Attitudes towards and strategies for repair of dental direct restorations

"Minimally Invasive Treatment approach"

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List of papers

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IV. Staxrud F and Dahl JE. **'Silanising agents promote resin-composite repair'.** International Dental Journal. 2015; 65: 311-5.

V. Staxrud F and Mulic A "**Bonding of Composite and Glass-ionomer to Amalgam"** (In manuscript)

Introduction

Historically

The central idea of this thesis is repair of direct dental restorations as an important part of minimal intervention dentistry. Is it possible to perform reliable repair of restorations in the harsh environment of the oral cavity? It should be regarded good treatment to keep most of, or as much as possible of old restorations in the teeth when there is need to take operative action. Dental materials of today are of satisfactory quality. Physically, mechanically and chemically they can be trusted for use when repairing defective restorations.

The history of dentistry, particularly clinical practice, is the story of relieving patients of pain and of restoring defective or missing teeth caused by oral diseases and traumas. Through the ages a variety of treatments and tooth substitutes have been considered. Many of the methods and materials have been rejected or disposed of after a while in clinical use. Through the 20th century dentistry has to a great extent, been built on the comprehensive work of Dr. Greene Vardiman Black and his associates. He gave us a solid foundation for operative dentistry through his invaluable work: *Operative Dentistry* - first published in 1908. It has been revised several times, but this pioneer work of systematising operative dentistry, created standards for the way professional dentists operate today. His understanding of causes to dental diseases and how to treat patients' needs, is in many aspects still valid. Concepts of prevention and efforts to avoid disease development have been of greatest importance in dentistry. Also the principals for operative treatment have been central for development of methods and techniques throughout the 20th century up till the present day.

Many things are different comparing 1908 and today. The social and economic conditions for the majority of people in most of the world have changed dramatically. Understanding of oral health (as of health generally) and what causes disease, has grown. Materials and techniques have been improved and people keep more of their teeth throughout life in

most developed countries. Prevalence of caries in the populations and caries incidence on the individual level have been reduced, resulting in better longevity for restorations and other kinds of operative dentistry performed by dentists. We have moved from running after caries, treating the effect of it, to be in front of the disease. The dental profession is working to stop caries through different preventive and controlling measures i.e. *treating the cause of caries*. As the longevity of restorations is much improved, the need for repeated replacement of restorations and consequently larger restorations are diminishing [Brantley et al., 1995; Elderton and Nuttall, 1983]. This gives possibilities to make smaller fillings and less invasive treatment options. Composite materials and adhesive techniques make it possible to tailor reparative work. We can limit the extension of the preparations to a minimum and we can replace parts of existing restorations.

Repair or extension of existing restorations has been performed for many years. Already in 1978 Inoue published an article on "Repair of amalgam and composite resin used in restorations" [Inoue, 1978]. Croll et al. reported in a paper in 1990 a step-by-step technique for repairing a defective Class I composite resin restoration [Croll, 1990]. The tendency of using composite also in posterior restorations increased throughout the 90's and in 1991 Puckett et al. wrote a paper about different bonding systems when repairing posterior composite restorations [Puckett et al., 1991]. In 1993 Ivar Mjør wrote an article on "Repair versus replacement of failed restorations". This article can, even today, be reviewed as up to date [Mjor, 1993].

«Minimal Intervention in the Management of Dental Caries»

To understand the discussion whether a restoration should be replaced or repaired, it would be a good approach to take a closer look at our increased understanding of the factors influencing diseases in teeth. The International Dental Association - FDI - initiated a Commission Project in 1997, which resulted in a paper published in 2000 [Tyas et al., 2000]. It was named: "Minimal intervention dentistry - a review, FDI Commission Project 1-97". This paper addressed the fundament for modern dentistry based on updated understanding of the caries process, and of the possibilities new adhesive material technology offers. The concept of "Minimal Intervention Dentistry" – MID, also named "Minimally Invasive Dentistry" or "Preservative Dentistry" evolved, and increased in

popularity as it has become more rooted in the consciousness of dental professionals, throughout the world, over the last decades. Our understanding of the pathogenesis of oral diseases has changed. The clinical focus has shifted from a *surgical* approach to a *biological* approach. Understanding of oral biology and pathology has given new expectations in caries treatment and the respect for the original tooth structures and how to preserve them, has increased markedly among dentists.

This work led to a FDI Policy Statement, adopted by the FDI General Assembly Oct. 1. 2002 - Vienna. (https://www.fdiworlddental.org/resources/policy-statements-and-resolutions/minimal-intervention-in-the-management-of-dental-caries) The statement was named; *"Minimal Intervention in the Management of Dental Caries"*. The document clarifies 5 important principles to build modern operative dentistry.

These principles are:

Modification of the oral flora

Dental caries is an infectious disease, and the primary focus should therefore be on control of the infection, plaque control and reduced carbohydrate intake.

Patient education

The aetiology of dental caries should be explained to the patient, together with the means of prevention through dietary and oral hygiene measures.

Remineralisation of non-cavitated lesions of enamel and dentine

Saliva plays a critical role in the demineralization/remineralization cycle, and its quantity and quality should therefore be assessed. There is strong evidence that 'white spot' lesions of enamel and non-cavitated lesions of dentine can be arrested or reversed. Such lesions should therefore be managed initially by remineralisation techniques. The extent of the lesion should be objectively recorded such that any progression can be identified at recall.

Minimal operative intervention of cavitated lesions

An operative ('surgical') approach should only be used when specifically indicated, e.g., when cavitation is such that the lesion cannot be arrested, or when there are aesthetic or functional requirements. Operative intervention should focus on the preservation of natural tooth structure and be limited to the removal of friable enamel and infected dentine. This can be done with hand, rotary, sonic, ultrasonic, air abrasive or laser instruments, depending on the circumstances. Each prepared cavity is therefore unique, and is primarily dependent on the extent of infected dentine rather than on a predetermined cavity design. Preparation of minimal cavities enables their restoration with adhesive materials such as glass-ionomer cement and/or resin composite. Some studies suggest that glass-ionomer cement may aid in the re-mineralisation of de-mineralised, firm, non-infected dentine; however, further clinical studies are needed.

Repair of defective restorations

Removal of restorations results in an inevitable increase in cavity size as a consequence of removal of sound tooth structure. Depending on the clinical judgement of the dentist, repair could be considered as an alternative to replacement in some circumstances.

[Tyas et al., 2000]

Understanding the Caries Process and Disease Control

Caries is not the main topic of this thesis, but a short outline of the caries process will be appropriate to understand caries as the underlying cause of why it is necessary to perform different kinds of operative treatment. We also know that secondary or recurrent caries is the most frequent reason for replacing or repairing dental restorations. Therefore, understanding caries as a disease is central and very important for the exercise of restorative dentistry. This short discussion is based on today's comprehension of research evidence in this field.

The central idea of the MID concept is “Disease control” [Ericson, 2007; Ismail et al., 2015; Murdoch-Kinch and McLean, 2003]. Caries is a disease that emerges in the interface between 1) *Patient* (with teeth), 2) *Diet* (containing fermentable carbohydrates) and 3) *Oral microflora* (able to ferment carbohydrates to organic acids) (Key’s triad, 1962). In other words; Caries is the result of the activity of bacteria working together in a biofilm on tooth surfaces. Later the *time* factor has been added as an important determinant in the development of caries. From fermentable carbohydrates bacteria produce hazardous organic acids capable of demineralising enamel. According to P.D. Marsh and the “Ecological Plaque Hypothesis”, it is possible to stop and redirect negative processes through removal or control of biofilm/plaque. This knowledge is essential as we understand that a change in the ecological balance in the microflora can promote pH raise leading to *remineralization* of dental hard tissue at all stages of caries development, not only before cavitation of the lesions [Marsh, 2003].

Fejerskov et al. has given an outline of new concepts for treating the caries process [Fejerskov, 2015; Fejerskov et al., 1981]. When a microflora is present, continuously supported by frequent intake of fermentable carbohydrates, the caries process will go on constantly. Bacteria that have been allowed to remain undisturbed for only a couple of days will start creating a biofilm. This biofilm develop into an organised bacterial community, which is able to produce acid constantly when supplied with fermentable carbohydrates. The acid produced by the bacteria in the biofilm lowers pH at tooth surface resulting in dissolution of hard tissue minerals i.e. hydroxyl-apatite (HA). If the biofilm is left undisturbed, more ions will constantly be dissolved from dental hard tissues. On the other side this results in super saturation of the fluid at the crystal surface with respect to apatite ions i.e. calcium, phosphate, hydroxyl and fluoride. This ion rich solution is slowing down or counteracting the dissolving process. Critical pH levels under which minerals will dissolve are approx. 5.5 for hydroxyl-apatite in enamel, and approx. 4.5 when fluoride is present. For dentine and root cement the critical pH level for dissolution is almost one pH unit higher than for hydroxyl apatite in enamel. Critical pH is not constant and is dependent on the total concentration of actual different ions in the fluids surrounding hard dental tissues. Presence of fluoride is crucially important to this process. When hydroxyl apatite dissolves at approx. pH 5.5, fluoride ions will immediately replace the newly dissolved hydroxyl ions, forming new flour-hydroxyl-apatite (FHA) crystals in the surface zone. This will take place as the solubility product for flour-apatite (FA) is much

lower than that for hydroxyl-apatite. The formation of FA or FHA will continue to pH levels of approx. 4.5. This de- and re-mineralisation process is constantly ongoing as a dynamic chemical process.

Remineralisation of caries lesions

If or when the biofilm is disturbed and removed, pH will rise and the process of re-mineralisation will start because of the super saturated (ion rich) hydration layer surrounding apatite crystals. At early stages of initial caries, tooth surface structures may be restored almost completely. Tooth brushing or cleaning will remove biofilm responsible for acid production and also acids from tooth surfaces resulting in pH rise. At a higher pH level (>4.5 when fluoride is present) remineralisation will take place if the total time of over saturation (of ions that can form crystals) is longer than the total time of under saturation. At the enamel surface when remineralisation is the dominant process, it leads to a fluoride-rich hard surface. Often the area under the surface of the enamel may appear white or whitish, so-called white spot lesions or sub surface lesions, due to increased porosity in the affected, more demineralised, sub-surface area which is not well remineralised under the hard surface [Larsen and Fejerskov, 1989]. When the sum of time of demineralisation is higher than the time of remineralisation, the surface will appear intact over the demineralised sub surface area for a long time until it eventually may collapse as the demineralisation has removed too much of the mineral substance underneath. The hard surface is protecting the area underneath, slowing down further de- and remineralisation. Any white spot lesion under an intact surface should be regarded as possible to arrest without surgical intervention (i.e. fillings). Removal of the biofilm stops the progression of the caries process as no further acid will be driving it. White-spot lesions should be treated with removal of biofilm and promotion of surface remineralisation, supported by fluorides. Fluorides are normally best supplied through dentifrices, but optional mouth rinse and topical application of fluoride varnish, fluoride lacquers or tablets may also be convenient [Fejerskov et al., 1981; Mejare et al., 2015].

Any carious site, whether with an intact surface or collapsed surface i.e. cavities in enamel, dentine or cementum, show harder, more mineralised outer surface [Tohda et al., 1996]. The same explanation is thought to be valid as the surface of any lesion is covered with a hydration layer around the apatite crystals supersaturated with ions from HA and FHA. This phenomenon may also exhibit properties for arrest or stabilising any caries lesion

when biofilm is controlled and in the presence of fluorides [Ogaard et al., 1990]. Any caries lesion accessible for biofilm control can be inactivated [Fejerskov et al., 1981; Nyvad et al., 1997].

Based on updated knowledge about the caries process and pathogenesis among Norwegian dentists, there has been a change in treatment choices concerning when to intervene in cases of primary caries [Vidnes-Kopperud et al., 2011]. The trend has moved from performing restorative treatment on initial carious lesions confined to inner part of enamel or white spot lesions, to wait and not do any irreversible restorative treatment before the lesion is "cavitated" or biofilm control is impossible. Instead, control and monitoring initial lesions have been focused, using remineralizing measures like different fluoride treatment options and biofilm control combined with patient education.

There may be cognitive challenges to the professional dentist to accept that any carious lesion can be arrested. Traditionally, dentists are taught to interrupt the caries process by surgical actions. On the other side, there are of course limitations, even though any cavity can be arrested or monitored, many defects need operative measures for *functional* and a*esthetical* reasons. Bottom line is; there are great opportunities of reducing the use of restorations as we acknowledge the nature and development of the caries process.

Secondary Caries

Secondary caries or recurrent caries are shown to be the most frequent reason for remaking restorations. Prevalence of secondary caries varies considerably in literature, and many studies and reports are connected with large variety of biases [Jokstad, 2016; Mjor, 1993]. The diagnostic difficulties are connected to dentists' subjectivity. Their skills and experience differ vastly; what do dentists see and register, and how is it interpreted? Nevertheless, a prevalence figure somewhere between 40 % and 60 % should be agreeable [Demarco et al., 2012; Mjor et al., 1990; Opdam et al., 2012].

Secondary caries is not a special kind of caries [Hals and Nernaes, 1971; Hals and Simonsen, 1971; Kidd, 2001]. The aetiology is the same as primary caries. The difference lies in the *site* of the caries lesion. Secondary caries emerges as a *new caries lesion*, with the same sub surface features as primary caries at sites *adjacent to existing restorations*. It does not start because of properties of the restoration material, but because there is biofilm formation adjacent to or at the margin of an existing filling or restoration.

Difficulties keeping enamel or root surface clean may be caused by improper anatomy of the existing restoration (variable craftsmanship). Gaps at the restoration margin (material defects) and under- or over-contoured fillings (overhang) are sites for biofilm accumulation, predisposing for new caries formation. Traditionally, secondary caries has been reviewed as two types; the *outer lesion* and the *wall lesion*. The wall lesion is thought of as emerging from gaps or ditches causing micro-leakage between the restoration and tooth substance. This may create sites unfavourable for tooth cleaning thus give opportunities for biofilm formation and subsequently caries. In 2016 Jokstad made an appraisal of studies on secondary caries where one focus was on the relationship between outer lesion and wall lesion. He concludes that wall lesions does not exist separately without an outer lesion [Jokstad, 2016]. Secondary caries in gaps or ditches will occur where there are possibilities for uncontrolled plaque accumulation resulting in new (secondary) caries formation.

Nedeljkovic et al. investigated whether secondary caries could be a material-based problem or not [Nedeljkovic et al., 2015]. She concluded that in some research papers there might be shown a correlation, but the main message was that patient related factors like individual risk of caries, remain the dominant determinant of development of secondary caries as the incidence in low-risk patients is considerably lower than in high-risk patients.

Patient education

As outlined above, it is essential to modify the biofilm by mechanically disturbing or removing it on a *regular basis*. Large parts of any operating dentist's job is to spend time to inform and teach patients. Our professional responsibility extends to make an adequate relationship for co-operation with any patient, creating an arena for explaining why and how to clean the teeth, and why and how to avoid too much and too frequent intake of fermentable carbohydrates, in order to maintain good oral hygiene. Through showing interest and concern for the patients, there are opportunities to make them understand their personal responsibility for own oral health care.

When the control of the biofilm is made impossible and it is no longer possible to remove plaque from affected surfaces or inaccessible cavities, the progression of caries may run out of control. Then it is often necessary to leap to surgical actions. When restoration is

indicated, minimally invasive methods for restoration of damaged tooth structure are preferred. Minimal cavity design, adhesive techniques and modern resin based composites are important tools. When needed, repair of defective restorations, to avoid unnecessary damage of tooth structure, before replacing well-functioning restorations is clearly in line with this thinking and is strongly recommended [Blum, 2015; Lynch et al., 2014; Schwendicke et al., 2016; Wilson et al., 2016].

Longevity of restorations

Knowledge about longevity of restorations is important when considering repair of restorations. If the clinician anticipates the filling to have short survival time, the fundament for keeping old restorations in place and repairing them could be evaluated "not a sustainable idea".

The longevity of amalgam restorations is considered to be good [Mjor, 1989; Mjor et al., 2000], but the longevity of composite restorations has been questioned for a long time. Through the last decades there has been published data from various authors showing equally good longevity performance for composite and amalgam. The annual failure rate (AFR) is reported to be somewhere between 1% and 8%, but it is not an easy task to compare the different studies because the study designs are incomparable or not quite the same. There is emerging evidence showing that an AFR about 2-6% is realistic. Longevity seems to be depending on several factors. Most important are caries-risk, patient cooperation, dentist's skills, restoration size, place in the dentition and social-economic factors etc.

Opdam et al. has shown that in patients with *low caries risk* and *regular attendance* to the same dentist over many years, the AFR for amalgam and composite combined (n=1494) may be as low as 1.83% over a 12 year period [Opdam et al., 2010]. For the *high caries risk* patients (i.e. caries incidence >1 new lesion pr. year) the AFR rises to 4.14%. Even better for composite restorations, when discriminating between composite and amalgam in the low-risk group, composite restorations showed an AFR of 0.98% compared to 2.05% for amalgam.

In a review from 2003 Brunthaler et al. sampled 24 studies of various design with observation time from 1 to 17 years. The AFR varied from 0.7% to 7% with an average about 2.5 - 3% for the studies lasting from 3-17 years [Brunthaler et al., 2003].

Demarco et al. reported in a review from 2012 an AFR between 1 and 3% [Demarco et al., 2012]. In 2004 Manhart et al. showed in the *"Buonocore Memorial Lecture"* an AFR to be about 3% for amalgam and 2.2% for direct composite [Manhart et al., 2004].

Other researchers confirm the figures to expect AFR rates between 1 and 3% [Beck et al., 2015; Da Rosa Rodolpho et al., 2011; Kopperud et al., 2012] for low risk patients attending the same dentist on regular basis.

Pallesen and Van Dijken presented in 2015 two randomized controlled studies, one with 27 years follow up and the other with 30 years follow up. The first gave an overall success rate of 56.5 % after 27 years, giving an AFR of 1.6 % [Pallesen and van Dijken, 2015a]. The other showed an overall success rate after 30 years of 63 %, with an AFR of 1.1 % [Pallesen and van Dijken, 2015b]. These low figures emerged from studies where one skilled dentist performed all the restorations, and the same dentist did all the follow ups, monitoring his/her own restorations. Although the reason for failure mainly was caries (primary and secondary caries), 54.1 % and 39.2 % respectively in the two studies, it shows that it is possible to achieve a very low AFR when the dentist and patient co-operate to maintain a good standard of oral health, thus keeping the caries risk low. When monitoring restorations of own production, knowing the patients' compliance and the patients' caries–risk and -activity, it is easier to postpone an intervention concerning small to medium restoration defects; "let us give it another year". It is more challenging to leave defective restorations at the Charlie level [Mjor, 1993; Ryge, 1980] (should be replaced but not necessarily now) when one does not know the patient very well.

Laske et al presented in 2016 a practice-based study. Data from 222.836 restorations of all kinds of material (85% composite) were sampled and AFR was calculated to be from 2.6 to 7%, with an average of 4.6% for composite which performed best of all materials [Laske et al., 2016]. No particular selection of dentists or practices was made and all kinds of dentists and clinics were put in one big pot. This may represent what is going on in everyday dental practice, but as mentioned above, dentists' subjective comprehension of single cases, may give rice to large variety of interpretations and treatment decision

choices. Possible bias of the amalgam restoration longevity may be replacement of restorations because of unpopular colour and patients' fear of mercury containing metal.

These figures tell us that it is difficult to predict the lifetime of dental restorations. Some papers demonstrate annual failure rates which indicate a median life-span of 6 years (AFR approx. 8 %), other papers give figures to expect 50 years (AFR approx. 1 %). When the AFR is 4.6 % as found by Laske et al., it would give a median survival time of approx. 10 years.

As one can expect the AFR shows a tendency to increase a little bit by the years [Opdam et al., 2010]. Therefore, the figures must be modified somewhat. However, the survival properties of restorations are so good in the reports where the *caries risk is low, and the patients are well-cooperating*, that median life-span lies between 16 and 50 years (AFR between 1 and 3%). The conclusion should be that there are *good reasons for performing repair.*

The rationale for repair

Already in his article from 1993 Ivar Mjør wrote about "Repair versus replacement" [Mjor, 1993]. He concluded: Based on the present clinical condition (of the restoration to be evaluated) there should be an evaluation of; restorative material employed, expected longevity of the repaired restoration, aesthetic considerations and the cost involved. Many alternatives are potentially advantageous and feasible. Decisions should be made on clinical *experience* and be *empiric* because of lack of good quality evidence. He postulates:

> "Repair of localised defects of restorations is a tooth saving alternative…emphasis must be placed on detailed definitions of acceptable versus unacceptable restorations…Excellence in operative dentistry is easily recognised. Similarly, most failures, except secondary caries, are easily diagnosed. The difficult part…is the transition from clinically acceptable to clinically unacceptable…
>
> …This critical issue must be debated, defined, illustrated and used in clinical calibration studies to obtain and establish distinct criteria for when to leave a

> restoration for observation and when to replace or repair it. Serviceable, but not necessarily optimal restorations, must be recognised as acceptable, that is, they are left for observation.
>
> Repair of localised defects is the next alternative to be considered. It must be based on knowledge of material properties, adequate access, cost involved and assessment of expected longevity of repaired restoration." [Mjor, 1993]

Mjør discusses the difficulties in detection of secondary caries or discriminating secondary caries from probe-catching non-carious voids, crevices, gaps or ditches. Many of these are mis-diagnosed to be carious. They could be left for observation as a time-and-money-saving option. Sealing smaller defects with flowable composite or finishing and polishing are often sufficient actions. Others should be repaired if the defect is easily accessed and the remaining restoration is judged to be adequate for its purpose functionally and aesthetically.

Today, there is sparse new evidence from RCTs, and still the decisions should be made on the same foundation of experience and empiric.

In 2016 Wilson et al. on behalf of "Academy of Operative Dentistry European Section" in a paper on "Criteria for Replacement of Restorations" suggest with strong emphasis that:

> "Developments in this area are such that the option of replacing a defective or failing restoration may, in the foreseeable future, be considered to be indicated *only when the possibility of repair has been ruled out*" [Wilson et al., 2016].

In their "Nationella riktlinjer för vuxentandvård" the Swedish Health Authorities make recommendations concerning treatment of smaller accessible defects caused by secondary caries in connection with or adjacent to an existing and otherwise intact restoration; Repair of the defect is given treatment recommendation score 4, while replacement of the entire restoration is given score 6. The highest (best) score possible in these cases is 3. See: http://www.socialstyrelsen.se/tandvardsriktlinjer.

There is immense evidence that the materials used in direct restorative therapy are physically and mechanically of very good quality. Several publications show that the composite restorations are of equal standard as amalgam if not better when comes to

longevity [Beck et al., 2015; Brunthaler et al., 2003; Da Rosa Rodolpho et al., 2011; Demarco et al., 2012; Laske et al., 2016; Manhart et al., 2004; Opdam et al., 2010].

As discussed above, the main reasons for restoration failure are secondary or recurrent caries and fractures of tooth structure. The longevity of restorations seems to be dependent on other factors than material strength. Caries activity, caries experience and caries-risk-factors are most important [van de Sande et al., 2016] and necessary to take into consideration when choosing therapeutic strategy, as mentioned and lined out in the ideas of "MID".

Advantages of repair (a Minimal Invasive Dentistry approach)

Blum et al. states in a paper from 2014 several advantages of choosing repair to replacement when appropriate or possible [Blum et al., 2014]:

1. Preservation of tooth structure/strength
2. Increased longevity of restoration
3. Reduction of potentially harmful effects on the dental pulp
4. Reduced need for local anaesthesia
5. Reduced risk of iatrogenic damage to adjacent teeth
6. Reduction of treatment time
7. Reduced cost to the patient
8. Good patient acceptance
9. Slowing of the «restorative death spiral»

The following section will give some comments on these statements.

1. **a) Preservation of tooth structure/strength**

   In the midst of the 90's Krejci et al. made efforts to demonstrate how much sound tooth tissue that were lost during removal of old restorations of different materials [Krejci et al., 1995]. They designed a method to measure volumetric loss of dental hard tissue, and found considerable loss as quite ordinary MOD (mesial-occlusal-distal) restorations with buccal cusp coverage were removed from teeth *in vitro*. The loss was highest for well bonded composite and glass-ceramic restorations

and lowest for glass-ionomer and amalgam restorations in this order. When removing composite, the loss of tooth substance was more than twice the amount lost at amalgam removal. The volumetric amount of hard tissue lost in this study varied from approx. 17 mm^3 after amalgam removal to approx. 42 mm^3 for the composite group. The reality of these figures are difficult to generalise, but the ratio between tissue loss for the 4 types of restoration material removal, and the considerable amount reported, gives an idea of the severity of preparation using rotating burs in the teeth. This obviously leads to weakening of the total strength of the teeth every time an operative treatment is performed. Hunter et al. found similarly higher loss of tooth substance when removing composite compared to amalgam. In both cases the loss of hard dental tissue was considerable [Hunter et al., 1995]. Plotino et al. investigated fracture resistance after endodontic treatment and found that most of the reduced strength compared to intact teeth was not because of desiccated or more brittle teeth, but merely because of loss of tooth substance and loss of marginal ridge integrity [Plotino et al., 2008]. The findings should encourage dentists to preserve as much as possible of the tooth substance whilst restoring defects.

Already in 1980, Mondelli et al. investigated the fracture strength of teeth with preparations. They found that the most important factor for tooth strength was the preservation of marginal ridges and secondly the inter-cuspal width of preparations [Mondelli et al., 1980]. Reeh et al. found similar results for endodontic treated teeth and states that cavity preparation is more detrimental to tooth strength than the endodontic procedures [Reeh et al., 1989]. They found for premolars, that endodontic treatment procedures alone decreased the tooth strength approx. 5 %, while the loss of one marginal ridge reduced the strength approx. 46 %, and the loss of two marginal ridges reduced the strength approx. 63 %. The figures cannot easily be generalized, but they are indicative and clearly infer that restorative preparation procedures are the most important factor for weakening of teeth. This also gives support to the idea of repair although the high level evidence from RCTs on this matter is still requested.

It is difficult to estimate exactly how much teeth and restorations have to withstand concerning bite forces. The load on one single tooth or on a limited part

of a restoration is dependent on which tooth that is involved, whether it is a male or female, how large is the contact area to bear the load, what is the angle of the contact point to the direction of the bite force? Ferrario et al. measured bite force on healthy single teeth in a small sample of Italian young adults [Ferrario et al., 2004]. They found significant differences between men and women. Men had larger bite force than women as would be expected. Bite force were largest around first molar and lowest at the incisors for both genders. Men show relatively large bite force on canines compared to women. Although the force measured in Newton, ranged from approx. 100 N in front to more than 300 N on first molar, it is not easy to estimate how much a restoration repair interface or a weakened cusp have to bear. However, when 300 N hit a spot the size of a pin point or less than one tenth of one mm^2, huge pressure is at work. (Three hundred Newton on one square mm gives a pressure of 300 MPa). Compared to loss of strength after destruction of the marginal ridges, it is easy to understand the importance of preserving tooth structures.

b) Preparation designs

The idea of preserving tooth strength by avoiding breakage of the marginal ridge led to development of alternative preparation designs. The "saucer-shape" preparation for proximal caries became popular through the 90'ies, but there was a tendency towards loss of restoration due to lack of resistance to bite forces, in particular lack of cervical horizontal support [Kopperud et al., 2012]. Nordbø et al. found that of restorations prepared with the saucer-shape technique, 70 % were acceptable for continued clinical use after approx. 7 years [Nordbo et al., 1998]. Caries and technical deficiencies were reasons for failure. They concluded that the saucer shape preparation saved more tooth substance than box preparation and should be preferred. The conclusion is debatable as the failure rate of more than 4 % pr. year shows a poorer longevity than more box-shaped restorations. Knowledge about the materials used is of great importance in decision making on how to design the preparation.

