results corroborate and reinforce the concept that more restorative failures occur in root-filled teeth that are directly restored than in those restored indirectly (ie, by an inlay, an onlay, or a crown). This is in accordance with the findings of a previous study by Spielman et al (11) but differs from the findings of other studies (12, 13).

Although the initial cost of an indirect restoration is higher than that of a direct restoration, it is uncertain whether in a 5-year perspective the overall cost is actually higher given the significantly greater further treatment required for the directly restored teeth. The poor longevity of direct restorations, especially in molar teeth, has been the focus of previous studies, and the problem does not seem to be limited to root-filled teeth (18). The economic consequences and implications of this finding will be topics for future studies.

In conclusion, this study revealed a low frequency of nonsurgical retreatment and root-end surgery in the 5 years after root filling and restoration. Extractions were more common. There were significantly fewer nonsurgical retreatments and extractions of indirectly than directly restored teeth but slightly more root-end surgeries. Teeth with direct restorations required significantly more additional restorative procedures; 30.3% underwent at least 1 further direct restoration, whereas the corresponding percentage for indirectly restored teeth was 6.4%. The results imply a better outcome for teeth with indirect restorations during a 5-year perspective. However, this may be a result of selection bias; thus the results should not be extrapolated to support a general recommendation that root-filled teeth should be restored with indirect restorations. Regarding the choice of coronal restoration of a root-filled tooth, little is known about the dentist's decision-making process. This will be the subject of future studies.

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IV

Coronal restoration of the root-filled tooth – a qualitative analysis of the dentist's decision-making process

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Abstract

Aim: To describe the decision-making process of the general dental practitioner (GDP) underlying the choice of coronal restoration of a root-filled tooth.

Methodology: GDPs were strategically selected with respect to gender, age, undergraduate dental school, service affiliation and duration of professional experience. Semi-structured in-depth interviews were conducted, focusing on the informant's personal experience of the process which leads to a decision as to how to restore a root-filled tooth. The informants were invited to describe in their own words the latest two cases involving selection of direct or full crown restorations respectively. The interviews were digitally recorded and transcribed verbatim. Interviews from 14 informants, aged 27 – 64 (mean age 46 years), were included and analyzed according to Qualitative Content Analysis.

Results: A theme (latent content) was identified: Clinical factors were considered important but were overruled by context and patient opinions, if in conflict. Three main categories, including seven sub-categories (manifest content), were identified. The categories were clinical factors, contextual factors and patient's views. Clinical factors underlying the GDPs' decision included the current dental status and the estimated longevity of the intended restoration. In certain cases contextual factors were also of importance, either supporting the GDPs' decision or modifying it. However, the patient's views played a decisive role in the final choice of coronal restoration, leading to either mutual acceptance or a compromise, taking into account the patient's economic status and opinions.

Conclusions: With respect to coronal restoration of a root-filled tooth, the GDPs' decision-making process was based not only on clinical factors, but also on decisive contextual factors and consideration of the patients' views.

Introduction

A determining factor for the successful outcome of endodontic treatment is a coronal restoration of adequate quality (1, 2). Regardless of whether a direct or an indirect restoration is chosen, the aim is to restore the function and aesthetics of the tooth and also to provide a tight marginal seal against oral microorganisms.

A laboratory-fabricated crown is often advocated as the optimal restorative treatment for the root-filled tooth. However, in Sweden the fee for a laboratory-fabricated crown is approximately 3–4 times higher than for a direct composite restoration (3) and usually the procedure is more time-consuming, adding to the cost. On the other hand, the prognosis may be better: 5–10 years after root-filling, the survival rates for teeth restored with laboratory-fabricated crowns are reported to be significantly better than those with direct restorations (4–6). Moreover, teeth restored with laboratory-fabricated restorations require fewer subsequent restorations, indicating that treatment failure is more common after composite restoration (7–9). Although the reported outcomes are in favor of indirect restorations (4–8) this may not necessarily imply that laboratory fabricated crowns are better than direct restorations in every case: selection bias cannot be excluded.

Fundamental to adequate treatment is clinical decision-making, a complex process whereby the clinician evaluates clinical findings and medical history (10). The clinical decisions are based not only on the clinician's theoretical knowledge and clinical experience of diagnosis and treatment options, but also on patient-related aspects such as empathy and ethics (11).

In Sweden, almost a quarter of million teeth are root-filled and restored annually (6). Thus many dentists make decisions about restoration of a root-filled tooth on a daily basis.

The choice of coronal restoration for a root-filled tooth may be influenced by such factors as technical and biological issues, the preferences of the dentist, the patient's wishes and various economic factors. The prognosis may also influence the dentist's decision: in a study by Chugal et al. a significant association was found between preoperative diagnosis and type of coronal restoration after root canal treatment: teeth with apical periodontitis (AP) were less likely to be restored with a crown than those without periapical disease (12). One survey investigated the opinions and clinical routines of general dental practitioners (GDPs) about the restoration of root-filled teeth (13), but most questions focused on different technical aspects. Factors of importance, other than those suggested by the authors, may not have been disclosed. Because there are so few studies in this field, little is known about the dentist's decision-making process with respect to the choice of coronal restoration of a root-filled tooth.