Another preparation technique, "tunnel preparation" and "tunnel restoration", became popular through the 80'ies and 90'ies [Knight, 1984]. The idea was to preserve the marginal ridge, excavate caries from an occlusal entrance without

disturbing the proximal surface, and finally fill and seal the cavity with glass-ionomer restoration material. Unfortunately, the survival rates were not as good as expected. Quite many marginal ridge fractures occurred and the control of the proximal caries turned out to be insufficient. Strand et al. showed in a 3-years study that 28 % of the restorations were replaced at 3 years follow up. Approx. half of the replacements due to marginal ridge fracture, half of them due to caries. After 3 years only 46 % of the restorations were assessed to be successful and clinically acceptable [Strand et al., 1996]. The technique may be too difficult, both preparation and control of caries in the proximal area are demanding. Materials used may also play a role, as silver reinforced glass-ionomer did not perform well. It does not adhere to tooth substrate quite as good as conventional glass-ionomers, which on the other side show low fracture resistance and a large tendency to dissolve and disintegrate at the surface. Forsten showed in 1993 that 40 % of dentists asked in a questionnaire experienced more complications with glass-ionomers than with amalgam which is comparable to composite materials [Forsten, 1993].

This experience led to concentration around "Mini-box/Slot" preparations with more horizontal support cervical, and internal macro-mechanical prepared retention to aid the adhesives, which seem to give good results [Ericson et al., 2003].

2. **Increased Longevity of Repaired Restorations**

The effect repair may have on restoration lifetime is not easy to predict, but there is today a growing amount of literature that supports the fact that repair may utterly increase the longevity of restorations.

Opdam et al. found in 2012 that; if a composite restoration with repair was judged as survived (success) the AFR for low-risk patients could be lowered from 1.83 % to 0.72 % for posterior restorations over a period of 17 years. For amalgam restorations the figures was 3.0% and 2.5% respectively [Opdam et al., 2012].

In the before mentioned review from 2012, Demarco et al. made a similar conclusion based on 35 studies: When both repaired and replaced restorations were considered failures, the AFR was 1.9% over a period of 22 years. If the

repaired fillings were considered success the AFR dropped to 0.7% [Demarco et al., 2012].

Casagrande et al. collected data from 11 Dutch general practices (24 dentists) in 2017. Over a period of 12 years nearly 60.000 restorations of composite and amalgam were evaluated. The sample can be said to be an average of dental restorative work in The Netherlands, and may represent what is actually going on in real dental practice life. They found that when all kinds of failures are counted in for composite and amalgam combined, the AFR equals 4.08%. When the repaired restorations were counted as survived, the AFR dropped to 2.88% [Casagrande et al., 2017].

A recent paper from Estay et al. in Chile, concluded in a 12 years controled clinical trial conducted by two examiners:

> "…the repair of resin composite and amalgam restorations is a good clinical option because it is minimally invasive and can consistently increase the longevity of restorations" [Estay et al., 2017]

The results from these studies support the idea of repair of defective restorations as a viable alternative to total replacement. Positive figures encourage dentists to leave most of good and well-functioning restorations in place and perform repair rather than replace the whole filling when standing opposed a restoration with a defect or secondary caries of limited severity. Evaluation of the entire defective restoration is an important issue in treatment decision making.

3. **Reduction of potentially harmful effects on the dental pulp**

To measure the possible harmful effect that preparation in dentine may have on the pulp is not an exact science. But any kind of stress to the pulp-dentine-complex may have possible harmful potential. Proximity to the pulp is essential for pulp survival and the effectiveness of cooling off friction heat from rotating burs plays an important role. One can easily imagine that "less is better" when comes to dentine preparation especially in the vicinity of the pulp.

4. **Reduced need for local anaesthesia.**

There is no evidence that the use of anaesthetics is reduced when repairing, only clinical experience tells so. However, the situation is often that repair is performed with less preparative actions and often further from the pulp. In addition, the sensitivity of the dentine is reduced in peripheral parts of teeth that have had restorations for a long time. Consequently, anaesthetics may be used less frequently.

5. **Reduced risk of iatrogenic damage to adjacent teeth**

Qvist et al. showed in 1992, that iatrogenic preparation damage is a frequent side effect of operative intervention [Qvist et al., 1992]. Kopperud et al. showed that there is an increased risk of caries on adjacent tooth surfaces when preparing for restorations [Kopperud et al., 2015]. They both indicate that this phenomenon most likely is due to rotating burs damaging the surface of the neighbour tooth. Kopperud et al. found that after an observation period of approx. 4.9 year, only 38.8% of the initially sound contact surfaces remained sound, 34.0% developed caries in enamel, caries grade 1-2 [Amarante et al., 1998], and 27.2% developed caries into dentine (grade 3-5). Almost 60 % of caries confined to enamel present at baseline remained in enamel, while more than 40 % progressed into dentine. There is a great risk of touching the surface nearby, creating various degree of permanent damage to enamel or restoration which will be predisposing for bacteria retention and development of caries or secondary caries. Other explanations may be that these areas already are vulnerable to caries as the neighbour recently developed caries and that many of the patients in this study were young patients in a period of mixed dentition. The problematic hygiene situation, adolescence and immature enamel may bias the results. The authors confirm that the patients' caries risk is of essence as the risk of developing caries on surfaces that initially were sound was higher in patients with poor or medium oral hygiene and high caries experience.

In addition, maxillary teeth and surfaces on the right side of the mouth were risk factors! They also found that the treating dentists had a significant impact on the caries development, which emphasises the importance of good craftsmanship; clinicians should be aware of a notable risk of caries development on adjacent tooth surface, especially when placing proximal restorations in high caries risk

patients. Use of physical protection of the adjacent tooth surface during preparation would be very helpful, as well as caries preventive strategies and non-operative treatment options that should be evaluated and repeated at every recall.

Beside the caries vulnerability, one should be aware of that damage exerted to neighbour tooth enamel, filling or crown might result in costly extra dental work.

6. **Reduction of treatment time**

This obviously self-evident statement is difficult to contradict. But there are situations where secondary caries is located approximally, and the restoration is not very old (made by the same dentist!) and otherwise excellent, one may be tempted to try repair rather than replace. These situations may sometimes be rather time consuming and a partial replacement may be advisable.

7 and 8. **Reduced cost to the patient and good patient acceptance**

The treatment cost will naturally be favourable to the patient as the reparative work normally is smaller and less time consuming than full replacement. From experience dentists would say that most patients are very content with as little dental work as possible. But there are patients who are afraid of "patch-work" and assumedly weak restorations, which prefer the "real thing". The patient information and education is of great importance in dealing with decision making.

9. **Slowing of the «restorative death spiral»**

As has been shown, the increased damage to teeth under repeated restoration, eventually will lead to tooth destruction [Brantley et al., 1995; Elderton and Nuttall, 1983; Krejci et al., 1995]. This is not true to the same amount today as it is evident that more patients keep their teeth through life, but the weakening of re-restored teeth is an important factor when decisions of treatment are made.

Repair of defective restorations

The literature does not give strong evidence to support repair. Unfortunately, very few of the clinical studies are randomized clinical trials (RCT) which would give good evidence to support the repair strategy. Sharif et al. posed this question in 2010:

> "Repair or replacement of restorations: do we accept built-in obsolescence or do we improve the evidence?" [Sharif et al., 2010b]

In Cochrane reports from 2010 Sharif et al. states this: The conclusion drawn is that one cannot rule out repair as a good treatment option, but there are not sufficient data from randomised controlled clinical trials (RCT) [Sharif et al., 2010a; Sharif et al., 2010c]:

> "As no relevant randomized controlled trials (RCTs) were identified in either of these systematic reviews, the evidence regarding the effectiveness of repair versus replacement of amalgam and composite restorations is weak and incomplete. The evidence as it currently stands *seems to favour repair over replacement*, but this is insufficient to make firm recommendations."

This paper has been followed up by two Cochrane reports in 2014, still concluding there is no evidence from reliable RCTs to draw explicit conclusions otherwise:

> "In view of the absence of high level evidence there is a need for further well designed RCTs. To add value to the evidence base these trials should be conducted in a general practice setting which will strengthen the generalisability and applicability of the research conclusions and enable dentists and patients to make informed decisions" [Sharif et al., 2014a; Sharif et al., 2014b].

Till now, no new and sufficiently strong data has been published, but there are some papers showing clear benefits to support the idea of repair over replacement or even more invasive treatment options [Demarco et al., 2012; Moncada et al., 2009; Opdam et al., 2012]. One of the most important arguments for repair is to preserve tooth structure and tooth substance in order to withstand the mastication forces they are exposed to. Doing so, dental treatment will help patients keep their teeth lifelong.

However, the repair-idea has become common practice in operative dentistry in many countries today. The topic is taught in several Dental Schools in Europe and North

America and is advocated by several merited professors and leading researchers in the field [Blum et al., 2014; Gordan et al., 2009a; Hickel et al., 2013; Lynch et al., 2014; Moncada et al., 2009; Moncada et al., 2006; Wilson et al., 2016].

In a comprehensive review from 2013 Hickel et al. have given "Criteria for decision making and clinical recommendations" [Hickel et al., 2013]. The conclusion states:

> "Repair of restoration is a valuable method to improve the quality of restorations and is accepted, practiced and taught in many universities. However, there is a need for methodologically sound randomized controlled long-term clinical trials to be able to give an evidence based recommendation".

Lynch et al. commented on the topic in 2014 that:

> " While there is a concern that high-quality evidence does not yet exist to support restoration repair, there is evidence to demonstrate the success of restoration repair when practiced appropriately. The view must be taken that the replacement of a restoration is contraindicated when the majority of the restoration concerned is intact and caries free. A repair offers an effective minimal intervention approach in such situations" [Lynch et al., 2014].

Demarco et al. concludes from a study of restoration longevity that:

> "Repair is a viable alternative to replacement, and it can increase significantly the lifetime of restorations. As observed in the literature reviewed, a long survival rate for posterior composite restorations can be expected provided that patient, operator and materials factors are taken into account when the restorations are performed" [Demarco et al., 2012].

As the idea of preforming repair of defective dental restorations is established, there are several materials available. Today resin based composites (RBC) must be said to be the material of choice in the European and North-American countries. Glass-ionomers (GI) have a place in most dentists' armament, but amalgam as it is banned in Norway and Sweden, is most certainly fading out. Therefore, this thesis will limit the testing and discussion to the use of mainly RBC and to some degree GI as repair material. Amalgam as repair material will not be discussed here. Neither will repair of other materials than

RBC or amalgam be discussed here as it is outside the scope of the research which is carried out.

When and what should be repaired – guidelines

In 2016 Wilson et al. representing a group of well merited professors and researcher in the field of operative dentistry published an article: Criteria for the Replacement of Restorations: Academy of Operative Dentistry European Section [Wilson et al., 2016]. These guidelines strongly support the ideas proposed by Mjør in 1993. They advocate the minimal invasive approach; repair rather than replacement when possible. There are however, as discussed by Mjør, difficulties concerning the diagnostics and the evaluation of existing restorations. Using the Ryge Criteria or the US Public Health Service (UHPHS) Criteria or the FDI Criteria, there will always be difficult to discriminate between the acceptable restorations and the unacceptable [Mjor, 1993]. Secondary caries is one criterion connected with subjectivity of the practitioner. Patient attendance is another issue that may be very important whether to "wait and see" or just take it out because the practitioner is not sure he will see the patient again in due time to control the consequences. In light of previously described advantages of repair, Wilson et al. [Wilson et al., 2016] suggests in their paper some core issues to consider before decisions are made:

- Is the patient *requesting or expecting* a replacement restoration? A patient who is dissatisfied with the appearance of a restoration or is experiencing pain, sensitivity, or discomfort associated with, for example, food impaction or sharp edges caused by a fracture of the restoration or remaining tooth tissue may reasonably be expecting operative intervention to resolve the difficulty.
- Are there lesions or forms of restorations failure present that carry an *unacceptable risk* to the viability and retention of the tooth if not addressed by some means of intervention?
- Would intervention, in particular intervention that is unexpected by the patient, *cause more harm than benefit*, or have any lesions or signs of restoration failure remained unchanged for some time, are they unlikely to progress, and could they reasonably be monitored, subject to the approval of the patient?"

Refurbish or Repair

In their review article from 2013 "Repair of restorations – Criteria for decision making and clinical recommendations", Hickel et al. gives the following definition of the handling options of imperfect restorations [Hickel et al., 2013]:

1. **No treatment** (monitoring): if only minor shortcomings, e.g. unfavourable colour/staining or sup-optimal margins are present, with no clinical disadvantages if untreated.
2. **Refurbishment:** can be done if shortcomings are adjustable without damage to tooth, e.g. removal of overhangs, re-contouring the surface, removal of discoloration, smoothening or glazing of surface including sealing of pores and small gaps, which can be improved without adding new restorative material (except glaze or bonding).
3. **Repair:** is indicated mainly in case of localized shortcomings, which are clinically unsatisfactory and no longer acceptable. Repair is a minimally invasive approach that implies in any case the addition of a restorative material (not only glaze or adhesive), with or without a preparation in the restoration and/or dental hard tissues.
4. **Replacement:** is indicated if generalized or severe problems and intervention are necessary, and a repair is not reasonable or feasible. Replacement is the complete removal of the restoration usually combined with more loss of tooth structure.

The definition of *refurbishment* should be understood as "the correction of the shortcomings of a restoration without damage to the adjacent tooth tissues or the addition of new restorative material" and *repair* is defined as "the correction of a localized defect in a restoration involving the addition of restorative material".

In addition to regarding the patients attending habits, whether he is a regular or occasional attender, other important factors must be taken into account when considering the replacement or repair/refurbishment of a restoration. What is the patient's wish? Is there any risk of causing more harm than benefit? Are there possibilities of monitoring

stable situations? The operator is very often in a conflict-zone between the request of clinical excellence and patient-centred care.

Indications for the repair of restorations are suggested to comprise: [Hickel et al., 2013; Wilson et al., 2016]

- Correction of limited marginal openings and cavo-marginal ditching
- Management of localized marginal staining
- Treatment of early lesions of secondary caries
- Repair of fractures that do not threaten the viability of the remaining restoration and tooth tissues
- Chipping of restoration margins
- Management of wear
- Correction of unacceptable aesthetics
- Restoration of an endodontic access cavity prepared through an existing restoration

Finances

Money normally plays an important role to the patient's decisions. Whether they have to pay for the treatment themselves or there are remunerative systems and how theses may be designed to support dentist or patient, will act as criteria in the decision-making processes. Traditionally, many practitioners and patients believe in the old saying that the best treatment when faced a defective or failing restoration is *''if in doubt, take it out''* (and replace it). Hopefully such disturbing ideas will fade as the evidence and empiric gives patients and dentists reason to think otherwise.

Contraindications

There will always be discussion whether to repair or replace. Any actual situation will pose a compromise, which may disadvantage as many patients as it benefits. The FDI World Dental Federation's ''clinically poor (replacement necessary)'' criteria provide a

list of situations in which restoration replacement should be considered necessary [Hickel et al., 2010]. This list provides a useful guide as to when to normally perform a restoration replacement despite the negative effects of such intervention. Standing on the refurbish or repair evidence base and the FDI World Dental Federation's ''clinically poor (replacement necessary)'' criteria, Wilson et al. suggest new guidance for restoration replacement in clinical practice giving the following criteria [Wilson et al., 2016]:

- The restoration has unacceptable qualities, with the probability of further, clinically significant deterioration and/or lesion progression.
- Repair is contraindicated.
- The benefits of replacement outweigh the negative effects and possible harm.
- The prospects for an acceptable clinical outcome are favourable.
- The patient consents.

The second point, "repair is contraindicated" may be further elucidated by the contraindications given by Blum et al. in 2014 [Blum et al., 2014], stating that repair is contraindicated when:

- Patient reluctance to accept a repair as an alternative to restoration replacement
- Irregular attendance
- High caries risk
- Presence of caries undermining most of the existing restoration
- History of failure of a previous repair.

To facilitate difficult decision making, it should be emphasized that monitoring, refurbishment, or repair should be considered first as the *''treatment of choice''*. When repair is not seen as good alternative, replacement should be considered. Knowledge, skills, understanding and experience is required to be effective in such patient-centred decision making. Many participators in this discussion wish for the impossible, hoping that operative dentistry is easily decided by simple *''treat''* or *''no treatment''* criteria. Decision making in operative dentistry has never been, nor can never be an *''exact science''*. Repair and replacement of restorations comprises more than half the daily operative work load in normal dental practice [Tyas et al., 2000] . Hence, it is of fundamental

importance to inform patients (and others) on these issues. Whatever decision is reached it should be clearly recorded in the patient's clinical records. Knowledge and teaching of these principles of treatment options across the world in dental schools and seminars may be viewed as a major step toward the universal adoption of minimal intervention dentistry. Research to develop new diagnostic tools and processes to ascertain the functionality and sufficiency of existing restorations would also be of great value. Practitioners who examine existing restorations with the old view *"if in doubt, take it out"*, should be encouraged to adopt the modern ideas of *"as a last resort, take it out"*. Considering these options in light of the development and improvements of techniques for the refurbishment and repair of restorations as an alternative to total replacement, in particular in regularly attending patients with acceptable standard of oral care and oral health, the option of replacing a defective or failing restoration may or should be considered to be indicated only when the possibility of repair has been ruled out.

Bonding agents

Bonding agents is an integrated part of composite technology, and it is at present time not possible to glue RBC to tooth or restoration surfaces without it. Therefore, a few words on the ideas and working mechanisms of dental bonding would be appropriate.

According to "Phillips Science of Dental Materials" there are 4 important factors involved in adhesive bonding in dentistry [Teixeira, 2013]

1. *Wetting*, (dependent on surface energy).
2. *Interpenetration*, (hybrid layer formation in dentin).
3. *Micromechanical interlocking*, (any undercut available).
4. *Chemical bonding*

In the case of restoration repair, RBC must be glued to old RBC or metal/ceramics. There are most certainly no reactive monomers available in the old composite (see paper 3 and 5) and definitely not on the amalgam or metal surfaces. To make a reliable connection we need a liquid solution with very low viscosity and the ability to flow over the material surface and penetrate into all kinds of porosities and irregularities to enhance *micromechanical interlocking*. This is called *wetting*, which requires that the surface

energy or surface tension of the solid material is equal to that of the liquid spread upon it. It is important that particles in the liquid and particles in the surface structure are so intimately close that physical attraction forces i.e. *hydrogen bonds* and *van der Waals forces*, or any possible *chemical bonds* can work between them. (We are talking about distance of <1Å, smaller than 1/10 of one nm). To make this work between old and new restoration materials, it is necessary to use a liquid that can flow over to create contact with the surfaces to be bonded. We need liquid bonding agents [Matinlinna, 2014; Van Meerbeek et al., 2011].

The working procedure for bonding systems is based on the following principles [EC, 2013]:

i. *Conditioning* the surface, (etching).
ii. *Priming* of the conditioned surfaces.
iii. Application *adhesive*.

Conditioning means to cleanse the surface from debris and to bring the surface energy to approximately the same level as the liquid bonding. This enables wetting of the surface and thereby excellent contact between liquid primer/adhesive and restoration material.

Priming is spreading the hydrophilic part of the liquid bonding on the conditioned surface. Primers must be of hydrophilic nature to be able to flow over the moist area and penetrate into all kinds of retention possibilities like pits and grooves and porosities (interlocking). It should also be of hydrophobic nature to be able to bond to adhesive and to lower the potential for hydrolysis.

Adhesive is the hydrophobic part of the bonding systems that bond to the hydrophobic resin in the composite, completing the bonding process.

Bonding systems of today may be divided into two main groups.

1. *Etch and Rinse*, (ER) is the traditional system, especially the 3-step variant that has proven excellent results for many years.
2. *Etch and Dry* - also called *Self-Etch* (SE) systems consisting of a self-etching primer with acidified monomers and an adhesive part (as the adhesive in 3-step)

The development and dentists' demand for easier handling, has in turn led to the simplification of the systems through mixing the acidified SE-primer and the adhesive into one bottle to make it quick and simple for the operator, so-called "All-in-one" or *"Universal bonding"*. These new bonding agents are promising; some of them have been in use for 5-10 years now and perform well [Matinlinna, 2014].

Norwegian Amalgam Ban

The use of amalgam as a dental restorative material is banned or strongly restricted for environmental reasons in Scandinavia. The Norwegian Ministry of the Environment regulated *the use of mercury* by law in 2008. This regulation included dental materials. There were only a few exceptions allowing mercury containing amalgam in certain situations, but this was totally stopped in 2011 [Norwegian Ministry of the Environment. Oslo, 2008]. Sweden has followed and other countries are evaluating the use of mercury containing materials. We shall probably, in line with the Minimata Convention, which entered into force on Aug 16th 2017, see more restrictions, all over the world, on the use of dental amalgam in the years to come (UNEP. Minimata Convention on Mercury, 2017. Available online: http://www.mercuryconvention.org)[Kielbassa et al., 2014]. Nevertheless, this debated material has been in use for more than a century. Hence it will be present in our patients for decades, and we will often find ourselves in a treatment decision situation where the question is repair or replacement of an amalgam restoration.

The MID concept poses interesting questions concerning treatment choices for secondary caries and fractures of parts of tooth structure or restorations. On this background it was interesting to investigate dentists' attitudes concerning repair. Whether repair of existing restorations is an actual option or not? How does the repair interface perform? Is it possible to take any measures to improve this connection?

The following Aims were formulated to answer these questions:

Aims

The overall aim of this thesis was

- To bring forth **knowledge about the fundament for repair in view of the *Minimal Intervention Dentistry* concept.**

The secondary aims were

- **To map the attitudes towards restoration repair among the general dental practitioners in Norway (Paper I and II)**
- **To investigate factors influencing the reliability of the repair interface (Paper III, IV and V).**

The aims of the specific projects/papers are described in the Material and Methods chapter.

Material and Methods

I. The first paper; «**Repair of Defective Composite Restorations. A Questionnaire Study among Dentists in the Public Dental Service in Norway**» is based on a pre-coded questionnaire (Q I) which was sent electronically to all dentists (n=1313) employed in the Public Dental Service (PDS) in Norway in February 2015. Internet-based software from *QuestBack* (Oslo, Norway) was used (For all details see Paper I). See Appendix I for the questionnaire.

The study was held in two parts:
In ***part one*** the participants were asked about age and gender, place of living, the size of the clinic and whether they performed direct restorative therapy or not, for the purpose of mapping their daily workload and work tasks. If yes;

1. How much of their working day was spent placing restorations?
2. How many fillings they placed during a normal working day
3. How many of them were due to
    a) Primary caries,
    b) Repair of old restorations or
    c) Replacement of old restorations.
4. What kind of bonding agents they used in their practice (Paper I, Table 1).
5. When repairing old restorations; what kind of pre-treatment of the residual restoration was performed? Multiple answers were allowed (Paper I, Table 2).

In ***part two***, the dentists were given three patient cases with tooth or restoration fractures of increasing severity (Paper 1, Fig. 1-3). We wanted to investigate the dentists' attitudes concerning treatment decisions to see if they would choose minimal invasive, medium invasive or invasive treatment options.

The respondents were asked to choose among the following alternatives when considering the best treatment strategy:

1) Repair with resin composite restorative material (RC),

Or total replacement of the restoration with:

2) Resin Composite
3) Ceramic restoration (CAD/CAM),
4) Ceramic restoration (manually produced by a dental technician),
5) Gold cast inlay,
6) Crown (unspecified),
7) Other treatment (to be specified) (Table 4).

Option 1 was considered to require minimal invasive treatment, 2-5 medium invasive and 6 invasive treatments according to amount of tooth substance removal.

Figure. 1. *Case one.* What treatment would you suggest for this upper right second premolar? The tooth has a MOD composite restoration where some of the mesio-buccal part of the filling has fractured off. There is enamel around the entire restoration and the damaged part. The X-ray shows no caries and the distance to the pulp is at least 1 mm. There is seen no other pathology or discomfort/sensitivity. The patient is a woman in the mid-fifties, with low caries activity and normal occlusion. There are no financial limitations concerning dental treatment and the patient has no desire to improve the esthetical appearance of the restoration.

Figure. 2. *Case two.* What treatment would you suggest for this lower right second molar? The toothhas a disto-buccal cusp fracture adjacent to a composite restoration. There is enamel around the entire filling and the damaged part. The X-ray shows no caries and the

distance to the pulp is at least 1 mm. There is seen no other pathology or discomfort. This patient is a woman in the mid-fifties, with low caries activity and normal occlusion. There are no financial limitations concerning dental treatment.

Figure. 3. *Case three.* What treatment would you suggest for this upper left first premolar? The tooth has lost the palatinal cusp. There is a remaining composite MOD restoration. There is enamel surrounding the entire filling and fracture. The X-ray shows no caries and the distance to the pulp is good and there is no other pathology. The patient is a woman in the mid-fifties, with low caries activity and normal occlusion. There are no financial limitations concerning dental treatment.

Statistical analyses

Statistical analyses were performed by descriptive statistics with chi-square tests. See paper I. Statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 20.0.0.1 (SPSS Inc., Chicago, IL, USA). A significance level of 5% was used throughout.

II. The second study; «**The Post-Amalgam Era: Norwegian dentists' Experience with Composite Resins and Repair of Defective Amalgam Restorations**» is based on another similar pre-coded questionnaire using the QuestBack software (Q II, Paper II).

It was sent electronically to all dentists (dental surgeons) with an e-mail address registered in the member register of the Norwegian Dental Association – (NTF) (This includes both Public Service dentists and private practitioners). The questionnaire is enclosed as Appendix II

Like the first questionnaire the participants were asked whether they performed direct restorative therapy or not for the purpose of mapping their daily workload and work tasks.

Information was collected regarding the respondents' sex, age, Home County, type of practice and to which extent the respondent was occupied with caries diagnosis and treatment in his/her practice. Questions were asked about the use of restorative material in Class II-restorations, opinion factors related to the failure of Class II composites and general attitudes towards composites.

Ethical considerations concerning questionnaires

In both questionnaires participation was voluntary. No remuneration was given to the respondents. Anonymity was ensured by *QuestBack*. The first QuestBack (QB) study was registered at the The Norwegian Data Protection Authority (ID: 70269). The second QB was approved by the Norwegian Social Science Data Services (NSD) (Project number 21170).

Statistical analyses

Statistical analyses were performed by descriptive statistics with chi-square tests and two separate logistic regression analyses. See paper II. Also in this study, aggregated data for each of 20 Norwegian counties on the variables; mean number of decayed, missing, and filled teeth (DMFT) for 18 year olds and number of patients per dentist (dentist density) in the respondents' respective counties of practice were extracted from Statistics Norway, Dental Health [Statbank, 2009]. Statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 20.0.0.1 (SPSS Inc., Chicago, IL, USA). A significance level of 5% was used throughout.

III. The third paper: "**Role of Bonding Agents in Repair of Composite Resin Restorations**" is an *in vitro* laboratory study. The scope was to evaluate the role

dental bonding agent play at the repair interface between new composite and aged composite in order to assess the reliability of repair interface.

The materials used for the experiments are given in Table 1, Paper III. They were selected for being the most commonly used products in Norway at that time.

Test substrate bases were made by packing composite in copper rings (8 mm diameter, 10 mm height) placed on a Mylar strip on a table. The composite cylinders were light-cured every 2 mm increment from the top, according to the manufacturers' specifications, using Demetron VCL 400 curing lamp (KerrHawe, Orange, CA, USA) with an irradiance of 859 mW/cm^2, as measured by the Norwegian Radiation Protection Authorities (Osteraas, Norway). After curing, the copper rings were carefully split and removed. Ten test substrate bases were produced of each composite product. In total 60 composite cylinders were made. One additional cylinder of each composite was made, ground as described below, and prepared for surface evaluation using a scanning electron microscope (Phillips XL 30, DX4i; EDAX International, Mahwah, NJ, USA). The specimen bases were placed in distilled water at 37°C immediately after production, and stored for a minimum of 60 d for water sorption. Water was changed every week to prevent bacterial growth. All test substrates were stored in distilled water at 37°C during the entire study.

The bonding procedure at repair interface was performed according to the bonding manufacturers' instructions and according to the test equipment and description in ISO/TS 11405:2003 [ISO, 2003].

Three test modes were performed for all substrates;

Test 1: *Testing of shear bond strength (SBS) after 24 hours (Short term test).*

The test procedure for measuring shear bond strength (SBS) is described in ISO/TS 11405:2003.

Test 2: *Test of shear bond strength (SBS) after ageing (thermocycling).*

Test specimens were thermo-cycled 5000 cycles in water at temperatures ranging from 5°C to 55°C (20 s at each temperature, intermediate time of 2-3 s) before the SBS test was performed.

Test 3: *Test of bonding to composite of unknown origin after aging 180 days (thermocycling).*

After 180 days in water, the substrates were randomly mixed and divided into three series and blinded with respect to the 'old' composite. We used repair composite with belonging bonding agent in two series and composite without bonding agent in the last series, thermo-cycling (5000 cycles, 5°C to 55°C) and SBS testing.

Statistics

The probability of failure in the test specimens was assessed by means of a distribution plot, and the significance of the differences was evaluated by the Kolmogorov-Smirnov test [Press WP, 1986]. The distribution of adhesive and cohesive fractures was analysed by the hypergeometric distribution and the differences in SBS between test 1 and test 2 were analysed using The Wilcoxon rank sum test/ The Mann-Witney Test [Rice, 1995]. Student t-test (paired) for two tailed samples was performed to compare the results for each treatment procedure.

IV. The fourth study "**Silanizing Agents Promote Resin Composite Repair**" aimed to test the role of silanizing agent on surfaces to be repaired. The materials and method is described in Paper IV. This *in vitro* laboratory test was split in two parts

Part 1: *Test of old composite repair*

The substrates were the same as used in Paper III, now 6 years older.

The old test substrates were used three times for testing three different bonding procedures when performing restoration repair:

1. Clearfil Bond SE without sializing agent (control).

2. Clearfil Bond SE with Bis-Silane pre-treatment.
3. Scotchbond Universal, containing silanizing agent.

All test specimens were thermo-cycled (5000/5-55°C) before Shear Bond Strength (SBS) test according to ISO/TS 11405:2003, as previously described in Paper III.

Part 2: *Test of new composite repair*

Sixty-six new test substrates were made as described in Paper III from the material of choice at the student training clinic, University of Oslo, (Filtek Supreme XTE,). After 60 days in water storage, the new substrates were divided into three groups of 22. They were tested according to exact same protocol as the old composite repair.

Statistics

The statistical analyses are all the same as for Paper III.

V. The fifth paper (which is in manuscript) deals with repair of amalgam restorations and has the title: "**Bonding of Composite and Glass-ionomer to Amalgam"**.

The test hypothesis was to see whether organic restorative materials would fix to inorganic amalgam when using *only* standard bonding procedures.

Test substrates were made by condensing amalgam (Dispersalloy) into copper bands, Θ 8mm height 10mm, and ground flat with sanding paper #500 FEPA (Struer, Denmark). In the present study, three widely used bonding systems were chosen; one 3 steps etch and rinse (ER) type; Optibond FL (OFL), one 2 steps "self-etch" (SE) bonding agent; Clearfil SE Bond (CSEB)and one 1 step SE, also called "Universal", bonding agent; Scotchbond Universal (SBU).

Three different glass-ionomers (GIs) were chosen as they might be a good alternative in not stress bearing areas. The chosen bonding materials were; GC Fuji II LC (with

and without conditioner), GC Fuji IX (with and without conditioner) and Ketac Universal Applicap (no conditioner according to manufacturer's recommendation). Materials used are listed in Table 1.

Repair material of composite (Filtek Supreme XTE, shade A3) was mounted as cylindrical buttons on the ground amalgam surface, Θ3mm, h: 2mm with the chosen bonding systems. Glass-Ionomer buttons were mounted with or without conditioner as described above.

Handling of the bonding materials, composite and glass-ionomers was performed according to manufacturer's instructions. They were light cured with Kerr Demi Ultra, pulse, irradiation 900-1000 mW/cm^2. The specimens were made according to ISO/TR 11405 [ISO, 2003] for shear bond strength (SBS) testing. The specimens were SBS tested in an Instron universal testing machine (Lloyds, England); overhead speed 1mm/min. Three different test modes were used:

Mode 1. Short term test; the substrates had new buttons of RC/GI fixed and the specimens were SBS tested after 48 h in water storage (no TC was performed).

Mode 2. Water storage 60 days; the test specimens were SBS tested after 2 months at 37°C in water (no TC was performed).

Mode 3. Thermo-cycling (5000 x 5/55°C) (TC); after mounting the repair materials (RC/GI) the specimens were stored in water (14 days) before TC and SBS testing.

The amalgam-composite-repair-specimens (test specimen) were tested in 9 different groups (3 series x 3 modes) of 20 specimens each, see Table 2. The amalgam-GI-repair specimens were tested in 15 groups (5 series x 3 modes).

"The Norwegian Environment Authorities" granted import of mercury containing dental amalgam to Norway for use in this project (ref. 2016/97).

Ethical concideration

"The Norwegian Environment Authorities" granted import of mercury containing dental amalgam to Norway for use in this project (ref. 2016/97).

Statistics

The statistical analyses for calculating mean and variance were performed using the Statistical Package for the Social Sciences (SPSS, Inc. Chicago, IL, USA version 24). The probability of failure in the test specimens was assessed by means of a distribution plot, and the significance of the differences was evaluated by the Kolmogorov-Smirnov test [Press WP, 1986].

The level of significance was set at 5%.

Main results

The results of our investigation are presented in full in the five papers. Paper I and II deal with the questionnaires and analyses of the answers from the dentists.

In paper III to V, the results from the investigations on different factors influencing the strength and reliability of repair interface are given and discussed. This section presents the main findings which will be discussed later.

Paper I

All dentists (n=1313) employed in the Public Dental Service (PDS) in Norway in February 2015, was invited to participate in the study. After three reminders, a total of 748 dentists had responded. This gave a response rate calculated to 55.8% according to Standard Definitions of the American Association for Public Opinion Research [AAPOR, 2015]. Women constituted 69.6% of the respondents and 30.4% were men. Age range of the dentists varied from 25 to 77 years with a mean of 41.8 years Standard Deviation (SD) was calculated to 12.4.

The study was held in two parts;

In Part one, the participants were asked about age and gender, place of living, the size of the clinic and whether they performed direct restorative therapy or not, for the purpose of mapping their daily workload and work tasks. The PDS dentists spent on average 57.5% of their working day placing restorations. They were making from 1 to 30 restorations per day, with a mean of 7.7 fillings made pr. Day, SD was 3.6. Reasons for operative treatment were mainly *Primary caries* which counted for 55.7% of the decisions with SD 19.1%. Repair of restorations constituted 26.7% of operative workload with a SD of 14.8%. Replacement of fillings contributed with 18.2% of the operative work. Here the SD was estimated to 11.2%.

The results from the answers concerning use of bonding agent systems showed that more than 80 % of the dentists used bonding agents when repairing composite restorations.

The proportion using 2-step etch and rinse (ER) was 48.7%, while 3-step ER were used by 24.6% of the dentists in PDS. The rest, 26.7% used different Self-etch (SE) systems. Only 7.4% reported to use a separate silanising agent when performing repair. Interestingly almost 80 % said they made extra retention by preparation in adjacent restoration (the restoration to be repaired).

In Part two: In the first of the three treatment choices, *Patient Case 1,* 89.6% of the respondents would choose repair with resin composite (RC). Only 4.5 % would replace the whole restoration with RC and 3.2 % would prefer to make a crown of some description. In *Patient Case two*, 86.9% would choose repair with RC, 3.3 % would replace the restoration with a new composite restoration and 6.6 % would prefer a crown. When it comes to *Patient Case 3*, the premolar with fracture of the palatal cusp, a clear change was seen in treatment choice and only 54.1% preferred the minimal invasive approach by choosing repair with RC. Here 13.8 % still would make composite restoration by replacing the old filling. The biggest difference was that 21.8 % would choose to make a crown.

The dentists' treatment decisions for *Patient Case 3* can be grouped according to amount of tooth substance removal as either

1) *Minimal invasive* treatment – repair with RC (54.1%, n=383),

2) *Medium invasive* treatment – replacement of the whole restoration with a filling or an inlay/onlay (24.0%, n=171) and

3) *Invasive* treatment – restoration of the tooth with a crown (21.8%, n=154). Minimally invasive treatment was preferred significantly more often among the oldest dentists compared with the younger dentists (≤38 years) ($p<0.01$).

Paper II

This second questionnaire was sent to all dentists (dental surgeons) with an e-mail address registered in the member register of the Norwegian Dental Association – (NTF) (Which includes both Public Service dentists and private practitioners). In total, 2375 out of 3654 dentists responded after two reminders. A response rate of 61.3% was calculated according to the Standard Definitions of the American Association for Public Opinion Research [AAPOR, 2015]. Composite was the preferred restorative material among 99.1%

of the dentists. Secondary caries was the most commonly reported cause of failure counting for 72.7%, followed by 25.1% restoration fractures. Longevity of Class II restorations was estimated to be approximately 10 years by 45.8% of the dentists, but 71.2% expected even better longevity if the restoration was made with amalgam. Repair using composite was suggested by 24.9% of the dentists in an amalgam restoration with a fractured cusp. Repair was more often proposed among young dentists ($p < 0.01$), employees in the Public Dental Service (PDS) ($p < 0.01$) and dentists working in counties with low dentist density ($p = 0.03$). There was a tendency towards choosing minimally invasive treatment among dentists who also avoided operative treatment of early approximal lesions ($p < 0.01$). Norwegian dentists showed positive attitudes towards composite as a restorative material. Most dentists chose minimally- or medium invasive approaches when restoring fractured amalgam restorations.

Paper III

The essence of the results of bonding tests at repair interface is given here:
Short-term SBS testing (*test 1*) gave mean breakage values ranging from 19.8 to 26.0 MPa when a bonding system was used, and 9.9 MPa (Filtek Z250) and 15.2 MPa (Charisma) without any bonding system.
After thermo-cycling (*test 2*) the mean values varied from 16.0 to 22.7 MPa. The product without adhesive had a mean value of 16.8 MPa (Charisma).
For the short-term SBS test, 67% of the fractures were apparent adhesive failures. The remaining 33% of failures were cohesive fractures. After thermo-cycling, 90% of the failures were found to be adhesive fractures.
Testing new known composite bonded to old unknown composite (180 d in water) (*test 3*) revealed that the mean values of SBS were 8.9 MPa and 12.7 Mpa when bonding was used. When no bonding was used the mean value was as low as 2.6 MPa. All fractures were of the adhesive type in this test. Test specimens where the new composite did not withstand the thermo-cycling procedure alone, or detached prior to SBS-testing, were given the value 0 N (Pre-test failures).

Paper IV

The results from the experiments with silanizing agents at composite repair interface are given in Table 2/Paper IV.

Part 1 of the experiments, i.e. repair of *old* composite, gave mean SBS at approx. 6.2 MPa for the control (Clearfil Bond SE only). This increased to approx. 14.8 MPa for Clearfil Bond SE plus silane, and 15.3 MPa for Scotchbond Universal bond with silane incorporated. This indicates an increase of bond strength when using silane at 140 % approximately for old composite repair in this experiment.

For *Part 2*, repair with new composite, the mean SBS for the control was 15.4 MPa (Clearfil Bond SE only). This increased to approx. 23.4 MPa for Clearfil Bond SE plus silane and 23.7 MPa for Scotchbond Universal containing silane. In this experiment we could observe an increase of bond strength when using silane at approx. 50 %.

A significant difference was observed between the control and the test groups with silanising agents, both in Part 1 ($P < 0.001$) and in Part 2 ($P < 0.005$).

Paper V

The SBS results for the bonding of RC to amalgam are given in Table 2 and Figure 1/Paper V. However, the GI substrates could not be SBS-tested as they would not adhere to the amalgam surface at all. Therefore, they are regarded as pre-test failures with the value = 0.

For the composite testing in 3 different modes with 3 different bonding agents the results were:

Mode 1) Short term test:	6.5-8.3MPa,
Mode 2) After 60 days' water storage:	6.4-7.7MPa,
Mode 3) After thermo-cycling:	0.6-2.2Mpa.

The thermo-cycling test-mode gave significantly lower figures than the other two modes, but it was not possible to see any significant difference between the results in mode 1 and 2.

All the specimens were analyzed for fracture mode after breaking off the repair material by means of a light microscope (Wild Photomakroskop M400, Wild Heerbrugg AG, Switzerland). One hundred percent were of adhesive type. A few specimens exposed remnants of repair material in small pits and grooves.

Discussion

Methodological considerations

Questionnaires

To answer the questions about Norwegian dentists' attitudes towards repair of defective restorations and their experience with composite restorations, it was decided to try mapping the situation through questionnaires. Two questionnaires were made and sent to dentists all over Norway. Before sending them, a preliminary questionnaire was carried out in a smaller region in South-East Norway (Buskerud Fylke). All the members of Buskerud Tannlegeforening (Buskerud Dental Association, a part of The Norwegian Dental Association) were asked a series of questions concerning restoration repair and therapeutic decision making. This questionnaire was slightly modified and sent to all the employees in Public Dental Service in Norway (PDS).

Using an electronic form of questionnaire survey (Internet-based software Questback - www.questback.com/no) certainly gives some advantages to conventional paper based questionnaires. The data files received were almost ready to use with SPSS statistical tools (IBM Statistical Package for the Social Sciences (SPSS) Statistics version 20.0.0.1 SPSS Inc., Chicago, IL, USA), but even better, the internet based distribution of material to participants is less costly. The handling of first and second reminder was automatically set up and performed by the software from Quest Back, making the distribution and collecting work quicker and easier. The software ensured the participants' anonymity and the Norwegian Social Science Data Services (NSD) approved the studies without reservations as they were familiar with the software tools.

Response rate

An essential measure of any questionnaire is the response rate i.e. how large is the proportion of the desired sample of the population that actually answered the request. The chance of non-response bias is reduced by a high response rate [Alderman and Salem,

2010]. There may be disproportionality between those who answer and those who refuse to do so [Gansky and Neuhaus, 2009]. Missing or incomplete data are not random. Who has answered and who has not answered? One cannot be certain of the distribution of the non-respondent's answers compared to the respondent's answers. What are the characteristics of the non-responders and their possible response? Do the respondents answer honestly or just what they think is right? Are there any similarities or differences in attitudes or preferences between the respondent- or the non-respondent groups that would make the samples different and therefore could bias the results? A publication from Alderman and Salem states that there should be at least 50 % response rate to make adequate analyses. Response rate of 60 % is considered good and 70 % is considered very good [Alderman and Salem, 2010]. Our questionnaire surveys reached 55.8% and 61.3 % respectively, which should be regarded as adequate and good for statistical purposes and in the high-end of what has been achieved in similar questionnaire studies elsewhere [Baraba et al., 2010; Domejean-Orliaguet et al., 2004; Domejean et al., 2015; Gordan et al., 2009b; Kanzow et al., 2017a; Kanzow et al., 2017b; Kanzow et al., 2018]. The Norwegian Dental Association (NTF) estimates that 90-95% of all practicing dentists in Norway are registered members. The relatively high response rate (61.3%) and the matching age distribution of the respondents are consistent with our sample being representative of the members of NTF and all authorized dentists in Norway. The independent variables concerning age and gender in Paper I and II, correlate well with data for all dentists in Norway, extracted from Statistics Norway, Dental Health, 2009 (https://statbank.ssb.no/en/statistikkbanken) [Statbank, 2009] and data from The Norwegian Dental Association.

Limitations of questionnaire studies

Any questionnaire study, like the present one, has some built-in limitations. Norton et al. have addressed and discussed possible bias related to this type of study [Norton et al., 2014]. They mention two different limitations, of which the first is response bias subjected to social desirability. In a clinical context, this would lead to responses which are politically correct according to guidelines or experts' opinions. The second limitation is the nature of non-validated self-reports, which may not reflect the actual behaviour. A third limitation in our study is that we were not able to reach private practitioners. It is likely that financial issues would affect the dentists' choice of treatment more in that

group compared with PDS-employed dentists. Also, the amount of restorations placed due to primary caries in our sample may be exaggerated since all patients aged 0–18 years, in Norway, are treated almost exclusively by the PDS.

Attitudes towards restoration repair among the general dental practitioners in Norway

Restorative treatment among Norwegian Dentists

The results of the first survey indicate that restorative treatment still lays claim on a large part of dentists' working day. From a lot of studies, going a long time back, we know this as a fact [Mjor, 1993; Tyas et al., 2000]. How large part of the working day spent on restorations (mean 57.5%, SD17%, *range 10–100%*) and how many fillings placed daily (mean7.7, SD 3.6%, *range: 1–30*), varied between the dentists. An explanation to the great variation in range could be that in some counties in Norway dental hygienists take a great part in the screening and recall examinations of patients and the dentists focus on operative treatment. In many counties the dentists do both recall examinations, preventive and operative treatment. Another important factor is that caries prevalence among children in Norway is skewed, especially between immigrant groups and native western groups in districts with many immigrant patients [Skeie et al., 2005]. This may explain why the number of restorations placed by the dentists and the main reasons for operative treatment may differ substantially, depending on which cohorts of patients the dentists see. Nevertheless, the data say that on average 57.5% of the working day is reserved for operative treatment.

The general opinion that secondary caries and restoration fracture are the most common reasons for failure of composite restorations is supported by evidence from the literature. A review of studies conducted in the 1990s on the longevity of dental restorations reported that secondary caries was the reason for replacement in 33–65% of failed composite restorations [Hickel et al., 2000]. Studies published later have reported varying rates: 25% [Da Rosa Rodolpho et al., 2011], 38% [Opdam et al., 2007a], 52% [Soncini et al., 2007], 57% [Pallesen et al., 2014], 58% [Kuper et al., 2012] and 88% [Bernardo et al., 2007]. A recent review on the longevity of posterior composite restorations states;

secondary caries and fracture of restoration are considered the two main reasons for failure [Demarco et al., 2012]. In our first survey primary caries was the reason for restorative treatment in more than half the patient cases, 55.7%, treated by PDS dentists. This may reflect that children represent the largest group of the patients in the PDS and the result is comparable to results from Mjør et al in surveys from 1996 and 2000/2001 [Mjor et al., 2002a].

In Paper II (both PDS and private practitioners, all age groups) we asked the dentists about reasons for operative actions, and it was established that in more than 70 % of the cases secondary caries was the main cause of failure. Fractures of restoration counted for approximately 25 %. This is in concordance with other researchers, although the proportions between secondary caries and fractures vary [Mjor, 1989; Mjor and Gordan, 2002; Mjor et al., 2002b; Mjor and Toffenetti, 2000; Opdam et al., 2007b].

Main Indications for repair among Norwegian dentists

The treatment goal of restorative dentistry is to produce long-lasting restorations of good quality without compromising the sound tooth tissue more than necessary [Gordan et al., 2009a; Maneenut et al., 2011; Mjor and Gordan, 2002]. Norwegian dentists report a willingness to perform repair of composite restorations. Our first questionnaire (see Paper I), revealed that approximately 25 % of restoration treatment in the PDS was repair of restorations, slightly higher than replacement of restorations that counted for a little less than 20%. This seems to be within the same range as found in another research paper from 2012 as Gordan et al. found similar figures for the repair proportion in a Dental Practice-Based Research Network in the USA and Scandinavia (Denmark) [Gordan et al., 2012].

Functional failures (i.e. fractures of restorations or tooth substance) seem to be the main reason for performing repair, although secondary caries seems to be the most frequent reason for restoration failure [Kanzow et al., 2017a; Kanzow et al., 2017b; Kanzow et al., 2018; Palotie and Vehkalahti, 2012]. Dentists seem more prone to perform replacement of the total restoration when opposed to secondary caries. The reason may be uncertainty about the caries process which very often is difficult to control and may undermine the existing restoration [Kanzow et al., 2017b]. Gordan et al. states in a questionnaire from 2012 that only 25% chose repair and 75% chose replacement of restorations judged to

have failures, although secondary caries was the main reason for treatment needs [Gordan et al., 2012].

When considering treatment options of defective restorations, the majority of the responding dentists chose a conservative approach, which in our studies was defined as repair. Almost nine out of ten dentists (89.6%, *Patient Case 1* and 86.9%, *Patient Case 2*) would prefer repair of a failed restoration when the damage was small. Our study cases showed minor tooth or restoration fractures. Even when the damage comprised one cusp of a bicuspid (*Patient Case 3*), more than half the dentists, 54.1%, would still prefer composite repair. Interestingly, in *Patient Case 3*, only 21.8% of the PDS dentists suggested crown therapy which was defined as "invasive treatment" in this study. Before sending out the questionnaire, we performed the alrewady mentioned preliminary study in the Norwegian county of Buskerud. The almost similar set of questions were sent to all dentists; both private- and PDS-employees in Buskerud County (unpublished data). The proportion of dentists working in PDS in Norway (and Buskerud) is about 1/3 of all dentists in the country [Statbank, 2009]. In this preliminary questionnaire 73 % were private and 23 % were from the PDS. There is of course, not possible to compare these data samples statistically because of sample size and conditions around data collection, but it may be speculated that private practitioners seem to choose more invasively. In *Patient Case 3* we found the most striking difference, as approx. 46 % of the dentists in Buskerud would make a crown, compared to only 22 % of the PDS dentists in Questionnaire I (see Paper I). The figures may be regarded as a confirmation that most Norwegian PDS dentists follow the concept of MID and try to save as much tooth substance as possible. The survey also indicates that older dentists may be more conservative than younger dentists as they prefer repair more often. This difference is difficult to explain. We might speculate that this is due to older dentists having more experience with dental materials and increased confidence in technical skills, or that younger dentists may be eager to practice crown preparation techniques? This question has not been answered. It was not possible to observe any relationship between gender and treatment choice for the three cases.

The use of bonding agents among Norwegian dentists when repairing restorations

The first survey (see Paper I) also made an effort to estimate the PDS dentists' preferences concerning use of bonding agents and macro mechanical preparation methods for retention purposes. The majority of the dentists, 83.3% (see Table 2, Paper I), chose etch-and-rinse (ER) types of bonding agents as their standard pre-treatment procedure for repair. A similar amount of dentists, 79.8%, reported that they also made extra macro mechanical preparation for retention (see Table 2, Paper I). This might be beneficial pre-treatment strategies for increasing the bond strength at the repair interface. Some bonding systems have, in vitro, shown to increase the strength of the repair interface significantly [Hickel et al., 2013; Staxrud and Dahl, 2011, 2015]. Theoretically, macro mechanical retention should be beneficial as it firmly locks the restoration in place and reduces direct stress on the repair interface. Only a few of the respondents, 7.4% used extra silanising agents as part of their repair protocol. Silanes have been proven, *in vitro*, to enhance bond strength of the repair interface [Eliasson et al., 2014; Lung and Matinlinna, 2012; Staxrud and Dahl, 2015] and should in the authors' opinion be used routinely when repairing RC restorations, either as a separate step in the clinical procedure or an incorporated ingredient in the bonding agent. Some of the newer bonding systems available on the marked today, contain silane which might negate the need of an extra silanising agent [Staxrud and Dahl, 2015].

Regarding the one-step (all-in-one) bonding systems there lies some uncertainty in the mixing of hydrophilic and hydrophobic monomers in the primer and adhesive. This may prevent the solvents in the primer to evaporate adequately before adding the bonding agent [Peumans et al., 2005]. In turn, this may enhance the formation of droplets in the bonding interface, caused by phase separation or osmosis because of high HEMA (hydroxyl-ethyl-meth-acrylate) content. HEMA's hydrophilic properties attract water and keep it there, which eventually might lead to weakening of the bonding strength [Van Landuyt et al., 2007a].

The hydrolytic instability of the coupling agents (silane compounds) is another important factor. Pre-hydrolysed silanes might be inactivated shortly after production due to water and chemical reactions with similar silane molecules. In addition the bonding between silanes and filler particles is vulnerable because of hydrolysis [Lung and Matinlinna, 2012]. It is suggested that the repair potential decreases with time because of higher water

content in old composite leading to hydrolysis and the reduced ability to form chemical bonds to old resin molecules [Breschi et al., 2008; Burtscher, 1993; Eliasson et al., 2014; Staxrud and Dahl, 2011, 2015]. Bonding systems have been through a tremendous development during the last decades [Van Meerbeek et al., 2011]. Regarding bonding to dental hard tissues there is a trend towards using self-etching systems with and without separate etching of the enamel. Both one-step (all-in-one) and two-step (separate prime and bond) variants are available. They are well acknowledged by scientists and some refer to the mild and extra mild etching systems (pH 2–2.7) as the new "Gold Standard" of dental bonding [Van Meerbeek et al., 2011]. The main advantage of self-etching primers is less destruction of mineralised dentin. Acidulated resin monomers etch hard dental tissue as they penetrate into dentin and enamel. Thereby a stronger hybrid layer will theoretically be created and the risk of postoperative hyper sensibility is reduced [Van Meerbeek et al., 2011]. It is recommended to etch enamel separately with a stronger acid as the mild acids do not penetrate the enamel sufficiently. Concerning acid etching on composite surface, the acid strength might not have the same relevance. The main purpose of the acid is to cleanse the material surface from debris, so-called smear layer, and increase surface energy for better wetting and close contact between the materials [Staxrud and Dahl, 2011, 2015; Teixeira, 2013; Van Meerbeek et al., 2011]. The shift in choice of bonding system does not seem to have reached the PDS in Norway yet as 73.3% of the dentists claimed they still use etch and rinse (ER) systems. An explanation for this could be that dentists in the PDS are obligated to follow business agreements, but could just as well be a result of confidence in the chosen material which performs very well.