Qualitative research methods are considered useful for analyzing people's thoughts, feelings, attitudes, perceptions and preferences (14) and are applied when depth, insight and understanding are required of a particular phenomenon, in its own context (15). Thus, a qualitative research method can be used to improve our knowledge and understanding of a variety of issues of importance to dentistry (15). The qualitative approach offers a potentially deeper understanding of the dentist's decision-making process with respect to the choice of coronal restoration for the root-filled tooth. The method allows exploration of factors of importance from the perspective of the dentist, which may not have been considered in depth in previous questionnaire studies (13, 16, 17).

The present study is based on a scientific method of analysis for qualitative data. The aim was to characterize the dentist's perspective of the decision-making process underlying the choice of coronal restoration of a root-filled tooth.

Material and methods

Qualitative content analysis

The present study was based on interviews with GDPs. The data were analyzed using Qualitative Content Analysis (18).

Research team and reflexivity

The three authors VD, EW and HF are specialists in Endodontics. EW is experienced in qualitative research, whereas HF and VD have only limited experience. Our preconception was that the improved survival rates reported for root-filled teeth restored with crowns may be attributable in part to selection bias. Apart from technical and biological factors, the dentist's decision-making process underlying the choice of coronal restoration may also be influenced by financial issues and dentist and patient preferences.

The Swedish context of root canal treatments and coronal restoration

In Sweden, root canal treatments and coronal restorations are undertaken primarily by GDPs, working within the public dental health service (PDHS) or the private sector.

All citizens of Sweden ≥ 24 years old are entitled to a dental care subsidy from the tax-funded Swedish Social Insurance Agency (SSIA) including a step-wise high-cost protection, whereby the patient pays 100% of dental fees up to 3 000 Swedish crowns (SEK) (approximately 280 Euro), and then 50% up to 15 000 SEK: thereafter the patient pays 15% of the fees. Most dental treatments are covered by the SSIA, provided that certain criteria are met. For example, for a crown restoration to be reimbursable, the defect of the tooth has to be extensive, that is 4 out of 5 surfaces for a premolar/molar and 3 out of 4 surfaces for an incisor/canine (19). Apart from this fee-for-service system, patients have the option of subscribing to basic dental care coverage for a fixed fee, through an insurance called Dental

Care for Health offered by the PDHS (20). This includes root fillings, composite restoration and single crowns. The dental clinic receives a fixed compensation for each patient. Some groups of patients are covered by other regulations, such as those with an increased need for dental care due to poor health, whereby fees for dental care are reduced but extensive restrictions apply, for instance fixed prosthodontics is usually not included. Dental care is free of charge for patients <24 years old.

Informants

A strategic selection was conducted of GDPs practicing in Sweden. Two absolute inclusion criteria applied:

- Recent experience of decision-making about coronal restorations for root-filled teeth
- Fluency in Swedish, essential for in-depth narration during the interview

In order to ensure a variety of participating GDPs and thereby different perspectives on the topic, the informants were strategically selected according to the following variables:

- Gender (female or male)
- Age (years)
- Undergraduate dental education: Stockholm, Gothenburg, Malmö or Umeå, i.e. any of the universities in Sweden providing undergraduate dental education
- Service affiliation: public dental health service (PDHS) or private practice
- Professional experience (years)

The distribution of the informants with respect to these variables is presented in Table 1.

Recruitment

Through personal contacts, informants were successively and strategically recruited and interviewed, until saturation was considered to be achieved. In total, 35 GDPs were contacted, either by telephone or e-mail. They were given information about the study and invited to participate. Figure 1 illustrates the process whereby 14 interviews were finally included in the analysis. Before the interview, the GDPs were asked to prepare an account of their four most recent cases of permanent restoration of a root-filled tooth: two restored with composite and two with laboratory-fabricated crowns. Furthermore, these cases were to involve teeth which had been root-filled by the GDPs themselves and had not been previously restored with a laboratory-fabricated crown. If the GDP considered it helpful, anonymized records, radiographs and plaster study models could be brought to the interview, to facilitate the description.

The study was approved by the Regional Ethical Review Board at Lund University, Lund, Sweden (Dnr 2016/547). Before the interview the GDPs received verbal and written information about the study and they provided written consent.

Pilot study and test interviews

Before study start, a pilot study, including three interviews, was conducted by two dental students. These interviews were not included in the analysis of the present study. Based on the pilot study, we decided to provide the informants with more comprehensive information prior to the interviews, with special reference to their personal experience, rather than their general opinions about coronal restoration. Furthermore, the number of cases was increased from two to four (2 x 2), and excluded teeth previously restored with crowns. Two test interviews with feed-back on the interview technique and transcription were conducted by VD before the start of the study.

Data collection

In-depth, semi-structured, interviews were conducted with 15 GDPs, with special reference to their personal experience in arriving at a decision as to the type of permanent restoration of a root-filled tooth. The interviewer invited the informants to express themselves freely on the topic. During the interview the informants were asked to describe:

- The latest two occasions on which a laboratory-fabricated crown was chosen for permanent restoration of a tooth after root-filling.
- The latest two occasions on which a direct composite restoration was chosen for permanent restoration of a tooth after root-filling.