The importance of the "Post Amalgam Era"

Although the present data were collected in 2009 and our conclusions are likely to be outdated in a Norwegian setting, the findings may have high clinical relevance in other countries where use of amalgam is still allowed. Our results reflect decision making on restoration replacement in a population of dentists that are not using amalgam anymore. In the UK, Lynch and Wilson have already used Norway as an example on how to manage a phase-down and eventually ban of amalgam [Lynch and Wilson, 2013]. The present study may be considered an important follow-up, providing information on how the Norwegian dentists cope with the amalgam ban.

The “Amalgam Era”. Restorations survived for almost four decades. They suffer from substantial wear, but are still in function. Note the composite repair on buccal surface tooth 46.

Composite has become the dominating material of choice in Norway one year after the amalgam ban. Almost all dentists (99%) stated that they “Often” or “Always” used composite when restoring a MOD-cavity due to primary caries being confined to the outer half of dentin. Similar trends have been found in other Norwegian studies [Vidnes-Kopperud et al., 2011; Vidnes-Kopperud et al., 2009]. International studies show similar trends; a study on trends in dental treatment in the USA showed that patients received approximately 50% fewer amalgam fillings in 2007 compared with 1992, while the rise in use of resin-based composite restorations was corresponding [Eklund, 2010]. In other countries, the use of amalgam has also decreased rapidly [Baraba et al., 2010; Domejean-Orliaguet et al., 2004; Eklund, 2010; Forss and Widstrom, 2001; Lynch et al., 2007; Opdam et al., 2007b; Sunnegardh-Gronberg et al., 2009]. More than fifty percent of the dentists in our questionnaire study (see Paper II) stated that they “Never” used other materials than composite. This is in accordance with a practice-based study from 2010 by Nascimento et al. showing that the overall use of other materials than amalgam and resin-based composite was only 5% for both US and Scandinavian dentists, when placing restorations in premolars and molars [Nascimento et al., 2010].

Large composite restoration made in tooth 16 after implementation of amalgam ban. It works well together with the old amalgam restorations survived for forty years.

The dentists in our questionnaire study (Paper II) considered moisture control during placement of composite restorations (58.9%) and the caries activity of the patient (52.1%) to be very important factors for the longevity of composites (Table III, Paper II). The findings are consistent with replies shown in Table IV (Paper II). Both these variables could be related to development of secondary caries. Nevertheless, the lack of standardized diagnostic criteria for marginal failure could cause over-registration of secondary caries [Kidd, 2001; Mjor, 2005]. Crevices and ditched restoration margins, in which the explorer sticks, could wrongly be diagnosed as secondary caries [Kidd and Beighton, 1996; Magalhaes et al., 2009; Mjor, 2005], particularly when there is marginal colour changes. One should bear this in mind when interpreting answers and results from this and other studies showing secondary caries to be the most frequent cause of restoration failure.

In Table IV Paper II, 58.5% of the dentists either “Agree” or “Totally agree” that secondary caries is more commonly seen in composite restorations compared to amalgam. This is in accordance with findings in a questionnaire study on Finnish dentists’ perceptions on the reasons for replacement of restorations [Palotie and Vehkalahti, 2012]. This perception is clinically established in the literature. In a retrospective clinical study by Kuper et al., resin composite restorations developed secondary caries twice as often as amalgam restorations [Kuper et al., 2012]. Similar results have also been shown in three earlier RCT studies [Bernardo et al., 2007; Haj-Ali et al., 2005; Soncini et al., 2007].

Post-operative pain or sensitivity were reported “Never” or “Seldom” to be the reason for failure by 50.5% of the dentists and additional 43.8% reported only “Sometimes”. This

corresponds well with the conclusion in a review by Hickel et al. (2001) that the problem with post-operative hypersensitivity was decreasing [Hickel and Manhart, 2001].

Allergic reactions were reported "Never" or "Seldom" to be the reason for failure by 93.8% of the dentists in our survey. The *Norwegian Dental Biomaterials Adverse Reaction Unit* has operated a national reporting procedure concerning suspected biologic adverse reactions experienced in relation to treatment with dental biomaterials. The prevalence of adverse reactions to composites, in Norway, is reported to be generally low. During the twenty years from 1993 to 2013, approx. 2100 reports have been received. In 2013, 28 % of the reports were related to composites and cements, a percentage that has remained relatively stable over the years following the amalgam ban (Björkman, L.; Gjerdet, N.R.; Lygre, G.B.; Berge, T.L.L.; Svahn, J.; Lundekvam, B.F. National Reporting of Adverse Reactions to Dental Biomaterials in Norway. Available online: https://www.researchgate.net/publication/266761514 National Reporting of Adverse Reactions to Dental Biomaterials in Norway, Accessed on 10 March 2016).

In general, the dentists' replies in *Patient Case 1* (Paper II) indicate a positive view on the longevity of restorations in a low-risk patient. Nearly half the dentists (45.8%) estimated the longevity to be more than ten years, while only 3% of the dentists estimated the longevity to be less than five years. The positive trend is consistent with the presented views in Table IV, (Paper II), where 74% of all dentists either "Agreed" or "Totally agreed" with the statement that composite is a good alternative to amalgam. Nevertheless, the fact that 71.2% of the dentists expected longevity to be better if the restoration was made with amalgam distorts the picture. These dentists were found significantly more often to be young, female and employed by the PDS. This diverges partly from what was previously found in a practice-based clinical study, where the dentists who preferred amalgam in Class II restorations were identified as being male and the patients to have high caries experience [Vidnes-Kopperud et al., 2009].

Logistic regression analyses revealed that minimally invasive treatment (repair) in *Patient Case 2* (Paper II) was suggested more often by dentists working in counties with low dentist density, while invasive treatment (crown) was suggested more often by dentists working in counties with high dentist density. These findings indicate that dentist remuneration may affect the treatment decision. Repair is a rapid and cheap alternative that can be preferred among dentists who have many patients attending their dental clinic, while a crown generally produces more work at a considerably higher cost, which could

be beneficial for dentists with few patients attending their dental clinic. This idea is supported by the finding that more dentists employed in the PDS also chose repair, since they often have high workload and, in many cases, a fixed salary.

Dentists choosing minimally invasive treatment in Patient Case 2, tended only to treat advanced stages of approximal caries lesions operatively. This is supported by findings in a study by Heaven et al. They found that dentists who recommended restorative treatment of primary occlusal caries and approximal caries at a more advanced stage were significantly more likely to recommend repair instead of replacement of a defective restoration [Heaven et al., 2013].

In conclusion, the results from questionnaire II show that Norwegian dentists have positive attitudes towards composite as a restorative material in posterior teeth one year after amalgam was banned. This has been confirmed by a later report by *The Norwegian Climate and Pollution Agency* (The Norwegian Climate and Pollution Agency. *Review of Norwegian Experiences with the Phase-Out of Dental Amalgam Use*; The Norwegian Climate and Pollution Agency: Oslo, Norway, 2012). This indicates that "dental personnel and patients generally are satisfied with the alternatives to dental amalgam". Most dentists choose minimally invasive- or medium invasive approaches when restoring fractured amalgam restorations. Dentists choosing minimally invasive treatments also avoid operative treatment of early approximal lesions.

Factors influencing the reliability of the repair interface

Laboratory tests of bond strength

For a long time, there have been discussions among researchers about what test method is the best for assessing the strength at the interface between different materials or in other words the capability of adhesives. In the laboratory studies presented in this thesis, shear bond strength (SBS) (i.e. macro shear bond strength) has been the chosen method. This SBS test method is described in the test standard ISO 11405 [ISO, 2003]. The ISO standard also describes a micro tensile bond strength protocol (μTBS), which is preferred by many scientists. The latter is by several researchers recognised to be the best methodology for testing bond strength between composite and dentine/enamel

[Armstrong et al., 2017]. Its pull-off working mechanism may be biased because of cracks created during technique sensitive preparation process of test substrates. Fracture lines may emerge at different places other than the bonding interface caused by unintentional punches from the drilling equipment. These infractions may propagate during the pulling procedure. Well prepared specimens would give good indications of the bond strength properties of the bonding material, but there has been reported many pre-test failures caused by the damaging phenomenon described above. The pre-test failures may bias the results substantially and it is important how they are dealt with in the statistical process.

The SBS testing has been criticised for low clinical relevance and for large variation in test results [De Munck et al., 2012; Versluis et al., 1997]. One main problem may be the absence of an independent control for example with a "Gold Standard" bonding material (e.g. Optibond FL) incorporated in the actual studies [Van Meerbeek et al., 2010]. Another problem mentioned is that the sharp edge of the test device does not hit the test specimen directly at the bonding interface. More often it hits the specimen a fraction of a millimetre away from the bonding interface (on the repair material), compressing and cracking the dentine or material bonded to composite, bending it in a perpendicular mode, giving rise to horizontal pulling forces in the upper, damaged part of bonding interface, and correspondingly compression forces at the lower parts of bonding interface. Even though the cohesive strength of the dentine or composite substrate is higher than the bonding strength, the damage made on the substrate surfaces by compression forces may cause pull-out of material from the substrates, imaging cohesive fractures and falsely high impression of the quality of the bonding agent [Versluis et al., 1997]. The cross-head speed seems to be important as when increasing it to 1mm/min or more, there may be seen a reduction in false cohesive fractures due to the described mechanics of the test [Versluis et al., 1997].

The objective of any laboratory test is to give an estimate to predict what can be expected of clinical outcomes. Van Meerbeek et al. have given arguments to some clear indications for correlation between laboratory tests and clinical Class-V pull out tests [Van Meerbeek et al., 2010]. The group concludes that; in particular bond-strength data with medium-term retention rates from "aged" specimens gives realistic measures. Consequently, not only "immediate" (short term) bond strength of adhesives should be measured, but bond

strength testing of the "aged" specimens should be encouraged in order to predict the clinical effectiveness of adhesives.

As addressed by de Munck et al. there are many parameters used in laboratory testing that may be changed or handled differently from study to study, making it impossible to compare different studies [De Munck et al., 2012]. They may therefore also be irrelevant for comparison with clinical handling and thus be uncertain prediction of clinical outcome.

Although, in laboratory tests used as base for this thesis, the SBS has been chosen. The most important reason is that shear bond strength testing in the author's opinion is highly relevant for clinical purposes as mastication movements and forces in many situations are of this kind. Secondly, materials to be repaired are not anisotropic like dentine and enamel, but of isotropic nature, responding differently to applied forces. This could be seen in the recorded results as there were mainly adhesive fractures in all aged specimens. For this reason, we chose SBS testing according to ISO 11405 and ageing methods by thermo-cycling and water storage.

Bonding composite-to-composite

In the study presented in Paper III, a fresh composite resin material was glued to old resin material that was aged in water for 60 days (test 1). SBS testing of the interface gave shear bond strength values comparable to values obtained for bonding of composite to dentin specimens (unpublished data from NIOM) [Bradna et al., 2008; Sunico et al., 2002]. However, the shear bond strengths found in the present study are lower than those observed by other researchers when joining an old and a new composite of the same brand [Brendeke and Ozcan, 2007; Celik et al., 2011; Frankenberger et al., 2003; Oztas et al., 2003; Papacchini et al., 2007a; Papacchini et al., 2007b; Rathke et al., 2009; Rodrigues et al., 2009].

After 60 days of water uptake, the composite is considered saturated with respect to water [Lagouvardos et al., 2003; Sideridou et al., 2004], and all substrates were aged by thermo-cycling. Ageing base specimens by thermo-cycling, lowered bond strength to repair material (test 3). There is an observed difference in mean SBS for all test groups combined before and after ageing (mean SBS: 21.8 MPa (test 1) and 18.1 MPa (test 2), respectively). This difference is not statistically significant for all specimens. Comparison within composite brands showed a statistical significant difference for CeramX/Xeno III

($p<0.01$) and for Tetric Evo Ceram/AdheSE ($p< 0.05$) before and after thermocycling, using Mann-Witney Test [Rice, 1995]. Filtek Z250 without bonding was statistically significantly different from all other products in test 1 ($p<0.01$). Still, test values were comparable to composite-dentin bonding obtained in laboratory tests. It is suggested that bond strength data gathered after laboratory aging to some extent predict the clinical performance on the longer term [Van Meerbeek et al., 2010].

In most situations when repairing or extending an old composite restoration, fresh dentin and enamel are exposed. For the best bonding of restorations to tooth structures the use of an adhesive system is required [Van Meerbeek et al., 2011]. Question is; Should the bonding procedure include the surface of the remaining composite restoration, or not? The present results show that the use of bonding systems, including acid-etching for the etch-and-rinse products, improve bonding strength between old and new composites, compared to joining the two materials without a bonding system. This finding was most striking in cases where the 'aged' material was exposed to thermo-cycling prior to the bonding procedure (test 3) (Table 5, Paper III). In these cases (test 3), new material was most likely of a different product than the "aged" ones due to substrate randomization. The results indicate that in order to obtain the best bonding, remaining resin-based restoration should be treated in the same way as tooth substance regarding bonding procedure. This facilitates a simpler clinical procedure in cases of repair or extension of an existing composite restoration because the entire cavity will then be treated uniformly.

It is unlikely that bonding between the new and old composite restorative material is of a chemical nature. There are probably only minor amounts of monomers left in old composite, which may have lost any ability to make chemical bonds with new resin. By time there is passive polymerization of resins and elution of residual monomers, both minimize the possibility of making chemical bonds. It has been shown that the half-life of free radicals in composites is approx. 50 h at 37°C, making it unlikely that there are any free radicals left after a few weeks of storage time [Burtscher, 1993]. Most likely, connection between new and the old composite is of a mechanical or micromechanical nature. Surface roughness and size and shape of filler particles provide possibilities for resin to flow into undercuts. These are important factors for micromechanical retention. Scanning micrograph studies (SEM) of freshly ground composite surfaces prior to the bonding procedure demonstrated an uneven surface with pits, grooves, grinding marks,

porosities and protruding filler particles (Fig. 3), which give ample opportunities for mechanical interlocking. Sandblasting with aluminium oxide or silica-treated aluminium oxide has been introduced and is used by many practitioners. This is shown to have a potentially better effect on the micromechanical bond strength [Cavalcanti et al., 2007; Rathke et al., 2009; Rodrigues et al., 2009]. However, these procedures require extra equipment and use of fully rubber dam-controlled working field in order to avoid damage to the periodontium and to protect the patient's airways. Roughening of the surface will markedly improve the retention [Celik et al., 2011; Rodrigues et al., 2009] and will of course be a natural part of cavity preparation.

Where a bonding agent was not used, (Charisma and Filtek Z250 in test 1, Tetric Evo Ceram without bonding in test 3), one could not see similar bond strength. Possible explanation for this might be that new hydrophobic composite adhere poorly to water-saturated 'old' composite. Modern adhesives use hydrophilic primers with a rather high content of previously mentioned 2-HEMA (2-Hydroxyethylmethacrylate), which is a low molecular weight monomer. This molecule has several positive features. The most important are; first, it has an ability to *wet surfaces* of old composite by altering the *surface tension*, and thus allows penetration deep into pits, grooves and porosities. As well as superior wetting, some adhesives have "water chasing" or dehydrating capabilities if they contain acetone or alcohol. Second, the very *small size* of 2-HEMA allows it to penetrate parts of composite containing water, due to it's *hydrophilic* nature. This is a very important hydrophilic property of 2-HEMA [Breschi et al., 2008; Van Landuyt et al., 2007b; Van Meerbeek et al., 2011]. It's amphiphilic nature, that is; it has *hydrophobic* properties also, provides chemical bonds to hydrophobic monomers in the bonding when light cured. Next step is hydrophobic monomers in the bonding resin bind easily to corresponding hydrophobic monomers in the restorative material. This is the same mechanism that is at work between bonding agents and dentine and enamel.

Composite repair of disto-palatinal cusp fracture in tooth 26.

Aging the test specimens revealed that interface bond strength between the old and new materials was dependent on the bonding layer. Shear bond strength testing of specimens after 24 h resulted in both adhesive and cohesive fractures (Table 4, Paper III). The cohesive fractures were in the aged specimens, indicating that the initial bond strength possibly may be superior to the inherent strength of the aged composite. Aged composite-composite specimens gave fractures of adhesive type, indicating a weakening of bonding interface through the ageing process (test 2 and 3). The hypothesis that there is no difference in fracture mode between short-term (test 1) and thermo-cycled specimens (test 2) was tested by comparing the hypergeometric distribution [Rice, 1995]. The hypothesis fails for Ceram X and Tetric Evo Ceram, but cannot be rejected for Charisma and Filtek Supreme. For Filtek Z250 and Filtek Silorane all specimens failed by adhesive fracture. Both bonding resin and new composite resin materials are inclined to take up water during storage in water and during thermo-cycling. Water will break chemical structures, such as carboxyl and hydroxyl esters, that are found in composite. This phenomenon is called hydrolysis, or splitting with water. The major factor affecting durability of bonding agents is hydrolysis of the resin interface and subsequent elution of the breakdown products [De Munck et al., 2005; Papacchini et al., 2007b]. The hydrolytic stability of bonding systems is of major importance for the success of a composite restoration repair. Some investigators suggest that improved hydrolytic stability and bond strength can be achieved by the use of flowable resin [Frankenberger et al., 2003; Papacchini et al., 2007b]. This is probably due the hydrophobic nature of such resins. Excellent strength values are shown when the repair is totally in composite, especially in combination with air abrasion techniques [Oztas et al., 2003; Papacchini et al., 2007a; Rathke et al., 2009].

Three-step, ethanol/water-based etch-and-rinse bonding agents remain the "gold standard" in terms of adhesion durability [De Munck et al., 2005; Van Meerbeek et al., 2011]. This is due to the hydrolytic stability of this bonding system, where most of the separate primer which contains hydrophilic resin, is evaporated by air blowing before applying hydrophobic resin. In the present study, average bonding values for specimens prepared using three-step etch and rinse procedure were the highest (Filtek Z250/Adper Scotchbond MP) when compared to other bonding strategies. This was found both after 24 h short term test (test 1), and after aging by thermo-cycling (test 2). The differences were, however, not statistically significant.

The conclusion is that the use of bonding agents increases shear bond strength between new and old composite at repair interface. The longer a resin-based composite restoration had been exposed to water or a humid environment before repair, the weaker shear bond strength, and the greater difference between repair with and repair without bonding systems.

The effects of silane to increase bond strength

Our *in vitro* investigation of effect of silanising products (Figure 1-3, Paper IV) shows a clear difference in shear bond strength between repair with and repair without silanizing agents (SA) ($p<0.01$) both for old and fresh composite. Still the shear bond strength in the repair interface is significantly weaker than the inherent strength of the composite itself. A preliminary test was performed on 15 fresh substrates, (data shown in figure 3, Paper IV).There was no significant difference between repair strength using a separate silanizing step; Silanising Agent + Clearfil Bond (SA+CB) and using a bonding agent containing silane; Scotchbond Universal (SBU) ($p>0.7$). The latter even had a smaller standard deviation, indicating a more predictable outcome. Both methods of silanizing are easy to handle chair side, and require no extra equipment [Brendeke and Ozcan, 2007; Eliasson et al., 2014].

It should be noted that these tests, repair of both old and new composite, were performed 14 dys after bonding procedure followed by thermo cycling (5000/5-55°C), and they cannot predict long term stability of repair [Van Meerbeek et al., 2010].

It is unclear whether favorable effects of silane are long lasting. The main problem of silanes is their long term hydrolytic instability causing hydrolysis, splitting Si - O – cation bridges over time. When repairing a restoration all surfaces are covered with at least one single sheet of water molecules which may be in conflict with the ideal condition. The bonding strength will partly become dependent on hydrogen bonds and molecular attraction forces like Van der Waals forces and not stronger covalent or ionic bonds. Bonding between silanizing agents and old composite is for this reason always vulnerable to hydrolysis of relatively weak bonds [Breschi et al., 2008; Lung and Matinlinna, 2012; Ruyter, 1987].

This leads to degradation of interface bonding [Lagouvardos et al., 2003; Lung and Matinlinna, 2012; Malacarne et al., 2006]. Content of hydrophilic monomers like HEMA in the bonding agent is an important parameter to predict water content in repair area. HEMA attracts water and keeps it there, thereby determining hydrolytic reaction. Stoichiometric configuration of molecules, especially silanes, may on the other hand prevent water movement and sorption in actual area, making an impact on long term stability. A lot of research remains in this field [Lung and Matinlinna, 2012; Matinlinna et al., 2018].

In our study, Scotchbond Universal (SBU), so-called “Universal Bonding”, was tested. SBU is a self-etching, all-in-one bottle adhesive. It contains acidified primer and bonding chemicals in one mixture, as well as pre-hydrolysed silanes. The manufacturer claims that the solution is stable at shelf life at least one year. In this short term test, it performed well. The silanes’ success lies in the ability to split off hydroxyl groups and form oxygen bridges to surface cations. The complex chemistry is not publicly available (due to patents), but the product showed remarkably good results in this short term *in vitro* study. The performance of the new “Universal Bonding” systems for a longer period of time, remains to see, as they have only been commercially available for a few years. Scepticism to simplified systems is still connected to the problems concerning evaporation of solvents and hydrophilic monomers, causing water sorption and hydrolysis, when all the ingredients are mixed in one bottle [Peumans et al., 2005; Van Meerbeek et al., 2010].

The good results for SBU may be due to another renowned ingredient, 10-MDP (10-methacryl-oyloxydecyl-di-hydrogen- phosphate) it is a 10 carbon phosphorylated acidic monomer that shows very good ability to form stable bonds to cations [Yoshida et al.,

2012; Yoshihara et al., 2010]. On the other hand, Clearfil Bond (CB) also contains MDP. When CB is used with additional silane treatment, results of the tests show significantly better results with silane than without extra silane, indicating a positive effect of the silanizer. In the study we chose two bonding agents containing MDP to minimise confounding factors. Likewise, we chose #500 grinding paper to minimize micro-mechanical interlocking effects at bonding interface.

One might speculate if the positive effect on SBS, when using silanes, was due to resilanizing of the filler particles at the prepared restoration surface, improving bond between filler particles in the old composite and resin matrix in the repair composite. The possibility of obtaining a chemical bond between resins in the old substrate and bonding agents, decreases with time. Old resin has no longer free radicals ready for bonding and polymerisation, due to radical half-life of approximately 48 hrs [Burtscher, 1993], and a slow chemical after cure combined with hydrolysis of available double bonds leaving the resin without possibility to form new bonds. We found much higher percentage increase of repair bond strength for old composite (140 %) compared with increase of repair bond strength for fresh composite (50 %). In addition, all the failures for the old composite repair were found to be of adhesive type, strengthen the idea that the silane has a strong possibility to form siloxane bonds to filler particles in composite also when the composite is old. Improved effect of silane in old composite substrates may reflect that hydrolytic degradations is higher in older specimens which was also shown as reduced strength in the material over time [Eliasson et al., 2014].

Another property of silanes, which may be beneficial to bond strength, is their ability to change surface energy in order to enhance wetting of the surface of inorganic materials which is essential to the intimate contact needed between different materials to obtain good bonding [Ruyter, 1987].

To put silane tests in perspective, it is of interest to compare bond strength found to composite with bond strength to dentine when applying silane as part of bonding procedure. We have no proof that silanes form bonds to cations in organic substrates like collagen/dentine [Lung and Matinlinna, 2012]. In order to investigate the role of silanes when bonding composites to dentine, preliminary tests were performed. These tests demonstrated no difference in bond strength between composite and dentine whether silane was used or not (unpublished data).

Conclusively**,** repair with use of silanizing agent performed significantly better than repair without. The age of old composite still seems to have an influence on the bonding possibilities as bonding to older composites gave poorer results. Repair of old restorations is still recommended as the results clearly show bond strength values of adequate strength (see comments on bite force and preparation technique).

Repair of amalgam restorations

Our studies on repair of amalgam restorations with composite- and glass-ionomer materials show rather low values for adhesion between composite and amalgam, and even lower for glass-ionomer as repair material. For repairing with composite, Rey et al. found similar results in a study from 2015 [Rey et al., 2015] When repairing composite to composite in laboratory studies the reported test values are found to be much higher. Our composite-to-composite tests discussed above showed values 3 to 4 times higher for short-term tests of composite-to-composite than for composite to amalgam repair. When thermo-cycling was performed, bond strength test results for composite to composite were about ten times higher. A likely explanation for higher values for composite repair is the possible re-silanating of filler particles in old composite and that there might be some functional monomers in the new composite to bond with resin in the old restoration after application of primer/adhesive. As mentioned earlier, laboratory tests are not *in vivo* experiments, but they can give some indication on how the materials will perform clinically [De Munck et al., 2012; Peumans et al., 2005; Van Meerbeek et al., 2011]. The results found in our study are initially rather low values, and in addition, they will certainly attenuate by time.

When fracture mode was examined in stereo light microscope, they were all of adhesive type. On a few occasions some remnants of repair material was found in grooves and porosities at amalgam surface, giving small spots of cohesive fractures (see Fig. 2, Paper V). This phenomenon may explain some of the variance in the results and it emphasises the importance of micro- and macro-mechanical retention.

Composite repair after fracture of disto-lingual cusp. The picture shows a 12 years old repair, still functioning very satisfactory.

Short Term mode (Mode 1) did not show any statistical significantly difference between the bonding agents. Storage in water for 60 days before testing (Mode 2) gave quite similar results. However, after thermo-cycling (Mode 3) we could see substantial drop in SBS values. An interesting finding in the present study is that the acknowledged gold standard for bonding agents, 3 step etch and rinse (3-step ER), Optibond FL, (OFL), did not perform better than the other two after thermo-cycling. Two-step Self-Etch seemed to be the better alternative. One difference between self-etch bonding types and OFL is that the latter is bonded after etching the surface to be repaired as this is the manufacturer's advised procedure for "etch and rinse" bonding type. Etching with phosphorus acid may affect the results to some degree as it is well known that phosphoric ions may bind to cations at the surface, blocking them for phosphoric compounds in the bonding agent, thus preventing adhesion. However, as the number of specimens that disintegrated before testing is high for all groups in Mode 3 (Fig. 1), the results must be considered uncertain. As TC was omitted in Mode 1 and 2 the results were quite within same range as for 3 steps ER and 2 steps SE. This brings up discussion around TC as aging method in studies like this, where the materials are very different. The idea of ageing bonding interface with TC might be more suitable for testing bonding interface between materials with similar thermal expansion coefficient than for two very different materials like resin composite and amalgam alloy. As amalgam tends to increase or decrease differently by volume with changing temperature than composite (this may vary

considerably) [Anusavice et al., 2013], there will be movement between the materials at the interface. These movements might physically tear off any newly formed bond/interlocking between adhesive and metal. Thermal expansion coefficients for amalgam and resin composite may vary as much as 2 times either way [Anusavice et al., 2013]. Thermal variation in the mouth does not fluctuate as much as the TC conditions although this phenomenon might be considered to a certain degree as hot and cold food and drinks pass the teeth. Hot drinks may have a temperature of 55°C, but it is unlikely that the tooth substance or restoration materials would reach this temperature as hot beverages with this temperature is almost impossible to keep in the mouth for such a period of time as required. In our studies TC is set to dwelling time in hot and cold bath of 20 sec. Even at this period of time it seems that such temperature rise is unlikely (unpublished data). The movement of food and drinks in the mouth along with the temperature controlling effects of saliva, tongue and mucosa, also plays an important moderating role.