The interviewer asked questions intended to encourage the informant to develop, specify, deepen and reflect on the narrative. Questions were asked in order to guide the narrative to cover the decision-making process in specific cases, when informants tended to talk more in general about coronal restoration of root-filled teeth. Before the interview was completed the informants were invited to add any further comments.

The interviews were conducted during October 2017 – October 2018 by one interviewer (VD) at a location chosen by the informant: at the GDP's clinic (n=14) or at the interviewer's office (n=1). Each informant was interviewed on one occasion. The duration was 15 – 40 minutes and the interviews were digitally recorded. During the interviews all but four informants showed radiographs of their cases. The interviews continued until no new information was forthcoming from the informants. One interview was excluded from the text preparation process and analysis, because the informant's narrative focused on technical details which were not relevant to the study.

Text preparation process

Fourteen interviews were transcribed verbatim by a contracted secretary and checked and complemented for non-verbal expressions by VD. The transcripts were then read several times to gain an overall impression of the material. The interviews were then separated into meaning units; when there was a change in the meaning of what the informant was describing, a mark was made in the text. Then the text of each unit was condensed into a shorter formulation by removing the excess words, while preserving the meaning. For the first interview, identification of meaning units and the condensation were undertaken by two of the authors (VD, EW) together. Thereafter one author (VD) undertook this process for the remaining interviews.

Data analysis

Meaning units related to the decision process underlying the choice of coronal restoration were identified and selected for analysis. Through abstraction of these condensed meaning units, they were given a code, reflecting the possible inherent meaning of the content. The first part of one interview was coded together by two of the authors (VD, EW). The remainder of the first interview and a further two more interviews were then coded separately by the authors (VD, EW, HF) and compared and discussed until consensus was reached. For the remaining interviews the coding was conducted by the first author (VD). In cases of uncertainty about the codes a discussion was held until consensus was reached.

When the coding process was completed, the emergent patterns, (codes sharing a commonality), were grouped into categories and sub-categories illustrating the manifest (the visible, obvious components) level of content. This was followed by identification of a theme illustrating the latent (interpretation of the underlying meaning) level of content. With respect to codes, sub-categories, categories and themes, consensus among the authors was achieved

by discussion. An example of the text preparation process and analysis is presented in Table 2.

Results

A theme covering the latent content was identified: *Clinical factors considered important but overruled by context and patient opinions, if in conflict*. The dentist's decision-making process was in each case characterized by an assessment of clinical factors for which, in certain cases, contextual factors were weighted and occasionally modified the choice. However, the patient's views prevailed (Fig. 2). Three main categories were identified, including seven sub-categories covering the manifest content (Table 3).

Clinical factors

Clinical factors, dental status in general and potential longevity of the restoration formed the basis of the GDPs' decision about the type of coronal restoration. Occasionally, one clinical factor was the sole determinant, while in certain cases, several factors in combination contributed to the decision.

Dental status

The status of the tooth to be restored and that of the surrounding dentition, were in each case assessed by the dentist. All informants mentioned the amount of remaining tooth structure as a factor influencing the decision as to type of restoration. In cases of a substantial amount of residual tooth structure, in the GDP's view, a composite restoration was chosen. Such teeth were described as being intact or having at the most two to three previously restored surfaces, apart from the endodontic access cavity preparation, making the decision to use composite self-evident:

”Because the tooth is actually ... unrestored. Except the acce..., access cavity preparation. So in that case, I do not do any prosthetic therapy, rather ..., ... it is a filling. A simple occlusal filling on it.”

An exception was however, expressed by the informants: the presence a crack overruled the amount of remaining tooth structure. For those teeth, a crown was preferred, as protection from further damage. When the loss of tooth substance was considered extensive, the GDPs’ decision tended towards a crown.

” And..., and the whole buccal side is in fact ..., is in fact like composite from *before*, you could say. So he ..., where he had some tooth substance *left* ..., there was in fact sound tooth substance palatally you see ...,... the palatal cusp. And if that had gone, broken that, eh . So..., so there was very little tooth substance left [...] And in order to do a ..., a restoration ...,... then the best solution was with fixed prosthetics, on a post.”

Few informants mentioned the potential impact of the endodontic treatment prognosis on the choice of coronal restoration. When mentioned, few cases concerned root-fillings done by the informant but by a colleague. Situations were described in which the GDPs were not completely satisfied with root canal treatment by the informant or by colleagues: in their opinion the technical quality of the root-filling was suboptimal. The unsatisfactory result contributed, along with clinical and contextual factors, to incline the dentist to recommend a composite restoration. On the other hand, some informants stated that adequate root-filling quality was a factor which supported their decision to choose a crown restoration:

“And then you feel a little more motivated to put a ...,... a *crown* on it I think. [...] If you have a good foundation then it ..., it feels more Er..., it feels in fact easy ..., or better to build a ..., a good cover over a good foundation.”

One informant considered that uncertainty about the prognosis for endodontic retreatment was the decisive reason for choosing composite, although the remaining tooth structure was considered limited:

“In the six (first molar) [...] There was an *enormous* composite on it [...] There was such extensive ... periapical destruction. [...] And so we root-filled it like that. Now we have to see whether that large periapical area disappears. And in this case I just did an occlusal composite, because ..., I want to see if it heals over time.”

The status of the surrounding dentition influenced the decision. A crown was the restoration of choice for a root-filled tooth which was to serve as an abutment in a fixed partial denture. The clinical status of neighboring teeth was also reported to have an impact on the GDPs' decision. Thus, good status and the need to function as an abutment weighed heavily in favor of a crown, while there was hesitation with respect to a crown restoration in a heavily restored dentition.

“In fact the teeth..., the surrounding tiss ..., teeth were in fact fine. And then ... so if ..., it the surrounding ..., surrounding teeth had been very heavily restored and therefore ...,... then..., then I feel a little like: ”No, but should we really put a..., a diamond among all the old...” * Little laugh * [...] And then I can be a little reluctant I think, or perhaps one doesn't suggest that as the treatment of choice. A bit grotty round about and ...,”

It was considered difficult to achieve satisfactory aesthetics when only one anterior tooth was to be restored with a crown and this favored the choice of a composite restoration. Other clinical considerations included tooth type (molars) and the decision then favored a crown, whereas in patients with high caries activity composite was preferred. Perceived technical difficulties could shift the decision towards crowns in some cases and composites in others.

Assessment of longevity

The choice of composite was preceded by an assessment of expected survival. A stable dentition and the absence of bruxism were mentioned as favorable factors when composite was chosen, as well as the position of the tooth. Anterior teeth are subject to lower forces, and this was considered advantageous for survival of the composite. The longevity of previous restorations was also mentioned:

“So there *can* be a crown ... in the future, for this 44. But ... no. Not at present. [...]
And they still seem to last in her mouth so that, ... [...] We have done loads of fillings.
* Little laugh *”

When loading forces were considered extensive, due for example to the lack of neighboring teeth or bruxism or just extremely heavy occlusal force, it was predicted that a composite restoration would fail and a crown was preferable. This was also the case when a composite filling had already failed.

“And then I also took his bite into consideration, as he lacks both second and third molars...,... that it is..., it should take a lot of load. So from a pure durability...point of view so...,... we thought then that the only reasonable thing was ... to put a crown on it.”

A somewhat contradictory situation arose in selection of composite restoration of already heavily restored upper incisors. The choice of restoration was based on the assessment that a crown restoration would not be durable without a post and core and this treatment was considered too extensive.

Contextual factors

When taken into account, contextual factors could support the GDPs' choice of coronal restoration and thus influence the choice of treatment. Contextual factors could also modify the proposal for restoration: although a crown might be preferable, the GDP could still amend the treatment plan to a composite filling.

Patient-related factors

Factors related to the patient were taken into account by the GDP. The patient's age, although not determinant, could support a decision, based on clinical factors, to restore the tooth with a crown, in cases where the patient was relatively young and the tooth was expected to be in function for a long time:

“He isn’t so... .. No, he was born in -73, or something ... I mean he is going to have the use of that tooth for a long time. ... And that sort of has some influence ... on my reasoning about..., about which therapy we choose.”

The impact of the patients’ motivation and interest in their teeth was exemplified by a situation in which a crown was the restoration of choice, because of the extensive loss of tooth structure. The patient was interested in her teeth and wanted to maintain them, thus, the motivation was high:

“[...] so there will be a crown on that tooth. [...] It is a patient who wants to keep her teeth. She is keen for me to do a crown, she is the sort of patient who wants me to do what is best.”

Needs and desires expressed by the patient were also taken into account. One patient requested improved aesthetics and a more durable restoration because the previous composite restorations had failed repeatedly. Based on clinical factors, the GDP considered a crown to be preferable to a composite – a decision which reflected the need expressed by the patient.

On the other hand, occasionally, the GDP’s understanding of a patient’s complex situation would influence recommendation of a composite instead of a crown:

“Because at first she wasn’t very interested in keeping her appointments. [...] In fact she has so many teeth which are doubtful, so that ... there’s not enough money to cover that sort of prosthetics. Erm... .. It will be very difficult to make a start, because it’s a bit difficult: Wherever should one start? [...] Getting oral hygiene established...,... erm..., get..., get control of ... yes, like active caries lesions ...,... and... * Little laugh * ... get..., finally finish the root fillings. Because this has taken ... We have been working on this for several years. * Laugh *”

Knowledge about the patient’s financial status could influence the choice of composite, although a crown in fact would have been better. Dental fear was sometimes also decisive for choosing composite:

“Is *extremely* anxious during dental treatment [....] She..., ... she says this: [....] Are you ready soon? ... The rubber dam makes me panic. [....] Lies on the side of the chair. Ehh... Brings a friend along, holds her hand. So ... this is difficult. [....] And I knew she wanted to get out of here as soon as possible. [....] Despite [....] ... nice surrounding teeth and intact dentition so..., ... so I chose a filling for this situation. [....] Despite it actually ... I might have done some type of porcelain restoration which held it together.”