Composite repair after fracture of buccal cusp tooth 14. Note the particular macro mechanical modified “dove-tail” preparation into the old amalgam. The repair was 18 years old when the picture was taken.

Repair with glass-ionomers

The glass-ionomer (GI) substrates disintegrated, or would not adhere at all, at the interface with amalgam. They de-bonded before we had any possibility of testing SBS, and should be regarded as pre-test failures with value 0. A conclusion to be drawn is that GIs

do not adhere to amalgam with any relevant force unless there is additional macro mechanical retention.

Aboush et al. found in 1989 and 1991 that Resin Modified Glass-Ionomers (RMGI) made relatively strong and reliable connections with amalgam [Aboush and Elderton, 1991; Aboush and Jenkins, 1989]. It was claimed that bond strength between amalgam and RMGI was comparable with strength to enamel and significantly higher than to dentine. They used micro tensile bond strength (μTBS) test method. Their figures in 1991 were from approx. 4 MPa to approx. 9 MPa. In our study we could not find any reliable figures for the bondage between GIs and amalgam. This does not necessarily mean that the interface between amalgam and GIs is leaky. It is well known that the interface between amalgam and dental hard tissue normally is tight due to corrosion products from amalgam filling up the gap, although there is no adhesion between dental hard tissue and amalgam. One might deduce from this knowledge that corrosion processes are at work between amalgam and GIs as well, and there is probably limited leakage between amalgams and GIs. Adhesion of GIs to teeth is mainly relying on chemical bonding to dentin and enamel and on possible undercuts the operator may prepare.

As repair of minor to moderate defects of dental restorations or fractured parts of teeth is up-to- date dentistry and in accordance with the minimal-invasive philosophy [Blum et al., 2014; Hickel et al., 2013; Wilson et al., 2016], there is a need for knowing how to use the suitable materials. It seems to be very low bond strength between composites/GIs and amalgam compared to composite to composite bond strength when using simple, ordinary bonding procedures. The bonding is simply not reliable alone and should be regarded as inadequate. Fortunately, the cavities or defects have other elements to which the bonding agents can bond e.g. enamel and dentine. Depending on size and shape of the cavity or defect, it should be recommended to create additional macro mechanical retention like dove tails and undercuts in the old restorations [Rey et al., 2015]. Other procedures have been tested by other researchers like air abrasion and alloy primer, silica coating and silane surface treatment, grooves and use of coarse burs could be favorable, but give limited improvements [Blum et al., 2012; Ozcan et al., 2011; Ozcan et al., 2010]. More complex bonding procedures with glass fiber reinforcement and metal primers would also be beneficial [Ozcan and Volpato, 2016].

Conclusions

Conclusions on the first part

To map the attitudes towards restoration repair among the general dental practitioners in Norway (Paper I and II):

- Norwegian dentists have **positive attitudes** towards repair of defective restorations.
- **Repair of both amalgam and composite** restorations is performed at a wide scale in Norway.
- One year after the amalgam ban, Norwegian dentists showed positive stand towards composite as **a good alternative to amalgam**.

Conclusions on the second part

Factors influencing the reliability of the repair interface

- Use of **bonding agents improves** the strength of repair interface for composite repair.
- Use of **silanizing** agent at repair interface performed significantly better than repair without.
- The **age of composite** to be repaired seem to have negative influence on the bonding strength concerning effect of both bonding agents and silanizing agents.
- Repair of old composite restorations is **highly recommended** as the studies clearly show bond strength values of adequate strength.
- **Repair of Amalgam** restorations of adequate standard with composite materials is highly recommended.
- **Glass-Ionomers** may be used for repair at amalgam restoration margins in not stress bearing areas.
- Extra **macro mechanical retention** for amalgam repair with composite is recommended.

Main conclusion

The overall aim of this thesis was to bring forth knowledge about **the fundament for repair in view of the *Minimal Intervention Dentistry* concept.** A final conclusion seems to be:

Norwegian dentists perform repair of direct dental restorations at a wide scale, as they seem to choose minimally invasive treatment, having strong confidence in longevity and quality of restoration materials. The repair quality of direct restorations is provided for and improved when following the recommendations for use of bonding materials, silanizing agents and preparation of additional macro mechanical retention.

Future perspectives

When going through present literature on repair of direct restorations, the two Cochrane reports from 2014 concluded: Currently there is no evidence to support repairing or replacing resin composite or amalgam fillings for adults. The main shortcomings are the lack of scientific evidence, especially lack of Randomized Clinical Trials, to support the idea of repair.

There is empiric evidence, and some cross-sectional and retrospective studies. There are also a few prospective studies showing potential benefit from repair, but future research in this field should aim to conduct randomized, preferably multi-centered, clinical trials for bringing scientific evidence to this matter.

The candidate's contribution

The candidate's contribution to the work in the studies is marked by asterix as follows:

Paper I

- Study design and experimental protocol *
- Data collection and calibration *
- Data analyses *
- Manuscript writing *
- Corresponding author *

Paper II

- Study design and experimental protocol
- Data collection and calibration
- Data analyses*
- Manuscript writing *
- Corresponding author

Paper III

- Study design and experimental protocol *
- Data collection and calibration *
- Data analyses *
- Manuscript writing *
- Corresponding author *

Paper IV

- Study design and experimental protocol *
- Data collection and calibration *
- Data analyses *
- Manuscript writing *
- Corresponding author *

Paper V

- Study design and experimental protocol *
- Data collection and calibration *
- Data analyses *
- Manuscript writing *
- Corresponding author *

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Errata

Paper III, Table 3, p. 318. For Ceram X and Tetric Evo Ceram the sign > for probability should be <.

Correct table is shown here:

Table 3

Results of the shear bond strength testing between specimens made of the same product after 22±2h of storage in distilled water and after thermocycling.

Test specimen	**Test 1: Test after 22±2h**				**Test 2: Test after thermocycling**				**p-value‡**
	Mean	**SD**	**Pf 10**	**Pf 90**	**Mean**	**SD**	**Pf 10**	**Pf 90**	
Filtek Z250/Adper Scotchb MP, 3M	26,0	10,7	1,5	34,4	22,7	4,3	16,7	28,5	p>0.05
Silorane/Silorane bonding, 3M	19,8	8,9	6,8	33,6	17,7	7,2	4,7	26,4	p>0.05
Charisma, Heraeus Kulzer	15,2	6,4	1,1	21,4	16,8	4,7	10,8	23,7	p>0.05
Filtek Supreme XT/Adper Scotchbond XT, 3M	22,0	7,1	1,5	30,7	19,0	5,6	11,9	27,4	p>0.05
Ceram X Mono/Nano III, Dentsply	22,1	4,8	17,6	32,4	16,6	4,4	8,0	23,2	p<0.01
Tetric Evo Ceram/AdheSE, Vivadent Ivoclar	25,5	7,5	15,0	36,3	16,0	9,8	0,5	33,6	p<0.05
Filtek Z250, 3M, Kontroll	9,9*	2,7	6,8	13,8					

Pf: Probability of failure; at what load a certain percentage of the specimens will be broken.

Pf 10: Probability of failure for 10% of the specimens

Pf 90: Probability of failure for 90% of the specimens

All values in MPa.

***** p<0.05 compared to other groups in test 1

‡ Difference between test 1 and test 2 for each product

Appendix

Questionnaire I

Questions about light curing, the two last pages at the end of the survey, is not part of this article (Paper I) and thesis. They are not numbered, but the bar at the page bottom says 83% and 92% “fullført” – (completed).

Questionnaire II

Reparasjon og lysherding av kompositttfyllinger

Kjære tannlege

Kompositt er i dag det vanligste fyllingsmaterialet blant norske tannleger og har tatt helt over for bruken av amalgam. En fordel med kompositt er at man med adhesive teknikker burde kunne reparere frakturerte fyllinger i større grad enn man kunne med amalgam. Kriteriene for hvor store defekter man kan reparere er imidlertid ikke klarlagt, og vi ønsker nå å gjennomføre en spørreundersøkelse blant norske tannleger for å kartlegge deres erfaringer med reparasjon av kompositttfyllinger. Vi vil også relatere dette til bruk av herdelamper på klinikkene.

Undersøkelsen er anonym og tar ca 5-10 minutter å besvare. Klikk på knappen merket **Neste>>** nedenfor for å begynne.

Dersom du ikke arbeider med fyllingsterapi til daglig ber vi deg likevel klikke på lenken nedenfor, og angi dette på den første siden i spørreskjemaet. Du vil da ikke trenge å besvare flere spørsmål.

Din identitet vil holdes skjult.

Les om retningslinjer for personvern. (Åpnes i nytt vindu)

Neste >>

8 % fullført

Reparasjon og lysherding av kompositttfyllinger

*** Fødselsår**

Velg alternativ ▼

*** Kjønn**

- Kvinne
- Mann

*** Hovedbeskjeftigelse**

- Privat praksis
- Den offentlige tannhelsetjenesten
- Annet, spesifiser her:

*** Arbeidsområde**

- Storby (>100.000 innbyggere)
- Mindre by
- Bygd/landet
- Annet, spesifiser her:

*** Klinikkstørrelse**

- 1-3 tannleger
- >3 tannleger
- Annet, spesifiser her:

Dersom du ikke arbeider med fyllingsterapi trenger du ikke å svare på de resterende spørsmålene. Klikk i så fall på det aktuelle svaralternativet nedenfor, og du vil bli videreført til avslutningssiden i spørreskjemaet når du klikker på **Neste>>**

*** Er fyllingsterapi aktuelt i din praksis?**

- Ja, jeg arbeider med fyllingsterapi
- Nei, jeg arbeider ikke med fyllingsterapi og vil gå til avslutningssiden
- Nei, jeg arbeider ikke med fyllingsterapi, men vil likevel delta i spørreundersøkelsen

<< Tilbake | Neste >>

17 % fullført

Reparasjon og lysherding av kompositttfyllinger

Tann 15 har en MOD kompositttfylling som det er frakturert en bit av mesio-buccalt. Det er ingen sekundærkaries. Kompositttfyllingen har emaljebegrensning rundt hele fyllingen og skaden. Røntgenundersøkelse viser at fyllingen er avsluttet med god avstand til pulpa. Det er ingen øvrig patologi.

Pasienten er en 52 år gammel kvinne med lav kariesaktivitet og normale bittforhold. Det er ingen økonomiske begrensninger knyttet til behandlingen. Fargen på fyllingen harmonerer bedre enn bildet viser, så pasienten føler ingen estetiske behov for å skifte ut fyllingen.

Hva mener du er beste behandling for tann 15?

- Reparere skaden med tannfarget fyllingsmateriale
- Skifte ut hele fyllingen
- Porselensinlay/onlay (CAD/CAM)
- Porselensinlay/onlay (teknikerfremstilt)
- Gullinnlegg
- Krone
- Annet, spesifiser her:

<< Tilbake | Neste >>

25 % fullført

Reparasjon og lysherding av kompositttfyllinger

Tann 47 har frakturert disto-buccale cusp i tilknytning til en kompositttfylling. Det er ingen sekundærkaries. Kompositttfyllingen har emaljebegrensning rundt hele fyllingen og skaden. Røntgenundersøkelse viser at fyllingen er avsluttet med god avstand til pulpa. Det er ingen øvrig patologi.

Pasienten er en 52 år gammel kvinne med lav kariesaktivitet og normale bittforhold. Det er ingen økonomiske begrensninger knyttet til behandlingen.

Hva mener du er beste behandling for tann 47?

- Reparere skaden med tannfarget fyllingsmateriale
- Skifte ut hele fyllingen
- Porselensinlay/onlay (CAD/CAM)
- Porselensinlay/onlay (teknikerfremstilt)
- Gullinnlegg
- Krone
- Annet, spesifiser her:

<< Tilbake | Neste >>

33 % fullført

Reparasjon og lysherding av kompositttfyllinger

Tann 24 har frakturert palatinale cusp i tilknytning til en MOD-kompositttfylling. Det er ingen sekundærkaries. Kompositttfyllingen har emaljebegrensning rundt hele fyllingen og skaden. Røntgenundersøkelse viser at fyllingen er avsluttet med god avstand til pulpa. Det er ingen øvrig patologi.

Pasienten er en 52 år gammel kvinne med lav kariesaktivitet og normale bittforhold. Det er ingen økonomiske begrensninger knyttet til behandlingen.

Hva mener du er beste behandling for tann 24?

- ○ Reparere skaden med tannfarget fyllingsmateriale
- ○ Skifte ut hele fyllingen
- ○ Porselensinlay/onlay (CAD/CAM)
- ○ Porselensinlay/onlay (teknikerfremstilt)
- ○ Gullinnlegg
- ○ Krone
- ○ Annet, spesifiser her:

<< Tilbake | Neste >>

42 % fullført

Reparasjon og lysherding av kompositttfyllinger

Hvis du reparerer kompositttfyllinger, gjør du noen forbehandling av restfyllingen?

(Du kan krysse av for flere alternativer)

- [ ] Ingen
- [ ] Syreets
- [ ] Bonding
- [ ] Silanisering
- [ ] Preparerer retensjon i den gamle fyllingen
- [ ] Reparerer aldri kompositttfyllinger
- [ ] Annet, spesifiser her:

Kommentarer:

<< Tilbake Neste >>

50 % fullført

Reparasjon og lysherding av kompositttfyllinger

Hvilken bondingtype benytter du som oftest på klinikken? Hvis du bruker flere typer kan dette kommenteres i kommentarfeltet nederst.

- 1-stegs selvetsende
- 1-stegs selvetsende m/separat emaljeets
- 2-stegs selvetsende
- 2-stegs selvetsende m/separat emaljeets
- 2-stegs ets og skyll (primer og bond i samme flaske)
- 3-stegs ets og skyll (primer og bond i to separate flasker)
- Annet, spesifiser her:

Kommentarer:

<< Tilbake

Neste >>

Reparasjon og lysherding av kompositttfyllinger

Bruker du noen form for foring mot pulpa når du legger kompositttfyllinger?

	Aldri	Av og til	Ofte	Alltid	Vet ikke
Kalsiumhydroksid - Dycal, Life, etc.	☐	☐	☐	☐	☐
ZnO-eugenol-produkter (IRM, etc)	☐	☐	☐	☐	☐
Glassionomercement	☐	☐	☐	☐	☐
MTA/Biodentine	☐	☐	☐	☐	☐

Hvilke kaviteter forer du?

- ☐ Kaviteter i ytre tredjedel av dentin
- ☐ Kaviteter i midre tredjedel av dentin
- ☐ Pulpanære kaviteter i indre tredjedel av dentin
- ☐ Forer ikke

Kommentarer:

<< Tilbake

Neste >>

67 % fullført

Reparasjon og lysherding av kompositttfyllinger

Anslagsvis, hvor mange fyllinger legger du i gjennomsnitt pr. dag?

Noter antall i feltet nedenfor:

Kan du angi ca. prosentandel av fyllingene som er...

...førstegangsfyllinger pga. primærkaries	▾
...reparasjon av gamle fyllinger	▾
...total utskiftning av gamle fyllinger	▾

Kommentarer:

<< Tilbake

Neste >>

Reparasjon og lysherding av kompositttfyllinger

Hvor mange sekunder lysherder du ett normalt lag med kompositt?

Noter antall sekunder i feltet nedenfor:

Bruker du noen form for øyebeskyttelse når du lysherder?

- ○ Nei
- ○ Nei, men jeg forsøker å se bort fra lyset
- ○ Ja, beskyttelsesdeksel som er fastmontert på lysherderen
- ○ Ja, beskyttelsesskjerm
- ○ Ja, beskyttelsesbriller
- ○ Annet, spesifiser her:

Kommentarer:

<< Tilbake

Neste >>

Reparasjon og lysherding av kompositttfyllinger

Vet du hvor gammel herdelampen din er?

Velg alternativ ▼

Vet du hvor mye lys lampen gir som ny, i følge produsenten? (Oppgi den verdien du bruker hvis det er flere nivåer)

- ○ <1000 mW/cm2
- ○ 1000 - 1499 mW/cm2
- ○ 1500 - 1999 mW/cm2
- ○ ≥2000 mW/cm2
- ○ Vet ikke

Hvilke retningslinjer følger du når du velger antall sekunder du lysherder et normalt lag med kompositt?

- ☐ Fyllingsmaterialeprodusentens anbefalinger
- ☐ Herdelampeprodusentens anbefalinger
- ☐ Universitetets anbefalinger
- ☐ Klinikkens egne retningslinjer
- ☐ Annet, spesifiser her:

Kontrollerer du herdelampen din regelmessig?

- ☐ Nei
- ☐ Ja, sjekker visuelt etter kompositttrester/riper/flekker/fremmedlegeme på lampetuppen
- ☐ Ja, bruker egen lysmåler på klinikken
- ☐ Ja, sjekkes av dentalleverandør ved service på unit
- ☐ Annet, spesifiser her:

Kommentarer:

<< Tilbake | Neste >>

92 % fullført

Reparasjon og lysherding av kompositttfyllinger

Hvis du har kommentarer eller spørsmål til spørreundersøkelsen kan du skrive dem i feltet nedenfor. Alle besvarelser vil bli behandlet anonymt.

Trykk **SEND**-knappen for å avslutte spørreundersøkelsen.

<< Tilbake

Send

100 % fullført

Takk for ditt svar!

Besvarelsene vil analyseres og svarene publiseres i nær fremtid.

UNIVERSITETET I OSLO

Spørreskjema om karies og behandling

Kjære tannlege

Hvor dypt skal kariesangrepet være før vi griper til boret? Dette spørsmålet har vært belyst gjennom spørreundersøkelser foretatt i 1983 og 1995 blant norske tannleger.

Hvordan er kriteriene for fyllingsterapi i 2009? Nå ønsker vi å gjennomføre en ny spørreundersøkelse, og vi har utarbeidet et spørreskjema som vi ber deg ta deg tid til å fylle ut. Resultatene vil bli publisert i internasjonale tidsskrifter.

Spørreskjemaet er sendt elektronisk til alle tannleger som har registrert sin e-postadresse hos Den norske tannlegeforening. Undersøkelsen er anonym og tar ca 5-10 minutter å besvare. Klikk **Neste>>** nedenfor for å begynne.

Dersom du ikke arbeider med fyllingsterapi til daglig ber vi deg likevel klikke på lenken nedenfor, og angi dette på den første siden i spørreskjemaet.

Ditt svar er anonymt
Les om anonymitet her...

Neste >>

7 % completed

Fylke *

- Velg alternativ -

Fødselsår *

- Velg alternativ -

Kjønn *

Kvinne Mann

Klinisk yrkesaktiv? *

Ja Nei

Hovedbeskjeftigelse *

Privat praksis

Den offentlige tannhelsetjenesten

Annet, spesifiser her:

Er kariesdiagnostikk og fyllingsterapi aktuelt i din praksis? *

Dersom du ikke arbeider med kariesdiagnostikk og fyllingsterapi trenger du ikke å svare på de resterende spørsmålene. Klikk i så fall på det aktuelle svaralternativet, og du vil bli videreført til avslutningssiden i spørreskjemaet når du klikker på **Neste>>**

Ja, jeg arbeider med kariesdiagnostikk og fyllingsterapi

Nei, jeg arbeider ikke med kariesdiagnostikk og fyllingsterapi og vil gå til avslutningssiden

Nei, jeg arbeider ikke med kariesdiagnostikk og fyllingsterapi, men vil likevel delta i spørreundersøkelsen

* Obligatoriske spørsmål. Må besvares for å kunne gå videre.

Hvor lang levetid vil du anslå at en kompositttfylling i molaren på bildet nedenfor vil få (før den må repareres ellers legges om)?

Pasienten er en 40 år gammel kvinne som kommer til din tannklinikk med et lite sekundærkariesangrep i en MO amalgamfylling i en molar i overkjeven (se bildet). Sekundærkariesangrepet er så vidt synlig på røntgen. Amalgamfyllingen har emaljebegrensning gingivalt i den approksimale kassen. Pasienten har tilfredsstillende hygiene, bruker fluortannkrem og går regelmessig til kontroll hos deg én gang i året. Hun ønsker å skifte ut hele fyllingen med kompositt.

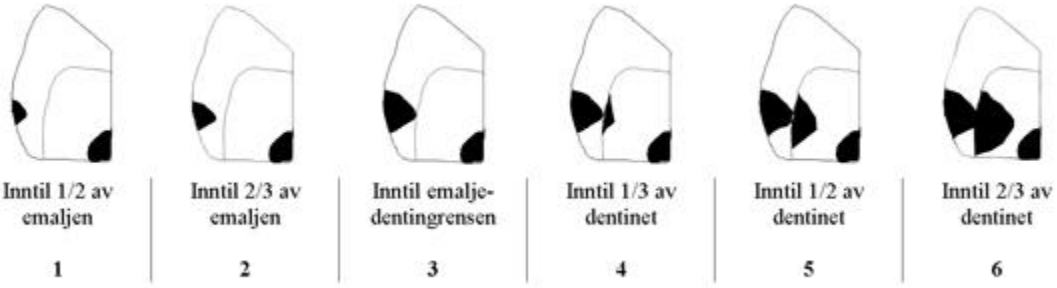
- Mindre enn 3 år
- Fra 3 til 5 år
- Fra 5 til 7 år
- Fra 7 til 10 år
- Mer enn 10 år

Hvor lang levetid mener du en tilsvarende fylling ville ha om den ble laget i amalgam?

- Kortere
- Samme
- Lengre

Figurene illustrerer ulike røntgenologiske avtegninger av approksimalkaries. Hvilken eller hvilke lesjoner mener du krever fyllingsterapi omgående?

Det siktes til kariesangrep som du ikke under noen omstendigheter vil utsette behandlingen av til neste tannhelsekontroll, selv om pasientens kariesaktivitet er lav og hygienen god (kryss av for ett eller flere alternativ).



☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

Hvilken prepareringsmåte vil du foretrekke for den minste av de lesjoner som du vil fylle (klasse II fylling), dersom lesjonen ligger distalt på 15?

Tenk deg at pasienten er 20 år, har tilfredsstillende hygiene og bruker fluortannkrem. Pasienten går regelmessig til kontroll én gang i året.

- ○ Tradisjonell kl.II
- ○ Tunnelpreparering
- ○ Skålformet preparering

I tilfellet over, hvilket fyllingsmateriale vil du foretrekke for den minste av de lesjoner som du vil fylle?

- ○ Kompositt
- ○ Kompomer
- ○ Konvensjonell glassionomersement
- ○ Lysherdende glassionomersement
- ○ En kombinasjon av kompositt og glassionomersement
- ○ Annet, spesifiser her: _____

Figurene illustrerer ulike kliniske avtegninger av okklusalkaries. Hvilken eller hvilke lesjoner mener du krever fyllingsterapi omgående?

Det siktes til kariesangrep som du ikke under noen omstendigheter vil utsette behandlingen av til neste tannhelsekontroll, selv om pasientens kariesaktivitet er lav og hygienen god (kryss av for ett eller flere alternativ)

Karies karakterisert ved en hvitlig/brunlig misfarging i emaljen uten substanstap (ingen kavitetsdannelse). Ingen røntgenologiske funn.

1

Lite substanstap med brudd i emaljeoverflaten, eller misfarget fissur med grålig/opak tilstøtende emalje og/eller karies begrenset til emaljen røntgenologisk.

2

Moderat substanstap og/eller karies i ytre tredjedel av dentin røntgenologisk.

3

Betydelig substanstap og/eller karies i midtre tredjedel av dentin røntgenologisk.

4

Stort substanstap og/eller karies i indre tredjedel av dentin røntgenologisk.

5

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Hvilken prepareringsmåte vil du foretrekke for en okklusalfylling på en 2. molar i underkjeven som har den minste av de lesjoner som du ville fylle i forrige spørsmål?

Tenk deg at pasienten er 20 år, har tilfredsstillende hygiene og bruker fluortannkrem. Ved oppboring går lesjonen inn i dentin.

- ○ Bore opp kun det kariøse området
- ○ Utvide prepareringen til å omfatte hele fissursystemet
- ○ Annet, spesifiser her: _____

I tilfellet over, hvilket fyllingsmateriale vil du bruke?
Ta utgangspunkt i at tannen er 2. molar i underkjeven.

- ○ Kompositt
- ○ Kompomer
- ○ Konvensjonell glassionomersement
- ○ Lysherdende glassionomersement
- ○ En kombinasjon av kompositt og glassionomersement
- ○ Annet, spesifiser her: _____

Hvor lang erfaring har du i å legge amalgamfyllinger etter du var ferdigutdannet tannlege?

- Ingen
- Mindre enn 5 år
- 5 - 10 år
- Mer enn 10 år

Hvilken prepareringsteknikk bruker du som regel når du lager en enkeltsidig kl. II komposittfylling på grunn av primærkaries i ytre halvdel av dentin?

- Tradisjonell kl. II som for amalgam
- Skålformet med okklusal retensjon
- Skålformet uten okklusal retensjon
- Annet, spesifiser her:

Hvilke materialer bruker du når du skal lage en MOD-restaurering pga primærkaries i ytre halvdel av dentin?
Spørsmålet gjelder premolarer og molarer hos voksne pasienter. (Alle linjer fylles ut)

	Aldri	**Sjelden**	**Av og til**	**Ofte**	**Alltid**	**Vet ikke**
Kompositt	o	o	o	o	o	o
Kompomer	o	o	o	o	o	o
Glassionomersement konvensjonell	o	o	o	o	o	o
Glassionomersement lysherdende	o	o	o	o	o	o
Porselensinnlegg (fra tanntekniker)	o	o	o	o	o	o
Porselensinnlegg (CEREC – CAD/CAM)	o	o	o	o	o	o
Kompositttinnlegg	o	o	o	o	o	o
Gullinnlegg	o	o	o	o	o	o

Hva mener du er årsaken når kl. II kompositttfyllinger i permanente premolarer og molarer må legges om?
(Alle linjer fylles ut)

	Aldri	**Sjelden**	**Av og til**	**Ofte**	**Alltid**	**Vet ikke**
Sekundærkaries	o	o	o	o	o	o
Fraktur av fylling	o	o	o	o	o	o
Fraktur av tann	o	o	o	o	o	o
Mistet fyllingen	o	o	o	o	o	o
Slitasje av fyllingen	o	o	o	o	o	o
Spalter	o	o	o	o	o	o
Kantdefekt	o	o	o	o	o	o
Kantmisfarging	o	o	o	o	o	o
Dårlig estetikk	o	o	o	o	o	o
Smerter/ising	o	o	o	o	o	o
Allergiske reaksjoner	o	o	o	o	o	o
Dårlig kontaktpunkt	o	o	o	o	o	o
Overheng	o	o	o	o	o	o
Underskudd	o	o	o	o	o	o
Porøsiteter	o	o	o	o	o	o

I hvilken grad mener du disse faktorene har betydning for varigheten til en kl. II kompositttfylling? (Alle linjer fylles ut)

	Ingen betydning	**Liten betydning**	**Middels betydning**	**Stor betydning**	**Meget stor betydning**	**Vet ikke**
Utforming av kaviteten	o	o	o	o	o	o
Dårlig matriseteknikk	o	o	o	o	o	o
Tørrlegging under fyllingsterapi	o	o	o	o	o	o
Tannlegens erfaring med kompositttfyllinger	o	o	o	o	o	o
Type kompositt som benyttes	o	o	o	o	o	o
Type bondingsystem som benyttes	o	o	o	o	o	o
At materialene brukes etter forskriftene (bruksanvisningen)	o	o	o	o	o	o
Pasienten har kraftig bitt	o	o	o	o	o	o
Dårlig hygiene	o	o	o	o	o	o
Høy kariesaktivitet	o	o	o	o	o	o
Pasientens kooperasjon ved legging av fyllingen	o	o	o	o	o	o

Hva mener du er beste behandling for tann 15?