One informant mentioned the dentist-patient relationship as important. In this case, the patient suspected that her former dentist had caused her toothache and this influenced the GDP's decision:

” a patient ... who ... says that her previous dentist caused her problem ..., ... then I always feel a little worried, because then it feels like if *I* were to treat her and she had discomfort afterwards then she would blame me for causing her ... problem. Even if perhaps it isn't what I have done *actually* which ..., which is the cause of it. Yes. That it..., that I become a little more ... restrictive..., ... about... * Little laugh * ... about..., what I do. So that... So that is in fact also a ..., ... a reason that ... from *my* perspective, not to do a crown.”

The informant also commented that this was a new patient and at the time of the decision to do a composite restoration they did not know each other very well. It would be good if they would consider a crown restoration later on.

Dentist-related factors

A desire to preserve sound tooth structure was expressed, thus, to remove and sacrifice healthy tooth structure in crown preparation was regarded as overtreatment:

” But it ..., in the mouth there is quite a small harmless amalgam filling. And there are no cracks or such. And so I think it feels a bit clumsy to ... start preparing that tooth afterwards. [....] Because I feel that is a bit like overtreatment ..., ... when the tooth has such a small filling.”

A somewhat contradictory example was that of a tooth entirely restored with composite, except for the buccal surface. The restorations were considered small and of high quality. The

dentist therefore perceived the tooth to be adequate and thought it was wrong to remove sound tooth structure to make a crown. Thus, the choice was a further composite restoration.

The informants considered that root-filled teeth restored with crowns survived longer, because the crown protects the tooth by encircling it and holding the remaining tooth structure together better than composite.

“I usually always suggest a crown as the treatment of choice. [...] Yes, it lasts better in the long run, in fact.”

Preference for a crown was also expressed in a general context, the GDP reflecting that for the patient, root canal treatment is uncomfortable, time-consuming and expensive and protection by a crown is justified. The GDP also commented:

“And then I also think it’s rather fun to do crowns.”

The dentist’s current state of mind also had an impact on the decision, in combination with clinical factors:

“Otherwise, I might well have just done a new filling as well. It wasn’t that bad at all. But ... my frame of mind that day was... * Laugh * Then the choice was for..., for the crown.”

External circumstances

The particular payment model and accompanying rules were mentioned by the informants in conjunction with the decision process underlying their choice of restoration. They stated that the SSIA’s regulations, although not decisive, were often kept in mind as some kind of guideline for the choice of restoration, even if clinical factors constituted the basis for the decision. When the GDP decided to recommend a crown it was mentioned that SSIA’s criteria had been met:

”Yes, it was in fact so that it came under these ..., according to the national guidelines. That a certain amount of tooth structure is missing. I believe that for a front tooth there have to be three surfaces missing ..., ... to be able to do a crown. So it was in accordance with the Swedish Social Insurance Agency ..., Yes it did. Mm.”

When composite was chosen, the informants often mentioned that SSIA’s rules did not support a crown. However, if the patient qualified for high-cost protection, some GDPs stated that it facilitated their decision to recommend a crown in cases of uncertain prognosis, because the treatment would not be very expensive for the patient. In the same way as for SSIA’s regulations, the rules within the payment model Dental Care for Health served as a guideline for the choice of restoration, along with the economy of the clinic:

“There has been a lot of fiddling about with that tooth. She has come to me for a number of appointments. [...] And moreover she is covered by Dental Care for Health ...[....] I expect that purely financially it would be better for the clinic to do a crown straight away ...”

However, the GDPs’ decision about coronal restoration was directly affected by the regulations which apply to certain patient groups, including restrictions for fixed prosthodontics. In these circumstances, the choice of composite was often obvious, although in the opinion of the GDP a crown would have been a better option. Another external circumstance influencing a GDP’s decision was the lack of time available for the preferred treatment – a crown restoration:

“Because there was like so possibility of doing anything other than a composite in the time available. Before she left for USA.”

Patient’s view

The GDP’s recommendation and the fee for the suggested treatment alternatives were presented to the patient. The reasons for choosing a certain restoration and prognostic information were given, when considered necessary. Depending on the patient’s response,

either consent was obtained, or the decision was modified according to the patient's financial circumstances and preferences – provided that the dentist found it acceptable. If not, an extended discussion was initiated by the dentist, to further explain why a certain treatment was considered necessary.

Mutual decision

The dentists' recommendation, based on their knowledge and clinical experience, was often decisive for the patient's decision. When a coronal restoration was suggested by the dentist, there was often not much discussion as the patients readily accepted and agreed, usually without any objections. Most patients were described by the informants as being amenable to the treatment recommendation. Trust and a good dentist-patient relationship were stated by some informants to be contributing factors for reaching a mutual decision:

“He has been a patient here for a long time in fact. He trusts me that I can ... what I do, like, and ...,...still a good relationship, I think. So that those who have been my patients for a while, well they..., they accept my suggestions, in fact. It..., it is very good.”