Tannen har en frakturert amalgamfylling. Det er ingen sekundærkaries. Amalgamfyllingen har emaljebegrensning gingivalt i de approksimale kassene. Røntgenundersøkelse viser at amalgamfyllingen er avsluttet med god avstand til pulpa, forøvrig ingen patologi.

Pasienten er en 52 år gammel kvinne med lav kariesaktivitet og normale bittforhold. Hun har ingen motforestillinger mot amalgam og det er ingen økonomiske begrensninger knyttet til behandlingen.

- (•) Lappe på fyllingen med tannfarget fyllingsmateriale
- ( ) Skifte ut hele fyllingen med tannfarget fyllingsmateriale
- ( ) Porselensinnlegg (CEREC – CAD/CAM)
- ( ) Porselensinnlegg (fra tanntekniker)
- ( ) Gullinnlegg
- ( ) Krone
- ( ) Annet, spesifiser her: _____

Ta stilling til følgende påstander (Alle linjer fylles ut)

	Helt uenig	**Uenig**	**Nøytral**	**Enig**	**Helt enig**	**Vet ikke**
Jeg opplever ofte at kompositttfyllinger må skiftes	o	o	o	o	o	o
Tørrlegging er det viktigste for å oppnå en optimal kompositttfylling	o	o	o	o	o	o
Kompositt er et godt alternativ til amalgam	o	o	o	o	o	o
Kompositt er et uegnet fyllingsmateriale hos pasienter med høy kariesaktivitet	o	o	o	o	o	o
Kompositt egner seg bare i små kaviteter	o	o	o	o	o	o
Kompositt egner seg ikke i molarer	o	o	o	o	o	o
Kompositt er uegnet hos pasienter med dårlig hygiene	o	o	o	o	o	o
Kompositt egner seg ikke hos pasienter med kraftig bitt	o	o	o	o	o	o
Man trenger ikke å fore under kompositt i dype kaviterer	o	o	o	o	o	o
Sekundærkaries forekommer oftere ved kompositt- enn amalgamfyllinger	o	o	o	o	o	o

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Repair of defective composite restorations. A questionnaire study among dentists in the Public Dental Service in Norway

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ABSTRACT

Objectives: This study aimed to investigate dentists' treatment choices concerning "repair or replacement" of defective restorations.
Methods: A pre-coded questionnaire was sent electronically to all dentists (n = 1313) in the Public Dental Service (PDS) in Norway. Part one: The dentists were asked about age and gender, whether they performed direct restorative therapy/amount of time spent on fillings made per day due to: Primary caries, Repair of restorations or Replacement of restoration/what kind of bonding agents used and pre-treatment of the residual restoration. Part two: The dentists were asked to consider the best treatment for three patient cases with tooth/restoration fractures.
Results: Response rate was 55.8%, (69.6% females, 30.4% males). Respondent age varied from 25 to 77 years (mean 41.8, SD 12.4). Part one: The dentists spent on average 57.5% of the working day placing restorations, making from 1 to 30 (mean 7.7, SD 3.6) restorations per day. Reasons for treatment were; Primary caries 55.7% (SD 19.1%), repair of restorations 26.7% (SD 14.8%), replacement of fillings 18.2% (SD 11.2%). Two-step etch and rinse (ER), 3-step ER and Self-etch (SE) were used by 48.7%, 24.6% and 26.7% of the respondents, respectively. A silanising agent was used by 7.4%. Part two: Treatment choices: Repair with RC: 89.6% in case one, 86.9% in case two and 54.1% in case three. Young dentists suggested invasive treatment more often than old dentists (>38 years).
Conclusions: Operative dentistry claims 57.5% of PDS dentists' working day. In addition to primary caries, repair and replacement of restorations accounted for 27% and 18% of the reasons for placing restorations.
Clinical significance: The idea of "minimal intervention dentistry" seems to have great influence among dentists in PDS (Norway), as they seek to preserve dental hard tissue as much as possible by choosing repair before replacement. No gender differences were observed, but older dentists seem to favour repair compared with the younger dentists.

1. Introduction

According to modern dental philosophy, repair of defective restorations should always be considered when evaluating treatment options [1,2]. Repair has become increasingly more popular over the last two decades as the concept of "Minimal Intervention Dentistry" (MID) has become rooted in the clinic [3–5]. In line with the concept of MID, resin-based composite (RC) will often be the first restorative material of choice for posterior restorations. One advantage with RC restorations over amalgam is that they are repairable [6,7]. According to many authors repair, refurbishment and monitoring restoration defects increase the survival time of restorations significantly [2,8–10]. Schwendicke et al. has in a recent publication on "Consensus Recommendations on Carious Tissue Removal" recommended the following: "Retreatment of restorations should aim to repair by resealing, refurbishing, or repolishing where possible, and replacement should be last resort (strong recommendation)" [11]. On the other hand, Sharif et al. concluded in a recent Cochrane review that there is no scientific evidence to claim that repair of RC has any advantages over replacement [12]. The main shortcoming stated in this review was the absence of randomisation of the clinical trials. This challenges the dental clinician with an existential question; "repair or replacement"? Often little information is available about the age and brand of the composite restoration in question. It has been shown that the success of repair is higher for newer composite than older composite [13]. The advantages of not replacing the entire restoration due to minor flaws are several; tooth structure

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Table 1
Bonding systems used by the PDS dentists.

Bonding systems	Frequence (%)
1 step self etch	5.5
1 step self etch with separate etch of enamel	9.0
2 step self etch	4.8
2 step self etch with separate etch of enamel	7.4
2 step etch and rinse	48.7
3 step etch and rinse	24.6

and strength are preserved [1]. Furthermore, there might be reduced risk of accidental pulp damage and iatrogenic damage to neighbouring teeth, not to forget the "cycle of re-restoration" that points to the repeated treatment of teeth as a journey to destruction of the tooth [14,15]. There is also a financial issue concerning the patients, repair can be performed quicker, at a lower cost and the need for local anaesthetics is reduced [1,2].

When deciding to repair RC restorations, strategies for pre-treatment of the restoration to be repaired are important [8,13,16,17]. Different additives to bonding systems, such as silanising agents and phosphates have been shown to improve bond strength [7,18,19]. To which extent dentists actually use these products, is however unknown. Data from Mjör et al. from 1989 have often been used as a reference to how much time is used on operative treatment in dental practices. It was stated that about 60% of all operative work done is attributed to replacement of restorations [20]. There is a need for updated information on this topic. Therefore, our study aimed to assess the proportion of Norwegian dentists' working day devoted to operative treatment, in addition to display if the trends of minimal intervention dentistry influence dentists' treatment choices concerning "repair or replacement" of defective RC. The study also aimed to record dentists' use of bonding systems and clinical routines for pre-treatment of defects at the tooth/restoration interface.

2. Material and methods

A pre-coded questionnaire was sent electronically to all dentists (n = 1313) employed in the Public Dental Service (PDS) in Norway in February 2015, using the Internet-based software *QuestBack* (Oslo, Norway). The software was configured to automatically send reminders to all participants who did not reply within 2, 10 and 14 weeks. Anonymity was ensured by QuestBack. Information was collected regarding the respondents' age and gender, and to which extent they were occupied with the use of restorative materials on a daily basis.

The questionnaire consisted of two parts. In *part one,* the dentists were asked whether they performed direct restorative therapy or not. If they did, how much of their working day was spent placing restorations? They were also asked how many fillings they placed during a normal working day, and how many of them were due to (a) Primary caries, (b) Repair of old restorations or (c) Replacement of old restorations. Furthermore, they were asked about the kind of bonding agents used in their practice (Table 1). Finally, the dentists were asked: when repairing old restorations, what kind of pre-treatment of the residual restoration did they perform? For the latter question multiple answers were allowed (Table 2).

Table 2
Type of pre-treatment used on the old restoration when repairing with RC. The respondents were allowed to choose more than one option.

Pre-treatment when repairing RC restorations	%	n=
None	2.0	14
Acid etch	82.3	587
Bonding agent	83.3	594
Silanising agent	7.4	53
Preparation of extra retention in adjacent restoration	79.8	569
Do not repair composite restorations	0.3	1
Other treatment	3.9	48

Fig. 1. *Case one.* What treatment would you suggest for this upper right second premolar? The tooth has a MOD composite restoration where some of the mesiobuccal part of the filling has fractured off. There is enamel around the entire restoration and the damaged part. The X-ray shows no caries and the distance to the pulp is at least 1 mm. No other pathology or discomfort/sensitivity is observed. The patient is a woman in her mid-fifties with low caries activity and normal occlusion. There are no financial limitations concerning dental treatment and the patient has no desire to improve the esthetical appearance of the restoration.

In *part two*, the dentists were given three patient cases with tooth or restoration fractures of increasing severity (Fig. 1–3). The respondents were asked to choose among the following alternatives when considering the best treatment strategy: (1) Repair with resin composite restorative material (RC), or total replacement of the restoration with: (2) RC, (3) Ceramic restoration (CAD/CAM), (4) Ceramic restoration (produced by a dental technician), (5) Gold inlay, (6) Crown (unspecified), (7) Other treatment (to be specified) (Table 3).

2.1. Statistical analyses

Statistical analyses were performed by descriptive statistics using chi-square tests. A significance level of 5% was used throughout. Statistical analyses were performed with IBM SPSS Statistics version 20.0.0.1 (Statistical Package for the Social Sciences; SPSS, Chicago, IL, USA).

2.2. Ethical considerations

Participation was voluntary and no remuneration was given to the respondents. Anonymity was ensured by *QuestBack*. The study was registered at the Norwegian Data Protection Authority (ID: 70269).

Fig. 2. *Case two.* What treatment would you suggest for this lower right second molar? The distobuccal cusp has fractured off adjacent to a composite restoration. There is enamel around the entire filling and the damaged part. The X-ray shows no caries and the distance to the pulp is at least 1 mm. No other pathology or discomfort/sensitivity is observed. The patient is a woman in her mid-fifties with low caries activity and normal occlusion. There are no financial limitations concerning the dental treatment.

Fig. 3. *Case three.* What treatment would you suggest for this upper left first premolar? The palatal cusp is lost. There is a remaining composite MOD restoration. There is enamel surrounding the entire filling and fracture. The X-ray shows no caries. The distance to the pulp is good and there is no other pathology. The patient is a woman in her mid-fifties with low caries activity and normal occlusion. There are no financial limitations concerning the dental treatment.

3. Results

Of the 1313 dentists invited to participate in the study, a total of 748 dentists had responded after three reminders. Respondents who stated that they did not normally work with restorative treatment (n = 35) were excluded from the statistical analyses. A response rate of 55.8% was calculated according to Standard Definitions of the American Association for Public Opinion Research [21]. The age of the respondents varied from 25 to 77 years (mean 41.8, SD 12.4), 69.6% were female and 30.4% male. Similar data for all PDS-employed dentists in Norway were extracted from Statistics Norway, Dental Health [22]. Our sample was found not to be significantly different from all PDS dentists regarding age ($p = 0.08$) or gender ($p = 0.68$) (chi-square tests). Almost all respondents considered the PDS as their main occupation (97.3%).

3.1. Part one

The respondents claimed that on average 57.5% of their working day was spent placing restorations (SD 17%, range 10–100%). The number of restorations placed during a normal working day varied from 1 to 30 (mean 7.7, SD 3.6%). The reasons for placing restorations were: (a) Primary caries (55.7%, SD 19.1%) (b) repair of old restorations (26.7%, SD 14.8%) and (c) total replacement of restorations (18.2%, SD 11.2%).

The dentists' use of bonding systems is given in Table 1. Table 2 shows the dentists' choices of pre-treatment of the residual restoration when repairing RC restorations.

3.2. Part two

The dentists' treatment suggestions for all three patient cases are presented in Table 3. Repair with RC was suggested by 89.6% of the dentists in case one, 86.9% in case two and 54.1% in case three. Regarding *Patient Case 3*, the spectre of treatment alternatives was used more actively than for the first two cases. The dentists' treatment decisions for *Patient Case 3* can be grouped according to amount of tooth substance removal as either (1) Minimal invasive treatment—repair with RC (54.1%, n = 383), (2) Medium invasive treatment—replacement of the whole restoration with a filling or an inlay/onlay (24.0%, n = 171) and (3) Invasive treatment—restoration of the tooth with a crown (21.8%, n = 154). Minimally invasive treatment was preferred significantly more often among the oldest dentists compared with the younger dentists (≤38 years) ($p < 0.01$) (chi-square tests) (Table 4).

Table 3
Percentage of respondents (n = 713) who suggested each of the different treatment options for the three cases shown in Figs. 1–3.

Treatment suggestions	Case 1 Tooth 15	Case 2 Tooth 47	Case 3 Tooth 24
1) Repair with RC	89.6	86.9	54.1
2) Replace restoration	4.5	3.4	13.8
3) Ceramic inlay/onlay CAD/CAM	0.7	0.6	1.1
4) Ceramic inlay/onlay (dental technician)	1.7	1.4	9.0
5) Gold cast inlay	0.3	1.1	0.1
6) Crown	3.2	6.6	21.8

Table 4
Treatment suggestions for Case 3 (tooth 24) with respect to the different age quartiles. Older dentists (Q3 and Q4) chose significantly more minimally invasive than the younger dentists in Case 3 ($p < 0.01$).

Treatment suggestion for *Case 3*	Q1 25–31 yrs	Q2 32–38 yrs	Q3 39–51 yrs	Q4 52–75 yrs	Mean
1) Repair with RC	48.4%	44.4%	60.1%	63.6%	54.1%
2) Replace restoration	12.9%	15.8%	9.6%	17.3%	13.8%
3) Ceramic inlay/onlay CAD/CAM	2.2%	1.2%	1.1%	0.0%	1.1%
4) Ceramic inlay/onlay (dental technician)	7.5%	14.0%	9.0%	5.8%	9.0%
5) Gold cast inlay	0.0%	0.0%	0.6%	0.0%	0.1%
6) Crown	29.0%	24.6%	19.7%	13.3%	21.8%

4. Discussion

The results of this survey indicate that restorative treatment still lays claim on a large part of the dentists' working day. Primary caries is the reason for restorative treatment in more than half the patient cases treated by PDS dentists. This may reflect that children represent a large group of the patients in the PDS. However, throughout Norway PDS dentists are treating patients of all ages. When considering treatment of defective restorations, the majority of the responding dentists chose a conservative approach (repair). Furthermore, the use of bonding agents and macro mechanical preparation for adhesion was found to be standard procedure for the pre-treatment of restorations.

Almost nine out of ten dentists (89.6%, *Patient Case 1* and 86.9%, *Patient Case 2*) would prefer repair of a failed restoration when the damage was small (in these cases minor tooth/restoration fractures). Even when the damage comprised one cusp of a bicuspid (*Patient Case 3)* more than half the dentists (54.1%) would still prefer composite repair. Interestingly, in *Patient Case 3* only 21.8% suggested crown therapy which was defined as "invasive treatment" in this study. This can be seen as a confirmation that most Norwegian PDS dentists follow the concept of MID and try to save as much tooth substance as possible. The survey indicates that older dentists may be more conservative than younger dentists as they prefer repair more often. This difference is difficult to explain. We might speculate that this is due to older dentists having more experience with dental materials and increased confidence in technical skills, or that younger dentists may be eager to practice crown preparation techniques. Although the majority of dentists were female (70%), no relationship between gender and treatment choice was observed for the three cases.

The treatment goal of restorative dentistry is to produce long-lasting restorations of good quality without compromising the sound tooth tissue more than necessary [23–25]. Recent studies show that the longevity of the restoration could benefit from being repaired as opposed to replaced. A clinical study of composite restorations with 22 years regular check-up visits showed an Annual Failure Rate (AFR) of 1.9% (replaced and repaired restorations) [6]. If, however, repaired restorations were considered not to be failures, the AFR improved to 0.7% [6,26]. Opdam et al. demonstrated a similar reduction of AFR from 1.83% to 0.72% when repair first was not considered a failure [9].

The majority of the dentists in our survey (83.3%, Table 2) chose etch-and-bond as their standard pre-treatment procedure for repair. A similar amount of dentists reported that they also made extra macro mechanical preparation for retention (79.8%, Table 2). This might be beneficial pre-treatment strategies for increasing the bond strength at the repair interface. Some bonding systems have been demonstrated *in vitro* to increase the strength of the repair interface significantly [2,7,13]. Theoretically, macro mechanical retention should also be beneficial as it firmly locks the restoration in place and reduces direct stress on the repair interface. Unfortunately, only a few of the participants (7.4%) used extra silanising agents during the repair procedure. Silanes have been proven *in vitro* to enhance bond strength of the repair interface [7,18,19] and should in the authors' opinion be used routinely when repairing RC restorations. Nevertheless, some of the newer bonding systems available on the marked today contain silane which might negate the need of an extra silanising agent [7]. These show promising results, but this type of bonding has only been available for a relatively short amount of time (3–4 years). The uncertainty regarding the one-step (all-in-one) bonding systems lies in the mixing of hydrophilic and hydrophobic monomers in the primer and adhesive. This may prevent the solvents in the primer to evaporate before adding the bonding agent [27]. Formation of droplets in the bonding interface, caused by phase separation or osmosis because of high HEMA content, is enhanced, which in turn may weaken the bond strength [28]. The hydrolytic stability of the coupling agents is another important factor. Pre-hydrolysed silanes might be inactivated shortly after production due to reaction with similar silane molecules. In addition the bonding between silanes and filler particles is vulnerable because of hydrolysis [18]. It is suggested that the repair potential decreases with time because of higher water content in old composite leading to hydrolysis and the reduced ability to form chemical bonds to old resin molecules [7,13,19,29,30].

Bonding systems have been through a tremendous development during the last decades [31]. Regarding bonding to dental hard tissues there is a trend towards using self-etching systems with and without separate etching of the enamel. Both one-step (all-in-one) and two-step (separate prime and bond) variants are available. They are well acknowledged by scientists and some refer to the mild and extra mild etching systems (pH 2–2.7) as the new "Gold Standard" of dental bonding [31]. The main advantage of self-etching primers is less destruction of mineralised dentin. Acidulated resin monomers etch hard dental tissue as they penetrate into dentin and enamel. Thereby a stronger hybrid layer is created and the risk of postoperative hyper sensibility is reduced [31]. It is recommended to etch enamel separately with a stronger acid as the mild acids do not penetrate the enamel sufficiently. Concerning acid etching on composite surface, the acid strength might not have the same relevance. The main purpose of the acid is to cleanse the material surface from debris/smear layer and increase surface energy for better wetting and close contact between the materials [7,13,31,32]. The shift in choice of bonding system does not seem to have reached the PDS in Norway yet as 73.3% of the dentists claimed they still use etch and rinse (ER) systems. An explanation for this could be that dentists in the PDS are obligated to follow purchase agreements.

The questionnaire did not ask specifically about the use of moisture control techniques when repairing composite restorations. However, in a recently published questionnaire performed among Norwegian dentists, 94. 3% agreed that moisture control during placement was the most important factor for longevity of restorations [33].

According to modern knowledge about caries development (primary and secondary), there is a stronger emphasis on treatment of caries as an illness, with focus on prevention and arrest of caries lesions [3]. Caries risk assessment and focus on the oral micro biotic environment is central factors in this change of perspective [3,5]. Nevertheless, our questionnaire study reveals that operative treatment still lays claim on a large part of the Norwegian PDS dentists' working day. In the majority of cases primary caries is the reason for restorative treatment in patients treated by PDS dentists. This fact indicates that caries still is a problem in Norway. It has been shown recently that most Norwegian dentists defer operative treatment until it is absolutely necessary [34,35]. Thus, the high number of restorations placed due to primary caries reported in our questionnaire study is not likely due to over-treatment.

As any questionnaire study, the present study has some built-in limitations. Norton and colleagues [36] have addressed and discussed possible bias related to this type of study. They mention two different limitations, of which the first is response bias subjected to social desirability bias. In a clinical context, this would lead to responses which are politically correct according to guidelines or experts' opinions. The second limitation is the nature of non-validated self-reports, which may not reflect the actual behaviour. A third limitation in our study is that we were not able to reach private practitioners. It is likely that financial issues would affect the dentists' choice of treatment more in that group compared with PDS-employed dentists. Also, the amount of

restorations placed due to primary caries in our sample may be exaggerated since all patients aged 0–18 years are treated almost exclusively by the PDS.

How much of the working day spent on restorations (mean 57.5%, SD 17%, range 10–100%) and how many fillings placed daily (mean 7.7, SD 3.6%, range: 1–30), varied between the dentists. The reason could be that in some counties in Norway dental hygienists take a great part in the screening and recall examinations of patients and the dentists focus on operative treatment. In other counties the dentists do both recall examinations, preventive and operative treatment. Another important factor is that caries prevalence among children in Norway is skewed, especially between immigrant groups and native western groups in districts with many immigrant patients [37], thereby the number of restorations placed by the dentists and the main reasons for operative treatment may differ substantially, depending on which cohorts of patients they see. Nevertheless, the data say that on average 57.5% of the working day is reserved for operative treatment.

5. Conclusion

Our questionnaire study revealed that on average 57.5% of the Norwegian PDS-dentists' working day is still occupied with operative dentistry. Primary caries is the most common reason for operative treatment among PDS-dentists, but repair of old restorations represented approximately one fourth of the daily operative workload. The included dentists seem to prefer repair over replacement, and thereby grasp the sound principles of "Minimal Intervention Dentistry" by focusing on oral health and tooth preservation. Most dentists chose well documented pre-treatment options like macro mechanical preparation and bonding procedures when repairing RC. No difference concerning treatment choices was observed based on gender, but older dentists seem to be somewhat more conservative as they chose repair significantly more often than younger dentists.

Declaration of interests

The authors report no conflicts of interests. The authors alone are responsible for the content and writing of the paper.

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Article

The Post-Amalgam Era: Norwegian Dentists' Experiences with Composite Resins and Repair of Defective Amalgam Restorations

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Abstract: Amalgam was banned as a dental restorative material in Norway in 2008 due to environmental considerations. An electronic questionnaire was sent to all dentists in the member register of the Norwegian Dental Association (NTF) one year later, to evaluate dentists' satisfaction with alternative restorative materials and to explore dentists' treatment choices of fractured amalgam restorations. Replies were obtained from 61.3%. Composite was the preferred restorative material among 99.1% of the dentists. Secondary caries was the most commonly reported cause of failure (72.7%), followed by restoration fractures (25.1%). Longevity of Class II restorations was estimated to be $\geqslant$10 years by 45.8% of the dentists, but 71.2% expected even better longevity if the restoration was made with amalgam. Repair using composite was suggested by 24.9% of the dentists in an amalgam restoration with a fractured cusp. Repair was more often proposed among young dentists ($p < 0.01$), employees in the Public Dental Service (PDS) ($p < 0.01$) and dentists working in counties with low dentist density ($p = 0.03$). There was a tendency towards choosing minimally invasive treatment among dentists who also avoided operative treatment of early approximal lesions ($p < 0.01$). Norwegian dentists showed positive attitudes towards composite as a restorative material. Most dentists chose minimally- or medium invasive approaches when restoring fractured amalgam restorations.

Keywords: dentistry; amalgam; composite resin; operative treatment; minimally invasive dentistry; minimal intervention dentistry

1. Introduction

As of 1 January 2008, the use of amalgam as a dental restorative material has been banned in Norway. The ban was not directly a ban of amalgam as a restorative material, even though the Norwegian government had put pressure on dentists to reduce the use of amalgam during the preceding years [1], but rather a general ban of all mercury-containing products issued by the Norwegian Ministry of Climate and Environment due to environmental considerations [2]. In a guest editorial in the most prestigious research journal in dentistry, this decision was highly criticized [3]. In a response to the editor, however, it was claimed that "As Norway decreases its own pollution, it will decrease global mercury pollution, enhancing global health" [4]. This reflects some of the controversy associated with amalgam as a restorative material in teeth. Previous studies from Norway show that the use of amalgam was decreasing and use of composites increasing in the years preceding the ban [5] and that in absence of amalgam, composite definitively became the most preferred material for restoration of posterior teeth [6]. Nevertheless, the ban was criticized by many dentists in Norway

whose general perception was that longevity of amalgam restorations was superior to that of composite. These opinions could be due to several previous cross-sectional studies showing superior longevity of amalgam compared to composite [7–10]. However, cross-sectional studies have been criticized for underestimating the longevity of newer restorative materials, due to differences in observation time such as new composite restorations in a time period where amalgam had been used for decades [11]. Thus, the assumption in the past that composites had a lower longevity than amalgam, as suggested by the referred cross-sectional studies, might not be true. Additionally, it has been suggested that the differences in longevity seen in previous studies were due to differences in the skill of placing composites, since many studies were performed in a time when dentists placed mostly amalgam restorations and few composite restorations [12]. The authors concluded that operators who are skilled in both placing amalgam and composite restorations should be able to achieve comparable longevity today.

According to modern dental philosophy, repair of defective restorations should always be considered when choosing among the available treatment options [13,14]. If a full replacement of the restorations is performed, a significant amount of tooth structure is removed and the preparation enlarged [15]. The major advantage of repair is to save tooth substance, and thus the approach is consistent with the concept of *minimal intervention dentistry* [16]. Composite restorations are considered repairable [13,17,18]. Repair of defective amalgam restorations with new amalgam has been shown successful [19,20], while repair of amalgam with composite has shown variable results [13,21]. So, how will Norwegian dentists treat defective amalgam restorations when the use of amalgam is not allowed? The present study aimed to evaluate dentists' satisfaction and opinions on composite compared with amalgam as a restorative material, one year after the amalgam ban was issued. Further, the study aimed to explore dentists' preference for treatment of a fractured amalgam restoration.

2. Material and Methods

In March 2009, a pre-coded questionnaire was sent electronically to all dentists (dental surgeons) with an e-mail address registered in the member register of the Norwegian Dental Association (Den norske tannlegeforening—NTF), using the Internet-based software QuestBack. Of the 4315 members of NTF, 3654 e-mail addresses were registered. Participation was voluntary and no remuneration was offered to the respondents. The software QuestBack was configured to send automatic reminders to all participants who did not reply within three and five weeks, respectively. Anonymity was ensured by QuestBack. The study was approved by the Norwegian Social Science Data Services (NSD) (Project number 21170).

Information was collected regarding the respondents' sex, age, home county, type of practice and to which extent the respondent was occupied with caries diagnosis and treatment in his/her practice. Questions were asked about the use of restorative material in Class II-restorations, opinion factors related to the failure of Class II composites and general attitudes towards composites as shown in Tables 1–4.