If the dentist and patient were unable to agree about the treatment plan, and the dentist found the patient's wishes unacceptable, the dentist initiated an extensive discussion, including a thorough explanation. Situations were mentioned in which patients requested extraction, but in the dentist's view the tooth was not in such bad condition that extraction was warranted – the recommended treatment was root-filling and subsequent restoration. After such a discussion, patients often changed their views, accepting the dentist's advice and a mutual decision was reached. This extended discussion concerned whether to retain the tooth or not; once it was agreed to retain the tooth, there were seldom problems in reaching a mutual decision about crown restoration. One informant stated that if the patient had not consented to a crown restoration instead of composite, the informant would have continued the discussion with the aim of persuading the patient.

Some informants stated that patients under the payment model Dental Care for Health readily agreed to the suggested treatment, no financial consideration was involved:

“So she was quite in agreement with having a crown. And moreover she is covered by Dental Care for Health ..., ... so then there is not much discussion ..., ... erm..., about the cost of treatment. So I was able to give my opinion. And then she agreed to it.”

Occasionally, several treatment options were possible: apart from crown restoration as part of a fixed partial denture to replace a missing tooth, implants and removable partial dentures were alternatives. And for some teeth, both composite and crowns were considered suitable. The options, including fees and information about the prognosis, were presented to the patient, who then made the choice, and in this way a mutual decision was reached.

Compromise decision

When the patient was unwilling to accept the dentist's suggestion for coronal restoration, the dentist took the patient's view into account and modified the decision accordingly. This was the case when a crown was considered to be the best treatment option, but composite was chosen instead. As reasons for compromise, the patient mentioned economic factors as well as personal preferences. For example, as expressed in the quote below, one patient just wanted to keep her tooth, infection-free, without having it restored to function.

“There is also major loss of tooth substance. Here I would be very, very happy to put a crown on this tooth. But she thinks it feels unnecessary and expensive. [...] But rather she wants me to root-fill the tooth and just like put a small cover on the top. Mm. And you also have to ... accept that.”

The informants expressed understanding and respect for the patient's preference for a composite instead of a crown restoration, irrespective of their own opinion about the choice:

“Of course I can understand this, when one is so old and ..., 80 years of age, and then ... still, it is so delicate that there is no great stress ..., ... then I think that..., really there is no ..., ver..., very important reason to prefer a crown. It functions well just the same.”

However, the dentists did not accept a compromise decision without reflection. When they agreed to composite instead of a crown, it was preceded by an assessment of longevity – that is, composite was expected to function, at least for the time being, albeit not as well as a crown. In this context the dentist considered the compromise to be acceptable:

“Yes. In this case, where ..., where... yes, then it was much for financial reasons that we did composite crowns. ... * Clears throat * And even that lass who was born in 1980 ..., ... erm..., she..., in fact she didn't have a very ..., not very strong jaws, instead she looked quite ..., ... not such a heavy *bite*. And so I felt quite confident to be doing plastic crowns. It might not last a lifetime, but ... yes, just the same it will function well for quite a long time.”

In conjunction with the compromise decision, the patient was given a prognosis: although a filling was assumed to survive in the short term, it was not expected to survive in the long run. Furthermore, the root-filled tooth restored with composite would be at greater risk of fracture than if restored by a crown.

Another circumstance in which a compromise decision was made occurred when the tooth in question was in fact in such poor condition that the GDP recommended extraction. In patients unwilling to consent to extraction, the dentist compromised and agreed instead to root filling in order to retain the tooth. In such cases, composite was the obvious choice for restoration because of the poor prognosis.

Discussion

The GDP's decision-making process for coronal restoration is complex and based on diverse factors. Clinical factors were considered important but could be overruled by context and patient opinions, if patient and dentist disagreed. In each case the dentist's decision process was characterized by an assessment of clinical factors for which, in certain cases, contextual factors were weighted, and occasionally modified the choice. However, the patient's views were decisive.

Recent experience of decisions about permanent restoration of a tooth after root-filling was an absolute inclusion criterion for participation in the study, as was fluency in Swedish, to ensure the ability for in depth narration, in order to explore the GDPs' decision process, a basically unexplored area.

Selection of informants was purposive, in order to achieve different perspectives of the dentists' decision-making process about coronal restoration, using the maximum variation sampling strategy (21). As the selected informants reflected a diversity of GDPs working in Sweden, with respect to gender, age, duration of professional experience, service affiliation and undergraduate dental school, the results may be considered valid for Swedish GDPs.

Despite the information provided prior to the interview, the informants' cases may possibly not have been the most recent ones. Some GDPs mentioned that the case was interesting and had therefore been included, however it is not known whether it was the most recent case. A few cases had been root-filled by a colleague but were included in the analysis, as the informants were responsible for the subsequent decision concerning coronal restoration.

The interview technique, comprising mainly open questions, invited the informants to express themselves freely on the topic, using their own authentic cases as a basis for the narration. This was considered to strengthen credibility, as it was possible to study the GDPs decision process in context. Semi-structured interviews cover pre-determined areas related to

the research question, allowing the interviewer to ask follow-up questions, to obtain a more detailed and clarified response (15). Using this approach, the GDPs were allowed to narrate from their perspective, disclosing which factors had been decisive in choice of coronal restoration, whilst the interviewer's influence was kept at a minimum – increasing the conformability.