Table 1. Which restorative materials do you use when restoring a MOD-cavity due to primary caries confined to the outer half of dentin (%)? The question is related to premolars and molars in adult patients.

Restorative Material	Never	Seldom	Sometimes	Often	Always	*n*
Composite	0.1	0.1	0.6	36.8	62.3	2019
Compomer	76.9	14.6	6.3	1.9	0.3	1560
GIC conventional	60.6	26.6	11.3	1.5	-	1607
GIC resin-modified	60.0	27.6	11.5	0.8	0.1	1602
Composite inlay	90.6	7.5	1.8	0.1	-	1591
Ceramic inlay	56.3	31.8	10.8	1.1	0.1	1617
Ceramic inlay (CAD/CAM)	85.6	9.2	4.0	1.2	0.1	1592
Gold inlay	52.5	36.7	10.3	0.4	0.1	1662

MOD: Mesial-occlusal-distal, GIC: Glass ionomer cement; CAD/CAM: Computer-Aided Design/Computer-Aided Manufacturing.

Table 2. What is in your opinion the cause when Class II composite restorations in permanent premolars and molars need replacement (%)?

Reasons for Replacement	Never	Seldom	Sometimes	Often	Always	*n*
Secondary caries	0.1	1.8	25.4	70.6	2.1	2006
Restoration fracture	0.8	23.5	50.8	24.3	0.8	2001
Poor approximal contact	0.4	12.6	63.5	22.7	0.7	2006
Marginal gaps	1.1	29.7	53.3	15.4	0.5	2008
Tooth fracture	1.6	34.2	48.9	14.7	0.6	2009
Marginal defects	1.3	32.5	52.2	13.8	0.2	2008
Lost restoration	3.4	46.6	39.0	9.9	1.0	2010
Restoration wear	4.3	47.3	40.0	8.1	0.3	2008
Marginal discoloration	8.7	47.8	36.3	7.1	0.1	1992
Pain/sensitivity	2.2	48.3	43.8	5.4	0.3	2005
Poor aesthetics	7.4	55.6	33.6	3.4	0.0	2003
Restoration deficiency	5.0	58.4	33.7	2.5	0.4	2009
Porosities	8.8	62.2	27.0	1.8	0.2	2010
Overhang	9.7	63.8	24.8	1.6	0.2	2001
Allergic reactions	45.1	52.7	1.1	0.2	0.9	1999

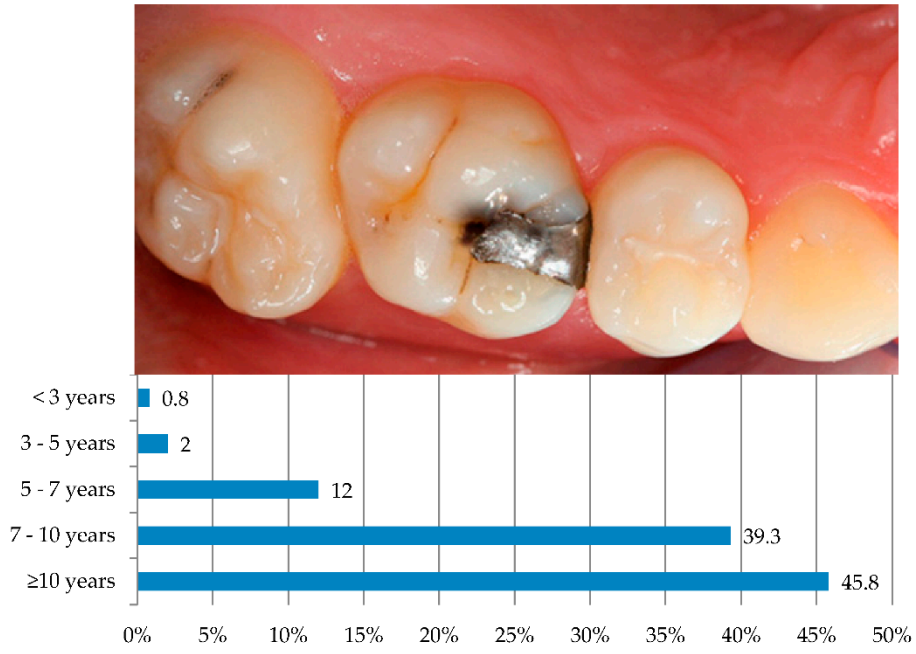
Table 3. To which extent do you think the following factors have significance for the longevity of a Class II composite restoration (%)?

Factors Relevant for Longevity	Do Not Know	None	Minor	Medium	High	Very High	*n*
Moisture control	0.1	0.1	0.7	4.8	35.4	58.9	2009
High caries activity	-	-	0.6	5.3	41.9	52.1	2005
Poor oral hygiene	-	-	1.1	11.5	46.2	41.0	2003
Poor matrix technique	0.3	0.1	1.0	11.6	50.4	36.4	2001
Patient cooperation	0.5	1.0	11.5	30	39.6	17.5	1999
Cavity design	0.1	0.3	11.1	37.6	40.8	10.1	2006
Hard bite (patient)	0.6	0.2	11.3	42.9	35.7	9.4	1992
Following manufacturer's instructions	0.2	0.5	7.9	51.0	40.3	0.2	2008
Dentist' s experience	0.6	1.5	11.0	54.4	32.4	0.6	2010
Type of adhesive	1.9	1.0	26.8	43.7	21.8	4.8	2008
Type of composite	1.8	2.2	37.4	44.3	12.0	2.3	2008

Table 4. Relate to the following statements regarding composite restorations (%).

Statements	Do Not Know	Totally Disagree	Disagree	Neutral	Agree	Totally Agree	*n*
Moisture control is the most important factor to achieve successful restorations	0.1	0.5	2.9	13.6	47.7	35.3	2014
Composite is a good alternative to amalgam	0.3	0.5	6.2	18.9	44.4	29.6	2016
Secondary caries is more commonly seen in composite restorations compared with amalgams	1.9	2.4	13.8	23.4	40.1	18.4	2003
Composite is not suitable in patients with high caries activity	0.4	2.8	31.5	35.8	23.7	5.7	2009
Lining is not necessary in deep composite restorations	0.2	13.2	40.9	17.9	21.6	6.2	2002
I often experience that my composite restorations need replacement	0.4	6.0	43.4	30.3	17.8	2.1	2010
Composite is not suitable in patients with poor oral hygiene	0.3	7.3	39.2	35.2	15.7	2.2	2003
Composite is not suitable in patients with a hard bite	0.4	6.0	48.5	34.4	9.9	0.8	2002
Composite is only suitable in small cavities	0.2	24.0	57.6	12.8	3.8	1.7	2015
Composite is not suitable in molars	-	39.0	53.9	5.6	1.1	0.3	2001

Two patient cases were presented to the dentists: *Patient Case 1* showed an upper first permanent molar with a small MO amalgam restoration that needed to be replaced (Figure 1). The dentists were asked what longevity they would estimate for a new restoration if the amalgam restoration was to be replaced with composite. The amalgam restoration was said to have a small secondary caries lesion that was barely visible on x-ray. The restoration had gingival enamel in the approximal box. The patient was a 40-year-old woman with satisfactory oral hygiene using fluoride toothpaste. She attended the dentist for a check-up every 12 months. She wanted to replace the whole restoration with composite.



What would be the longevity of a similar restoration made in amalgam?
1.4% Poorer
27.3% Equivalent
71.2% Better

Figure 1. *Patient Case 1:* What longevity would you estimate if the amalgam restoration in this upper first molar was to be replaced with composite? The amalgam restoration has a small secondary caries lesion that is barely visible on x-ray. The restoration has gingival enamel in the approximal box. The patient is a 40-year-old woman with satisfactory oral hygiene, uses fluoride toothpaste and has a dental check-up every 12 months. She wants to replace the whole restoration with composite.

Patient Case 2 showed an upper second permanent premolar with a fractured amalgam restoration and no sign of secondary caries (Figure 2). The restoration was said to have cervical enamel in both approximal boxes. Radiological examination showed that the amalgam restoration had good distance to the pulp. No other pathology was noticed. The patient was a 52-year-old woman with low caries activity and normal bite. She had no contradictions towards amalgam and there are no economical limitations on the preferred treatment. The respondents could choose what they considered to be the best treatment from a precoded list. Their treatment decisions were grouped according to amount of tooth substance removal as either (1) Minimally invasive—Repair with composite; (2) Medium invasive—Replace the restoration with either filling or inlay; or (3) Invasive—Restore the tooth with a crown.

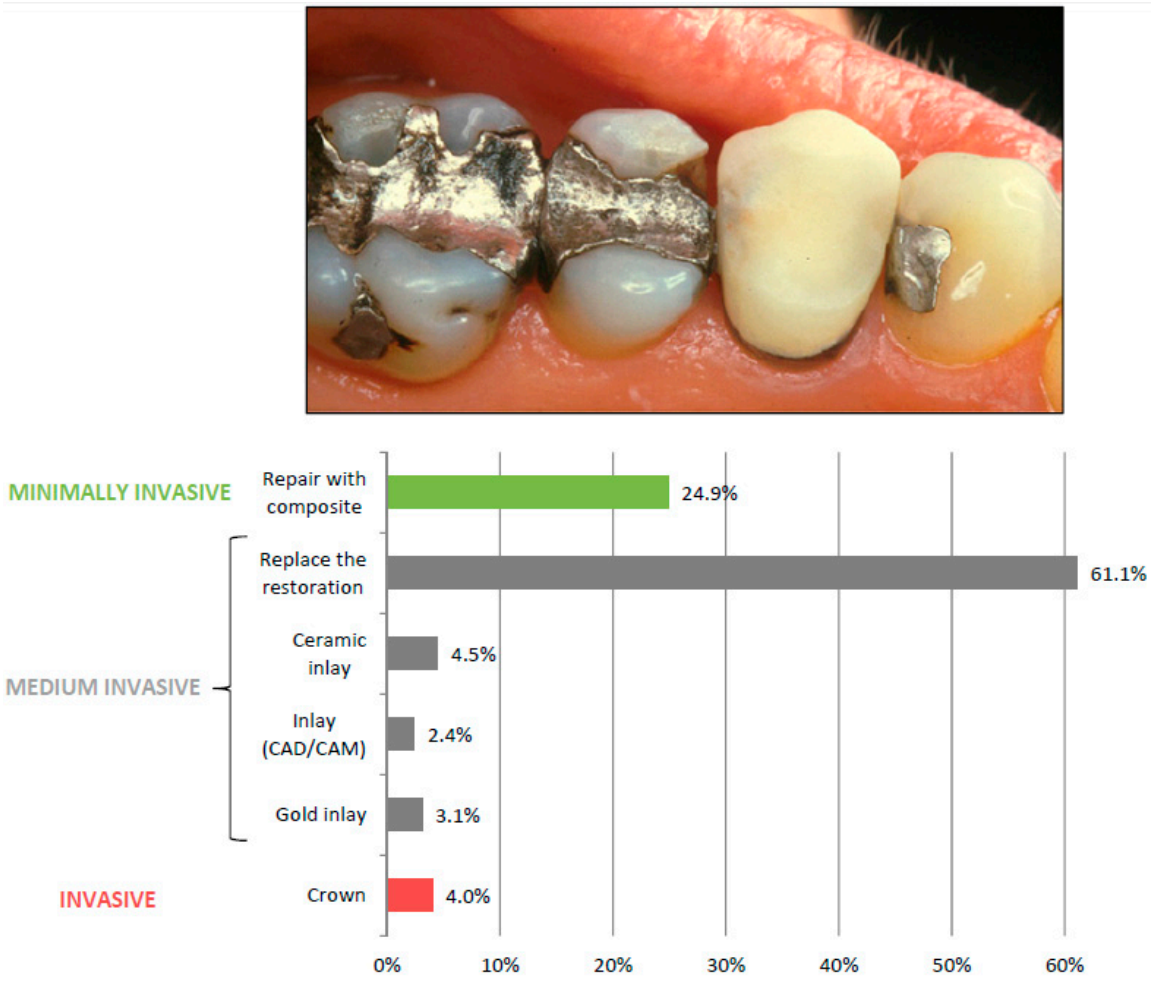


Figure 2. *Patient Case 2*: What is in your opinion on the best treatment for this upper second premolar? The tooth has a fractured amalgam restoration. There is no sign of secondary caries. The restoration has cervical enamel in both the approximal boxes. Radiological examination shows that the amalgam restoration has good distance to the pulp. No other pathology is noticed. The patient is a 52-year-old woman with low caries activity and normal occlusion. She has no aversion towards amalgam and there are no economical limitations regarding the choice of treatment.

Statistical analyses were performed by descriptive statistics with chi-square tests and two separate logistic regression analyses with the dependent variables: "Minimally invasive treatment" and "Invasive treatment" (Figure 2). Independent variables were the dentist' s age and gender, type of practice, mean number of decayed, missing, and filled teeth (DMFT) for 18 year olds and number of patients per dentist (dentist density) in the respondents' respective counties of practice. Aggregated data for each of 20 Norwegian counties on the two latter variables were extracted from Statistics Norway, Dental Health [22]. Variables significant at $p \leqslant 0.2$ level in the unadjusted analyses were entered into the adjusted logistic regression analysis. Collinearity was checked using the criterion Variance Inflation Factor < 5 and no independent variables were found to invalidate the analysis. Statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 20.0.0.1 (SPSS Inc., Chicago, IL, USA). A significance level of 5% was used throughout.

3. Results

In total, 2375 out of 3654 dentists responded after two reminders. A response rate of 61.3% was calculated according to the Standard Definitions of the American Association for Public Opinion Research [23]. Respondents 69 years of age and older (n = 63) and those who did not normally work

with caries and filling materials (n = 286) were excluded from the statistical analyses, leaving a total of 2026 included respondents. The mean age of the included dentists was 46.2 years (SD 11.9), 47.1% female and 52.9% male. The distribution of age and gender of the included respondents did not differ significantly from all dentists in the NTF member register and the Norwegian Registration Authority for Health Personnel (SAFH) [6]. According to the type of practice, 690 (34.1%) of the included respondents were employed by the Public Dental Service (PDS), 1299 (64.1%) were private practitioners and 37 (1.8%) were employed elsewhere, e.g., in research or administrative work. In the member register of the NTF, 32.9% were employed by the PDS and 67.1% were registered as private practitioners.

Composite was the preferred restorative material for Class II restorations in premolars and molars among the majority of dentists (Table 1). Other restorative materials and techniques were sparsely used. Tables 2–4 show the dentists' opinions on the reasons for failure and factors affecting the longevity of Class II composites. Secondary caries was the most commonly reported cause of failure, stated by 72.7% of the dentists to be "Often" or "Always" the cause for replacement. Restoration fractures and poor approximal contact were the second and third most common reasons for replacing composites, reported "Often" or "Always" by 25.1% and 23.4% of the dentists, respectively. Moisture control during placement of composite restorations (58.9%) and the caries activity of the patient (52.1%) were considered to be very significant factors for the longevity. In *Patient Case 1* (Figure 1), almost half of the dentists (45.8%) estimated the longevity to be ⩾10 years for an MO composite replacement of a defective amalgam restoration, 39.3% estimated 7–10 years longevity and 14.8% estimated longevity of less than 7 years. The majority of the dentists (71.2%) expected an even better longevity if the restoration was made in amalgam, 27.3% anticipated equivalent longevity, while 1.4% estimated a poorer longevity of an amalgam *versus* a composite restoration. Among the dentists who anticipated better longevity of an amalgam restoration compared with composite in *Patient Case 1*, more were females, dentists in the two youngest age groups (<48 years) and those employed in the PDS ($p < 0.01$). Only 34.4% of these dentists estimated the longevity of a composite restoration in *Patient Case 1* to be ⩾10 years, compared with 73.4% of dentists who expected equivalent or poorer longevity of an amalgam restoration ($p < 0.01$). In Table 4 it is shown that 74.0% of all dentists agreed (either "Agreed" or "Totally agreed") with the statement that: «Composite is a good alternative to amalgam». Concerning *Patient Case 1*, 66.8% the dentists who expressed that they anticipated a restoration in amalgam to have better longevity than composite, agreed with the statement above. When it comes to those who expressed the opinion that amalgam in this case had equivalent or poorer longevity compared to composite, 91.9% agreed with the statement.

The dentists' treatment decisions for *Patient Case 2* are illustrated in Figure 2. The treatment decisions were grouped according to amount of tooth substance removal as either (1) Minimally invasive—Repair with composite (24.9%, n = 502); (2) Medium invasive—Replace the restoration with either filling or inlay (71.1%, n = 1432) or (3) Invasive—Restore the tooth with a crown (4.0%, n = 80). Their choices of treatment were examined by use of logistic regression analyses. Minimally invasive treatment was significantly more often proposed among young and female dentists, employees in the PDS and dentists working in counties with a low dentist density (unadjusted analyses). When adjusting for all other variables, dentists' gender did not reach significance, while all other variables remained significant (Table 5). Invasive treatment (crown) was significantly more often proposed by male dentists and dentists working in counties with high dentist density (unadjusted analyses). Both variables remained significant when adjusting for all variables (Table 5).

Combining the respondents' answers to *Patient Case 1* and *Case 2* showed that dentists who chose a minimally invasive approach in fact had a more pessimistic view on the longevity of composite restorations compared with dentists who chose a medium invasive or invasive approach. A significantly smaller amount of the dentists who chose a minimally invasive approach in *Patient Case 2* estimated the longevity of a composite restoration in *Patient Case 1* to be ⩾10 years (36.1%), compared with dentists choosing an either medium invasive or invasive approach (48.8%) ($p < 0.01$).

Table 5. Variables related to the dentists choice of a minimally invasive and invasive treatment approach in *Patient Case 2*.

Independent Variables	% (*n*)	Minimal Invasive Treatment						Invasive Treatment					
		Unadjusted			Adjusted			Unadjusted			Adjusted		
		OR	95% CI	*p*-Value	OR	95% CI	*p*-Value	OR	95% CI	*p*-Value	OR	95% CI	*p*-Value
Dentist's Age													
⩾35 years	27.5 (557)	-	-	-	-	-	-	-	-	-	-	-	-
36–47 years	27.0 (548)	0.73	0.56–0.95	0.02	0.80	0.61–1.05	0.10	0.76	0.42–0.95	1.41	0.71	0.39–1.32	0.28
⩾48 years	45.5 (921)	0.51	0.40–0.65	<0.01	0.54	0.42–0.69	<0.01	0.87	0.51–0.65	1.46	0.74	0.43–1.27	0.28
Dentist's Gender													
Female	48.1 (974)	-	-	-	-	-	-	-	-	-	-	-	-
Male	51.9 (1052)	0.62	0.51–0.76	<0.01	0.82	0.65–1.02	0.07	1.97	1.23–3.18	<0.01	2.06	1.24–3.42	2.06
Practice Type													
Private Practice	64.1 (1299)	-	-	-	-	-	-	-	-	-	-	-	-
Public Dental Service	34.1 (690)	2.36	1.92–2.91	<0.01	2.19	1.76–2.72	<0.01	0.62	0.37–1.03	0.07	0.79	0.46–1.35	0.38
Other	1.8 (37)	1.37	0.64–2.94	0.42	1.52	0.70–3.30	0.29						
DMFT in County													
Continuous Variable	100 (2026)	1.03	0.88–1.19	0.73				0.89	0.63–1.24	0.49	-	-	-
Number of Patients per Dentist in County													
Continuous Variable	100 (2026)	1.01	1.00–1.01	0.01	1.01	1.00–1.01	0.03	1.01	1.00–1.01	0.01	1.01	1.00–1.01	0.01

Also, significantly more dentists choosing a minimally invasive approach expected the longevity to be longer if the restoration was made in amalgam (77.6%), compared with dentists choosing an either medium invasive or invasive approach (69.1%) ($p < 0.01$).

The dentists' thresholds for instigating operative treatment of approximal caries lesions have been explored in a previous paper [6]. Table 6 shows a cross tabulation of the treatment decisions for *Patient Case 2* and the decision to operatively treat approximal caries. There was a significant tendency towards choosing minimally invasive treatment in *Patient Case 2* among dentists who also avoided operative treatment of early approximal primary caries lesions ($p < 0.01$). Likewise, dentists who chose an invasive treatment strategy in *Patient Case 2* also treated early stages of approximal caries more often ($p < 0.01$).

Table 6. Cross tabulation of the decision on how to treat *Patient Case 2* and threshold for operative treatment of approximal primary caries. Most dentists choosing minimally invasive treatment in *Patient Case 2* only treated advanced stages of approximal caries operatively.

Treatment decisions in *Patient Case 2*			
	Enamel Caries	**Caries in Outer Third of Dentin**	**Caries in Middle and Inner Third of Dentin**
Minimally invasive (repair) ($n = 501$)	4.8%	50.5%	44.7%
Medium invasive (restoration/inlay) ($n = 1428$)	7.1%	58.8%	34.1%
Invasive (crown) ($n = 79$)	10.1%	63.3%	26.6%

4. Discussion

The Norwegian Dental Association (NTF) estimates that 90%–95% of all practising dentists in Norway are registered members. The relatively high response rate (61.3%) and the matching age distribution of the respondents are consistent with our sample being representative of the members of NTF and all authorized dentists in Norway. Our response rate was considered satisfactory, and in the high-end of what has been achieved in similar questionnaire studies elsewhere [24–28].

In Scandinavia, use of amalgam is more or less banned; in Norway since 2008 [2] and in Sweden since 2009 [29] with some exceptions. The use of amalgam is still allowed in Denmark, but the government has put strong restrictions in place. The Minamata Convention on Mercury is a global treaty to protect human health and the environment from the adverse effects of mercury. The treaty is at present signed by 128 countries [30] and its repercussions call for a phase-out of dental amalgam [31]. Thus, a ban on amalgam could also be forthcoming in other countries and experiences among Norwegian dentists after the ban could be a valuable contribution to a foregoing debate on this subject. Although the present data was collected in 2009 and our conclusions are likely to be outdated in a Norwegian setting, the findings may have high clinical relevance in other societies where use of amalgam is still allowed and being phased-out. Our results reflect decision making on restoration replacement in a population of dentists that are not using amalgam anymore. In the UK, Lynch and Wilson have already used Norway as an example on how to manage a phase-down and eventually ban of amalgam [32]. The present study could be considered an important follow-up on this matter, providing information on how the dentists cope with a ban of amalgam.

Table 1 shows the dentists' preferred restorative material in a MOD-cavity. It demonstrates that composite has become the dominating material of choice in Norway one year after the amalgam ban. Almost all dentists (99%) stated that they "Often" or "Always" used composite when restoring a MOD-cavity due to primary caries being confined to the outer half of dentin. Similar trends have been found in other Norwegian studies [5,6]. International studies show similar tendencies; a study

on trends in dental treatment in the USA showed that patients received approximately 50% fewer amalgam fillings in 2007 compared with 1992, while the rise in use of resin-based composite restorations was equivalent [33]. In other countries, the use of amalgam has also decreased rapidly [12,24,26,33–37]. More than fifty percent of the dentists in our questionnaire study stated that they "Never" used other materials than composite. This is in accordance with a recent practice-based study showing that the overall use of other materials than amalgam and composite was only 5% for both U.S. and Scandinavian dentists, when placing restorations in premolars and molars [38].

The general opinion that secondary caries and restoration fracture are the most common reasons for failure of composites (Table 2) is supported by evidence from the literature. A review of studies conducted in the 1990s on the longevity of dental restorations reported that secondary caries was the reason for replacement in 33%–65% of failed composite restorations [39]. Studies published later have reported similar rates: 25% [40], 38% [12], 52% [41], 57% [42] 58% [43] and 88% [44]. In a recent review on the longevity of posterior composite restorations, secondary caries and fracture of restoration are considered the two main reasons for failure [45]. The dentists in our questionnaire study considered moisture control during placement of composite restorations (58.9%) and the caries activity of the patient (52.1%) to be very important factors for the longevity of composites (Table 3). The findings are consistent with replies shown in Table 4. Both these variables could be related to development of secondary caries. Nevertheless, the lack of standardized diagnostic criteria for marginal failure could cause over-registration of secondary caries [46,47]. Crevices and ditched margins in which the explorer sticks, and marginal colour changes, could be wrongly diagnosed as secondary caries [47–49].

In Table 4, 58.5% of the dentists either "Agree" or "Totally agree" that secondary caries is more commonly seen in composite restorations compared to amalgam. This is in accordance with findings in a questionnaire study on Finnish dentists' perceptions on the reasons for replacement of restorations [50]. This perception is clinically established in the literature; in a retrospective clinical study by Kuper *et al.*, composite restorations developed secondary caries twice as often as amalgam restorations [43]. Similar results have also been shown in three earlier RCT studies [41,44,51]. Post-operative pain or sensitivity were reported "Never" or "Seldom" to be the reason for failure by 50.5% of the dentists and additional 43.8% reported only "Sometimes". This corresponds well with the conclusion in a review by Hickel *et al.* that the problem with post-operative hypersensitivity was decreasing [52]. Allergic reactions were reported "Never" or "Seldom" to be the reason for failure by 93.8% of the dentists. The prevalence of adverse reactions to composites in Norway is reported to be generally low. From 1993, the Norwegian Dental Biomaterials Adverse Reaction Unit has operated a national reporting procedure concerning suspected biologic adverse reactions experienced in relation to treatment with dental biomaterials, but during the twenty years from 1993 to 2013, only about 2100 reports have been received. In 2013, 28% of the reports were related to composites and cements, a percentage that has remained relatively stable over the years following the amalgam ban [53].

In general, the dentists' replies in *Patient Case 1* indicate a positive view on the longevity of restorations in a low-risk patient. Nearly half the dentists (45.8%) estimated the longevity to be more than ten years, while only 3% of the dentists estimated the longevity to be less than five years. The positive trend is consistent with the presented views in Table 4 where 74% of all dentists either "Agreed" or "Totally agreed" with the statement that composite is a good alternative to amalgam. Nevertheless, the fact that 71.2% of the dentists expected longevity to be better if the restoration was made with amalgam distorts the picture. These dentists were found significantly more often to be young, female and employed by the PDS. This diverges partly from what was previously found in a practice-based clinical study, where the dentists who preferred amalgam in Class II restorations were identified as being male and the patients to have high caries experience [5].

Logistic regression analyses revealed that minimally invasive treatment (repair) in *Patient Case 2* was suggested more often by dentists working in counties with low dentist density, while invasive treatment (crown) was suggested more often by dentists working in counties with high dentist density. These findings indicate that dentist remuneration affects the treatment decision. Repair is a rapid and

cheap alternative that can be preferred among dentists who have many patients attending their dental clinic, while a crown generally produces more work at a considerably higher cost, which could be beneficial for dentists with few patients attending their dental clinic. This idea is supported by the finding that more dentists employed in the PDS also chose repair, since they often have high workload and, in many cases, a fixed salary.

Dentists choosing minimally invasive treatment in *Patient Case 2*, tended only to treat advanced stages of approximal caries lesions operatively (Table 6). This is supported by findings in a study by Heaven *et al*. who found that dentists who recommended restorative treatment of primary occlusal caries and approximal caries at a more advanced stage were significantly more likely to recommend repair instead of replacement of a defective restoration [27].

5. Conclusions

Norwegian dentists showed positive attitudes towards composite as a restorative material one year after amalgam was banned. This has been confirmed by a later report by The Norwegian Climate and Pollution Agency which indicates that "dental personnel and patients generally are satisfied with the alternatives to dental amalgam" [54]. Most dentists choose minimally invasive- or medium invasive approaches when restoring fractured amalgam restorations. Dentists choosing minimally invasive treatments also avoid operative treatment of early approximal lesions.

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Abbreviations

The following abbreviations are used in this manuscript:

CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
DMFT	Decayed, missing and filled teeth
GIC	Glass ionomer cement
MO	Mesial-occlusal
MOD	Mesial-occlusal-distal
NSD	The Norwegian Social Science Data Services
NTF	The Norwegian Dental Association
PDS	The Public Dental Service
SAFH	The Norwegian Registration Authority for Health Personnel

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Bonding of Composite and Glass-ionomer to Amalgam

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Abstract. The **aim** of this *in vitro* study was to investigate bond strength between dental amalgam and a) composite or b) glass-ionomers (GI) to mimic restoration repair. **Material & Methods:** Cylindrical substrates of amalgam were made and ground (sanding paper #500). Repair materials were fixed to amalgam in groups of 20 specimens. Composite and three different bonding agents were tested in 3 modes; 1) short term (48h water storage), 2) water storage for 60 days, 3) thermo-cycling (TC) 5000/5-55°C. For the two Self-etch bonding-agents, the amalgam surface was not etched with acid. Three glass-ionomer products were tested in the same modes, two of them with and without dentine conditioner (optional from manufacturer). Altogether 24 groups were tested for sheer bond strength according to ISO /TS 11405. **Results:** None of the GIs adhered to the amalgam surface, resulting in bond strength value of 0 MPa. Composite testing: Mode 1) 6.5-8.3MPa, Mode 2) 6.4-7.7MPa, Mode 3) 0.6-2.2Mpa. There was no significant difference between mode 1 and 2. Mode 3 differed significantly from mode 1 and 2. **Conclusion:** GIs did not bond to amalgam. Composite-amalgam repair bond strength is low compared to previous results on bonding composite to composite. TC seems to be detrimental to composite-amalgam repair-interface.

Introduction

All dental restorations have a limited lifespan and will eventually be replaced or repaired. According to modern dental philosophy, repair of defective restorations should always be considered when evaluating treatment options [Blum et al., 2014; Hickel et al., 2013; Wilson et al., 2016]. Repair has become increasingly more popular over the last two decades as the concept of "Minimal Intervention Dentistry" (MID) has been rooted in clinical practice [Ericson, 2007; Ismail et al., 2015; Tyas et al., 2000] .

The use of amalgam as a dental restorative material is banned or strongly restricted for environmental reasons in Scandinavia [Norwegian Ministry of the Environment. Oslo, 2008]. Other countries are evaluating the use of mercury containing materials, and we shall probably, in line with the Minimata Convention, which entered into force on Aug 16th 2017 - (UNEP. Minimata Convention on Mercury 2017. Available online: http://www.mercuryconvention.org) - see more restrictions on the use of dental amalgam in years to come [Kielbassa et al., 2014]. Nevertheless this debated material has been in use for more than a century and will be present in our patients for decades. Dental surgeons will often be in a situation where the question is repair or replacement of an amalgam restoration. In a questionnaire from 2015, Norwegian dentists were asked about their view on what to do with defective amalgam restorations. In many cases repair with composite was the preferred option [Kopperud et al., 2016]. The Norwegian dentists positive attitude towards repair was also confirmed in another questionnaire from 2016 concerning defective composite restorations [Staxrud et al., 2016]. Treatment goals are long-lasting restorations of good quality, and repair of resin-based composites is reported to have a favourable outcome for the longevity and quality of the restoration without compromising the sound tooth tissue more than necessary [Gordan et al., 2009; Krejci et al., 1995; Maneenut et al., 2011; Mjor and Gordan, 2002] .

According to many authors; repair, refurbishment and monitoring restoration defects increase the survival time of restorations significantly [Gordan et al., 2006; Hickel et al., 2013; Moncada et al., 2009; Opdam et al., 2012]. Schwendicke et al. have in a publication on "Consensus Recommendations on Carious Tissue Removal", recommended that "Retreatment of restorations should aim to repair by resealing, refurbishing, or re-

polishing where possible, and replacement should be last resort (strong recommendation)" [Schwendicke et al., 2016].

The advantages of not replacing the entire restoration due to minor flaws are several. Tooth structure and strength are preserved [Blum et al., 2014]. There might be reduced risk of accidental pulp damage and iatrogenic damage to neighbour teeth, not to forget the "cycle of re-restoration" that points to the repeated treatment of teeth as a journey to destruction of the tooth [Brantley et al., 1995; Elderton and Nuttall, 1983]. There is also a financial issue concerning the patients, repair can be performed quicker, at a lower cost and the need for local anaesthetics is reduced [Blum et al., 2014; Hickel et al., 2013; Wilson et al., 2016].

Ray et al. found that repair of amalgam with amalgam gave adequate bond strength, but that repair of amalgam with composite demanded extra retention [Rey et al., 2015]. Today, in line with the concept of MID, resin-based composite (RC) will often be the first restorative material of choice for both new restoration and as repair material [Demarco et al., 2012; Lynch et al., 2014; Opdam et al., 2012]. Özcan et al [Ozcan et al., 2011; Ozcan et al., 2006] found that when repairing amalgam with adhesive approaches and composite, the bonding strength was significantly improved when using metal primers (containing sulphur compounds), silica coating air abrasion, silanising agents and glass fibre mesh at the interface before applying bonding agents. The procedures seem safe and reliable and a repair protocol has been launched [Ozcan and Volpato, 2016]. The problem is that most dentists in a clinical situation do not take time to go through a comprehensive and complicated procedure for minor restoration repair. Many are relying on bonding procedures, with the intention to obtain adequate and reliable strength at the repair interface with simple use of bonding agents.

The aim of this *in vitro* study was to investigate the bond strength at the repair interface between amalgam restorations and; 1) composite as repair material with 3 different bonding agents, or 2) 3 different GIs (with and without dentin conditioner).

The following null hypotheses were therefore proposed:

a) There is no bond strength between amalgam and RC at repair interface when using only bonding agent as adhesive medium.
b) There is no bond strength between amalgam and GI at repair interface.

Material and Methods

Test substrates were made by condensing amalgam (Dispersalloy) into copper bands, Θ 8mm height 10mm, and ground flat with sanding paper P #500 FEPA (Struer, Denmark)(Particle size 30.2 μm, corresponding to extra fine diamond burs). In the present study, three commonly used bonding systems were chosen; one 3 steps etch and rinse (ER) type; Optibond FL (OFL), one 2 steps "self-etch" (SE) bonding agent; Clearfil SE Bond (CSEB)and one 1 step SE, also called "Universal", bonding agent; Scotchbond Universal (SBU).

Three different glass-ionomers (GIs) were chosen as they might be a good alternative in not stress bearing areas. The chosen bonding materials were; GC Fuji II LC (with and without conditioner), GC Fuji IX (with and without conditioner) and Ketac Universal Applicap (no conditioner according to manufacturer's recommendation). Materials used are listed in Table 1.

Repair material of composite (Filtek Supreme XTE, shade A3) was mounted as cylindrical buttons on the ground amalgam surface, Θ 3mm, h: 2mm with the chosen bonding systems, bonded area equals 7.07 mm^2. Glass-Ionomer buttons were mounted both with and without conditioner as described above.

Handling of the bonding materials, composite and glass-ionomers was performed according to manufacturer's instructions. They were light cured with Kerr Demi Ultra, pulse, irradiation 900-1000 mW/cm^2. The specimens were made according to ISO/TR 11405 [ISO, 2003] for shear bond strength (SBS) testing, which was performed in an Instron universal testing machine (Lloyds, England). For this test the specimens were fixed in a specially designed jig and the force applied directly at the bonding interface parallel to this, at cross-head speed of 1mm/min. Maximum load at breakage is registered by the instruments. Three different test modes were used:

Mode 1. Short term test; the substrates had new buttons of RC/GI fixed and the specimens were SBS tested after 48 h in water storage (no TC was performed).

Mode 2. Water storage 60 days; the test specimens were SBS tested after 2 months at 37°C in water (no TC was performed).

Mode 3. Thermo-cycling (5000 x 5/55°C) (TC); after mounting the repair materials (RC/GI) the specimens were stored in water (14 days) before TC and SBS testing.

The amalgam-composite-repair-specimens (test specimen) were tested in 9 different groups (3 series x 3 modes) of 20 specimens each, see Table 2. The amalgam-GI-repair specimens were tested in 15 groups (5 series x 3 modes).

"The Norwegian Environment Authorities" granted import of mercury containing dental amalgam to Norway for use in this project (ref. 2016/97).

Statistics

The statistical analyses for calculating mean and variance were performed using the Statistical Package for the Social Sciences (SPSS, Inc. Chicago, IL, USA version 24). The probability of failure in the test specimens was assessed by means of a distribution plot, and the significance of the differences was evaluated by the Kolmogorov-Smirnov test [Press WP, 1986].

The level of significance was set at 5%.

Results

The SBS results for the bonding of RC to amalgam are given in Table 2 and Figure 1. The composite repair gave rather weak results, however the GI substrates could not be SBS-tested as they did not adhere to the amalgam surface at all. Therefore they are regarded as pre-test failures with the value = 0.

All the specimens were analyzed for fracture mode after breaking off the repair material by means of a light microscope (Wild Photomakroskop M400, Wild Heerbrugg AG, Switzerland). One hundred percent were of adhesive type. A few specimens exposed remnants of repair material in small pits and grooves (Figure 2).

Discussion

The results of this study show rather low values for adhesion between composite and amalgam. When repairing composite to composite in laboratory studies the reported test values are found to be much higher. Earlier tests in the same laboratory, with the same equipment and personnel [Staxrud and Dahl, 2011] showed values 3 to 4 times higher for short term tests of composite to composite than for amalgam to composite repair. When TC is performed the results for composite to composite are about ten times higher. A likely explanation for the higher values for composite repair is the possible re-silanating of filler particles in old composite and that there might be some functional monomers in the new composite to bond with resin in the old restoration after application of primer/adhesive. Laboratory tests are not *in vivo* experiments, but they can give an indication on how the materials will perform clinically [Peumans et al., 2005; Van Meerbeek et al., 2011]. The present results are initially rather low and will certainly attenuate by time.

Fracture mode was examined in stereo light microscope for all specimens and they were all of the adhesive type. On a few occasions some of the repair material got into grooves and porosities at the amalgam surface giving small spots of cohesive fractures (Fig. 2). This may explain some of the variance in the results and emphasise the importance of micro/macro-mechanical retention.

The Short Term mode (Mode 1) did not show any statistical significant difference between the bonding agents. Storage in water for 60 days before testing (Mode 2) gave similar results. After thermo-cycling (Mode 3) we could see a substantial drop in SBS values. An interesting finding in the present study is that the 3 step etch and rinse (3-step ER) (OFL), did not perform better than the other two when TC was performed. Rather, it looks like 2-step Self-Etch was the better alternative. One difference between the two self-etch bonding types and OFL is that the latter is bonded after etching the surface to be repaired as this is the manufacturer's advised procedure for "etch and rinse" bonding type. This may affect the results to some degree as it is well known that phosphoric ions in the acid may bind to cations at the surface blocking them for phosphoric compounds in the bonding agent thus preventing adhesion. However, as the number of specimens that disintegrated before testing is high for all groups in Mode 3 (Fig. 1), the results must be considered uncertain. As TC was omitted in Mode 1 and 2

the results were quite within the same range for 3 steps ER and 2 steps SE. This brings up the discussion around TC as aging method in studies like this where the materials are very different. The idea of ageing the bonding interface with TC might be more suitable for materials with similar thermal expansion coefficient than for two very different materials like resin composite and amalgam alloy. As amalgam tends to increase less by volume with increasing temperature than composite (this may vary considerably) [Anusavice et al., 2013], there will be a movement between the materials at the interface. These movements might physically tear off any newly formed bond/interlocking between adhesive and metal. Thermal expansion coefficients for amalgam and resin may differ as much as 3 times [Anusavice et al., 2013]. Thermal variation in the mouth does not fluctuate as much as the TC conditions although this phenomenon might be considered to a certain degree as hot and cold food and drinks pass the teeth. Hot drinks may have a temperature of 55°C, but it is unlikely that the tooth substance or restoration materials reach this temperature in 20 sec. The movement of food and drinks in the mouth along with the temperature controlling effects of saliva, tongue and mucosa, plays an important moderating role.

The idea of ageing amalgam was omitted, as amalgam does not take up water and the surface to be repaired is ground and rinsed for slurry, revealing a fresh surface of both new and old substrates.

The GI substrates disintegrated, or would not adhere at all, at the interface with amalgam. They de-bonded before any possibility of testing SBS, and should be regarded as pre-test failures with the value 0. A conclusion to be drawn is that GIs do not adhere to amalgam with any relevant force unless there is additional macro mechanical retention.

Aboush et al. found in 1989 and 1991 that Resin Modified Glass-Ionomers (RMGI) made relatively strong and reliable connections with amalgam [Aboush and Elderton, 1991; Aboush and Jenkins, 1989]. It was claimed that bond strength between amalgam and RMGI was comparable with strength to enamel and significantly higher than to dentine. They used micro tensile bond strength (μTBS) test method. Their figures in 1991 were from ca.4 MPa to ca. 9 MPa. In our study we could not find any reliable figures for the bonding strength between GIs and amalgam. This does not necessarily mean that the interface between amalgam and GIs is not tight. It is well known that the interface

between amalgam and dental hard tissue normally is tight due to corrosion products from amalgam filling up the gap, although there is no adhesion between dental hard tissue and amalgam. One might deduct from this knowledge that this corrosion phenomenon is at work between amalgam and GIs as well, and there is probably limited leakage between amalgams and GIs. Oxides present at the amalgam surface might form some bonds to GIs, but as it is recommended to prepare and roughen the surface for reasons of retention and clean surface, any possible oxides would most certainly be removed. The adhesion of GIs to teeth is mainly relying on chemical bonding to dentin and enamel and on possible undercuts the operator may prepare. According to these results null hypothesis *a)* have to be rejected, however null hypothesis *b)* cannot be rejected from current evidence.

As repair of minor to moderate defects of dental restorations or fractured parts of teeth is up-to- date dentistry and in accordance with the minimal-invasive philosophy [Blum et al., 2014; Hickel et al., 2013; Wilson et al., 2016], there is a need for knowing how to use the suitable materials. It seems to be very low bond strength between composites/GIs and amalgam compared to composite to composite bond strength when using simple, ordinary bonding procedures. The bonding is simply not reliable alone and should be regarded as inadequate. Fortunately the cavities or defects have other elements to which the bonding agents can bond e.g. enamel and dentine. Depending on the size and shape of the cavity/damage it should be recommended to create additional macro mechanical retention like dove tails and undercuts in the old restorations. Other procedures have been tested by other researchers like air abrasion and alloy primer, silica coating (providing oxides) and silane surface treatment, grooves and use of coarse burs would absolutely be favorable, and give bond strength improvements [Blum et al., 2012]. More complex bonding procedures with glass fiber reinforcement and metal primers could also be beneficial [Ozcan and Volpato, 2016].

The main reasons for restoration failure are still caries and fractures [Heintze and Rousson, 2012; Hickel and Manhart, 2001; Kopperud et al., 2012; Opdam et al., 2010, 2012; Opdam et al., 2014]. Cusp fractures restored with composite adjacent to old amalgam restorations seem to be good practice, likewise treatment of secondary caries at the margins of crowns or amalgam restorations with composite or GI. When taking into account the advantages and limitations of the bonding agents, the repaired

restorations are long lasting and may prolong the longevity of the existing restoration considerably [Demarco et al., 2012; Opdam et al., 2012].

Conclusions

Amalgam restorations of adequate standard and condition can very well be repaired with composite, but there should be provided for extra retention into the amalgam filling as the bond strength alone is not adequate. Glass-Ionomers may also be used for repair at amalgam restoration margins in not stress bearing areas, but they need enamel and dentine for retention and possible undercuts towards amalgam interface.

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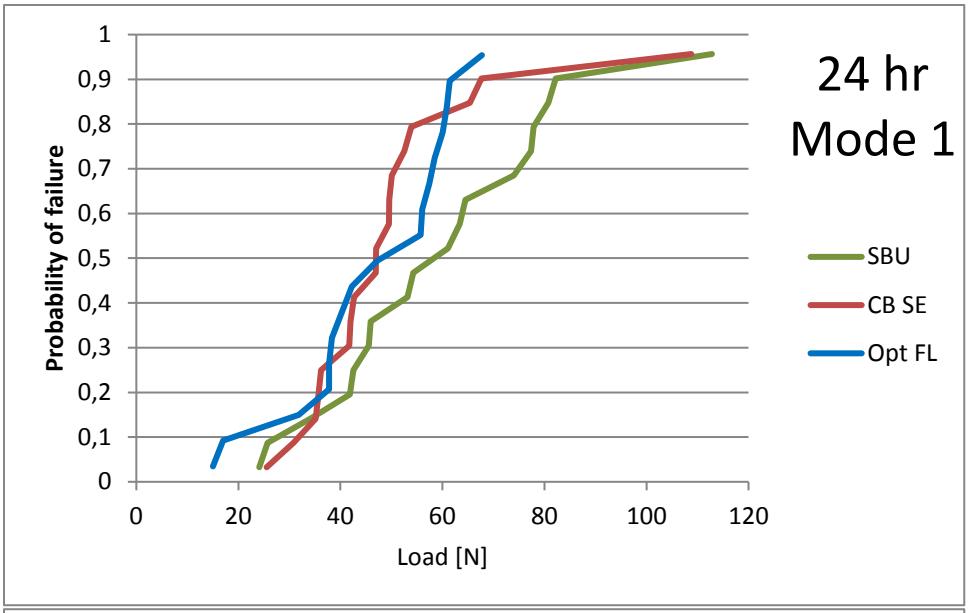
Table 1. Materials used

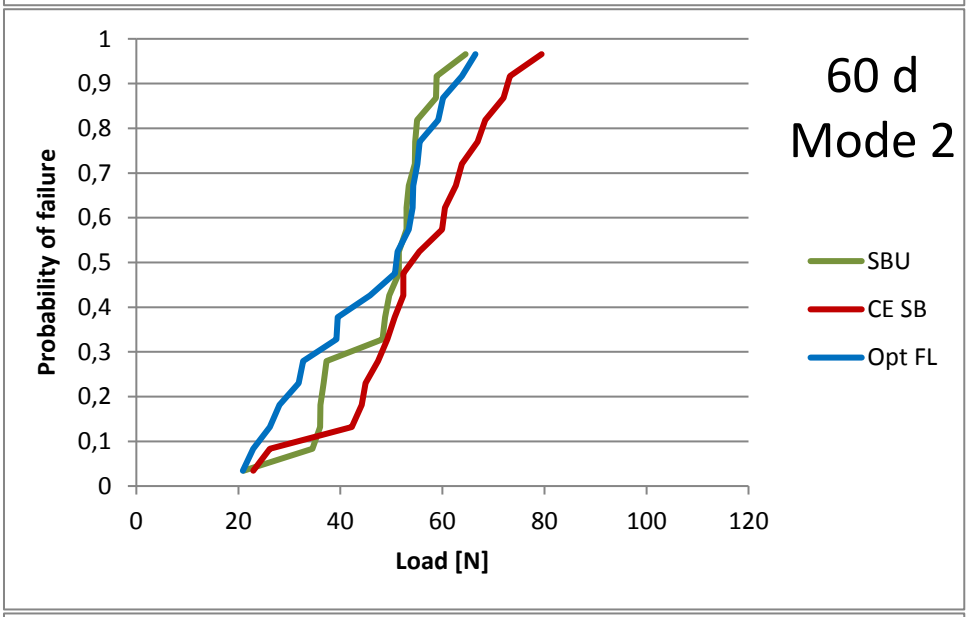
Material	Manufacturer	Bonding type	Lot
Amalgam			
Dispersalloy	Dentsply Caulk, DE, USA		160309
Composite			
Filtek Supreme XTE,	3M ESPE, MN, USA		N491979
Bonding agent			
Clearfil SE Bond (CSEB)	Kuraray Noritake, Japan	2 step SE	000200
Scotchbond Universal (SBU)	3M ESPE, Germany	1 step SE «Universal»	633337
Optibond FL (OFL)	Kerr Italia, Italy	3 step ER	5962575
Glass ionomer (GI)			
GC Fuji II LC	GC Corporation, Japan		160416A
GC Fuji IX	GC Corporation, Japan		160224A
Ketac Universal Aplicap	3M ESPE, Germany		614726
Conditioner			
GC Dentin conditioner	GC Corporation, Japan		1602041

Table 2. SBS test results.

Material fixed to amalgam	Bonding agent	SBS(SD)
Composite repair:		
Mode 1; Short term		**MPa**
Filtek Supreme XTE	Clearfil SE Bond	**6.9 (±2.6)**
	Scotchond Universal	**8.3 (±3.2)**
	Optibond FL	**6.5 (±2.2)**
Mode 2; 60 days in water		
Filtek Supreme XTE	Clearfil SE Bond	**7.7 (±2.0)**
	Scotchond Universal	**6.8 (±1.5)**
	Optibond FL	**6.4 (±2.0)**
Mode 3; TC 5000,5/55°C:		
Filtek Supreme XTE	Clearfil SE Bond	**2.2 (±2.1)**
	Scotchond Universal	**1.6 (±1.5)**
	Optibond FL	**0.6 (±0.9)**
Glass-ionomer (GC) repair:		
All three ageing modes		
GC Fuji IX	Conditioner	**0**
	No conditioner	**0**
GC Fuji II LC	Conditioner	**0**
	No conditioner	**0**
Ketac universal	No conditioner	**0**

N=20 for all groups. Ketac Universal does not need conditioner according to manufacturer. Glass Ionomers would not adhere to amalgam in any of the modes. Thermo-cycling seems to be devastating to the interface bond strength when combining two materials with very different thermal expansion coefficient.


24 hr
Mode 1
Probability of failure
Load [N]
SBU
CB SE
Opt FL


60 d
Mode 2
Probability of failure
Load [N]
SBU
CE SB
Opt FL

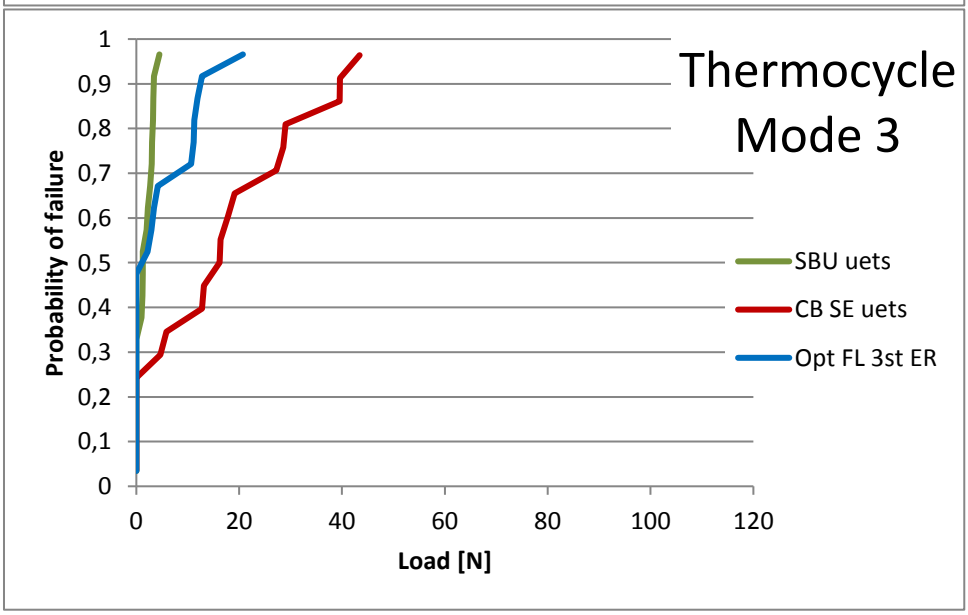
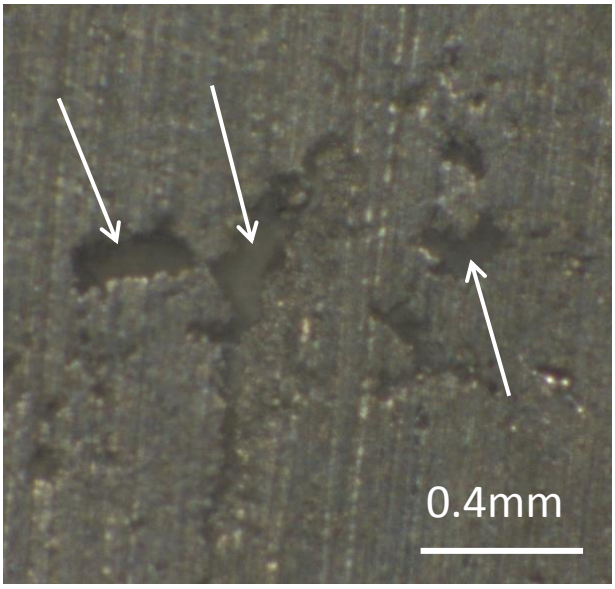
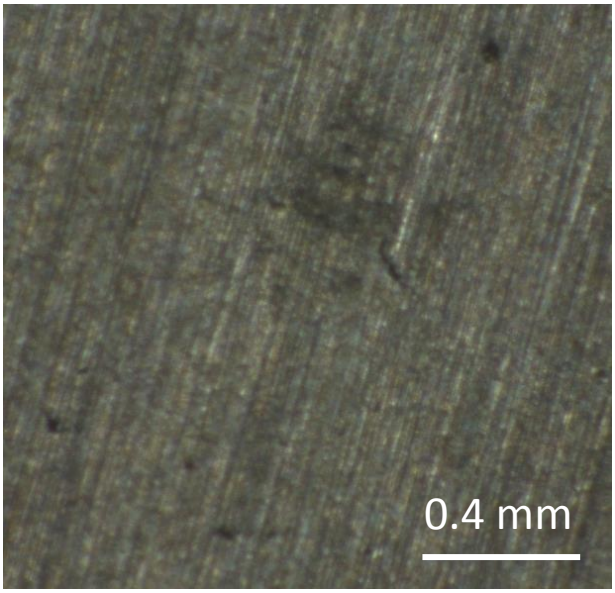

Thermocycle
Mode 3
Probability of failure
Load [N]
SBU uets
CB SE uets
Opt FL 3st ER

Fig. 1. Distribution plot of the results of the SBS tests of composite in a vertical set up for ease of comparison between the modes.

There is no statistical significant difference between the results in Mode 1 and Mode 2, $p<0.05$. Mode 3 (TC) gave statistically significant different results (lower) than Mode 1 and 2. Within Mode 3 Optibond FL and Scotchbond Universal gave statistically significant lower results compared with the other bonding agent. CSEB=Clearfil SE Bond, SBU=Scotchbond Universal, OFL=Optibond FL.



a)



b)

Fig 2. a) Remnants of composite in defects, pits and grooves teared off cohesively (arrows), but no composite on the ground surface as in b) where the composite has been detached adhesively from the amalgam.