The pilot study was considered a strength, disclosing the informants' tendency to describe their decision process in more general terms, rather than their actual reasoning in the specific case. Thus, even more detailed information about the aim of the study could be provided to the GDPs before the interviews included in this study were conducted. The interviewer was also better prepared to guide the narration, asking questions to redirect the focus towards the specific, on occasions when GDPs tended to talk about coronal restoration in more general terms. Thus the context in which the GDPs' decisions were made could be elucidated even more clearly.

A relaxed informant improves the potential for optimal disclosure of data during an interview (15). In the present study, by letting the informants choose a location for the interview, it is reasonable to assume that the interviews were conducted in an environment comfortable to them. Even so, it is possible that some informants might have been in awe of the interviewer, a specialist in endodontics, perceiving her as an 'authority', potentially critical of the GDP's decisions. Thus, some informants may have modified their narrative to please the interviewer. However, before the interview the GDPs were informed about the lack of knowledge on this topic and that the informant's specific experience would provide valuable information.

The number of informants required in a study using a qualitative approach depends on the quality of the data obtained and the complexity of the phenomena being studied (18). For the present study, data from 14 informants were considered sufficient to address the research

question, as saturation had been achieved. The authors independently coded 3 interviews and then discussed their results. Although some codes were not labelled in exactly the same way, the same meaning was expressed in different words. In light of the good agreement among the authors, the first author then coded the remaining interviews. To increase credibility, quotations from the interviews were presented in the Results section as examples of the identified patterns. The results were largely in accordance with the authors' preconceptions. In addition, some factors were more crucial than others for the decision.

The GDP's decision-making process involved diverse factors. After a dialogue with the patient and clinical assessment, an evaluation was made, followed by a decision. In some cases the GDP's decision was uncomplicated. In other cases the decision was more complex, involving not only clinical factors but also different contextual factors. The clinical factors considered in decisions about coronal restoration are in accordance with those described in textbooks (22) and in clinical guidelines of importance when planning restorative treatment for a root-filled tooth: the amount and quality of remaining tooth structure, the position of the tooth in the arch, anatomy and function (23). Residual tooth structure was the clinical factor most often mentioned: when regarded as substantial the choice of composite was obvious, but a crown was preferred when only limited tooth substance remained. The SSIA's rules were to some extent regarded as an underlying guideline for indications for a crown restoration. Although important, the amount of tooth structure was overruled by the presence of a crack – regardless of the amount of tooth structure remaining. This decision is in accordance with findings of a high expected survival rate (92%) for a root-filled cracked tooth restored with a crown, provided the crack is limited to the coronal part (24).

The technical quality of the root-filling was not mentioned as having any great impact on choice of restoration. This was a somewhat unexpected finding as it is a factor of importance for the outcome of the root canal treatment (1). The reason why root-filling quality was not

mentioned more often is unknown. A recent study found that GDPs view root canal treatments as complex and difficult but also “illogical”, as successful outcomes are sometimes achieved despite the poor quality of a root-filling and sometimes failures occur in cases of adequate quality (25). However, no such views were expressed in the present study. On the other hand, it is possible that root-filling quality is important even though it was rarely mentioned: some informants commented that a crown restoration seemed to be a more appropriate choice in the case of an adequate root-filling. Another interesting issue concerned teeth root-filled by colleagues. For all informants, the decision about coronal restoration was preceded by an assessment of the technical quality of the root filling, followed by a decision to re-treat when it was deemed inadequate. It is possible that the GDPs found it more comfortable, in discussion with a specialist in endodontics, to comment on the quality of root-fillings done by their colleagues rather than their own. However, the results imply that the prognosis of the root canal treatment influences the decision, but to what extent is unknown.

The importance of the context in which the decision about coronal restoration was made, was a significant finding. Although clinical factors were important, they were not always decisive for the GDPs’ decision. Patients suffering from dental fear, the dentist’s current frame of mind, lack of time and payment model are examples of contextual factors that overruled clinical factors, leading the GDP to recommend composite instead of a crown. In the same way, the patient’s preferences could also overrule clinical factors, sometimes resulting in a compromise decision. This is in accordance with a previous study of dentists’ restorative treatment decisions, reporting that not only disease status was important: dentists’ personal views, patients’ preferences, professional fees/time and ethical aspects also had an impact on the decision (26).

The results of the present study support our preconception, that selection bias may account, at least in part, for the favorable outcomes reported for root-filled teeth with indirect

restorations. Selection bias arises when the operator or the patient influences which treatment option is selected (intervention versus control), causing systematic differences between the treatment groups (21). Thus the comparability of the groups is affected. Previous studies of tooth survival (4-6, 27), are not prospective, randomized controlled studies. Thus, the choice of direct or indirect restoration in the above-mentioned studies is not controlled and the status of the teeth may not be comparable. The present study disclosed that some teeth were obviously less likely to be restored with a crown, despite meeting clinical indications: uncertain prognosis, patients with low motivation or poor economic status, or a particular payment model which did not cover crowns. Thus, it is likely that the groups restored by direct and indirect restoration may be different with respect to clinical status of the teeth and patient-related factors that could possibly influence the prognosis of root-filled teeth. Thus, the higher extraction rates of teeth with composite (4-6, 27) may be attributable to factors other than restoration with composite.

Systematic reviews of the literature have highlighted the lack of scientific evidence on which to determine whether indirect restorations maintain the longevity of a root-filled tooth better than a direct restoration (28, 29). However, a crown restoration is often advocated as the optimal restorative treatment for the root-filled tooth. This view was expressed by some GDPs in the present study, either explicitly or implicitly, on the basis of clinical experience and evidence, which is in accordance with a previous study (30). Decisions in favor of a crown were always motivated in terms of clinical factors, but a preference for crown restorations may have facilitated the choice. On the whole, Swedish GDPs restore more root-filled teeth by direct (57.7%) than indirect (22.5%) restoration (8).

Insurance and reimbursement regulations were not described as a direct reason for choosing a certain restoration but indirectly had an impact on the decision. In conjunction with a crown decision, it was often mentioned that the SSIA's criteria had been met. None of the GDPs

mentioned cases where a crown was chosen, even though the criteria had not been fulfilled. Although such situations may arise, there will be a higher fee for the patient, because the crown will not be reimbursed by the SSIA. Thus, the GDPs may be more likely to suggest composite in such cases. In the present study, although the criteria for a crown were met, it was not always the chosen treatment.

The GDPs' decision about coronal restoration always took into account the patient's views, which had a significant impact on the decision. The GDPs stated that patients usually agreed with to the suggested treatment. Trust and confidence in the dentist was expressed as a factor facilitating the patient's decision. This has been reported earlier as the most important factor influencing acceptance of the proposed treatment plan by patients (31). Other factors influencing the patients' decision include fees, past dental history and pain and discomfort associated with treatment (32). When patients did not accept the recommendation of a crown the informants usually associated this with economic factors, but also divergent opinions expressed by the patients about what the treatment was expected to achieve. The association between patients' financial status and choice of coronal restoration after root canal treatment has been demonstrated previously (33).

Conclusion

GDPs reported that their decision-making process, leading to the choice of coronal restoration of a root-filled tooth, was based not only on clinical factors but also on decisive contextual factors and the patients' views. In each case the decision-making process was characterized by an assessment of clinical factors for which, in certain cases, contextual factors were weighted, occasionally modifying the choice. However, the patient's views were decisive.

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Table 1. The distribution of 14 informants with respect to gender, age (<35, 35-50 or > 50 years), location of undergraduate dental education, service affiliation and length of professional experience.

Gender (n)	Male	(8)
	Female	(6)
Age, years (n)	<35	(2)
	35-50	(7)
	>50	(5)
Undergraduate dental education (n)	Gothenburg	(3)
	Malmö	(3)
	Stockholm	(3)
	Umeå	(5)
Service affiliation (n)	PP	(5)
	PDHS	(9)
Professional experience, years (n)	<10	(5)
	10-20	(2)
	>20	(7)

PP: Private practice

PDHS: Public Dental Health Service

Table 2. The text preparation process. An example of a meaning unit with its corresponding condensed form, code, sub-category and category.

Meaning unit	Condensed meaning unit	Code	Sub-category	Category
Er... Yes, but it was in fact ... fr... One was fractured at the gingival margin. And so it was prosthetic therapy. There was like nothing to to build on. * Little laugh * There was, to be sure, no ... tooth substance remaining.... And the other one was also ... It had an apical periodontitis and major loss of tooth substance. On both of them.	Fractured at the gingival margin, so it was prosthetic therapy. Nothing to build on. No remaining tooth substance. The other one also had apical periodontitis, and major loss of tooth substance.	Obvious decision for a crown on the basis of extensive loss of tooth substance	Dental status	Clinical factors

Table 3. The theme, the categories and the sub-categories with corresponding codes

Theme	Clinical factors considered important but overruled by context and patient opinions, if in conflict		
Category	Clinical factors	Contextual factors	Patient's view
Sub-category and codes	Dental status Major loss of tooth substance favors a crown Poor prognosis favors C A crack is a determinant for choice of crown therapy	Patient-related Dental fear obviously supports choice of C Relationship with patient influences decision	Mutual decision Dentist's recommendation determines patient's decision Different motives but agreement on appropriate treatment (dentist and patient – C)
	Longevity assessment Longevity assessment basis for choice of crown Longevity for C considered good – contributes to decision	Dentist-related Dentist's preference influences recommendation (always a crown) Dentist's current frame of mind influences decision (chose a crown but could have chosen C instead)	Compromise Patient's wishes determine decision – dentist compromises (C instead of crown) Respect patient's decision despite different treatment goals
		External circumstances Lack of time – dentist chooses C Social subsidies support choice of C Social Services regulations determine recommendation for C	Clear information a prerequisite for compromise

C: Composite restoration

Figure 1. Flow chart of GDPs invited to participate in the study to the interviewed informants.

Figure 2. The dentist's decision process was based on clinical factors (blue arrows). In certain cases contextual factors were also weighted and occasionally modified the choice (green arrow), but the patient's preference was decisive, resulting in either approval (arrows unchanged) or modification (purple arrow) of the dentist's decision.

Figure 1.

Figure 2.

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