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Influence of misfit on the occurrence of veneering porcelain fractures \(\text{(chipping)}\) in implant-supported metal-ceramic fixed dental prostheses: an \textit{in vitro} pilot trial

Restoring missing teeth with the aid of dental implants has become a predictable treatment option offering several advantages. Implant-supported restorations help improve masticatory function, esthetics, and overall quality of life \cite{Yao2014}. Satisfaction after treatment with dental implants appears to be evident in a number of studies \cite{Yao2014}. Long-term follow-up studies show excellent survival of both the supporting implants and the suprastructures \cite{Pjetursson2014}.

Despite excellent survival rates and continuous improvements, implant treatment is not completely free of problems \cite{Pjetursson2014}. Technical and biological complications in implant-supported fixed dental prostheses (FDPs) are more than twice as common compared to tooth-supported FDPs, 38.7\% compared to 15.7\% after 5 years \cite{Pjetursson2007}. Although the overall cost-effectiveness of dental implant treatment has been found to be sound and comparable to that of conventional tooth-supported restorations, a review concluded that the differences in complication rate will likely have implications for long-term costs \cite{Vogel2013}. Reducing complications will be beneficial from the point of view of patients and caregivers as well as society in general.

The most frequent technical complications are fractures of the veneer material, abutment or screw loosening, and loss of retention \cite{Pjetursson2007}. Fractures of the veneering porcelain were three times as common in the implant-supported group. Fractures appear at a rate of 13.5\% for small-span implant-supported FDPs after 5 years and have been reported to reach 33.3\% and 66.6\% for full-arch implant-supported FDPs.
At 5 and 10 years, respectively [Papaspynidakos et al. 2012; Pjetursson et al. 2012]. The reported rate of chipping is even higher when the substructure is ceramic [Larsson & Wennemer 2014; Le et al. 2015; Pjetursson et al. 2015; Sailer et al. 2015].

The cause of veneer fractures is not entirely clear and is probably multifactorial [Pang et al. 2015]. Inappropriate thickness of veneering porcelain and/or poor design with unsupported porcelain as a result has been suggested. Residual stresses may originate from differences in thermal expansion coefficients between veneer and framework as well as from inappropriate cooling rates. Clinical factors such as occlusal forces, wear, and microcracks from cyclic sliding contacts during chewing have also been discussed [Rekow et al. 2011; Pang et al. 2015]. Such factors, however, could not sufficiently account for the differences in frequency observed between natural teeth and implant-supported FDPs. The lack of periodontal proprioception is often hypothesized as the main reason for this difference [Brägger et al. 2001]. Yet, the impact of misfit of the reconstruction is poorly understood. Natural teeth can soon "neutralize" misfit of an FDP through orthodontic movement and adjustment to the occluding forces [Poyser et al. 2005] but not the ancyloitic implants.

Misfit between a restoration and the implant/abutment is not uncommon [Abduo et al. 2011]. Teeth and implants differ in many ways, and one of the most important is that the implant is in direct, rigid contact with alveolar bone, whereas the tooth is supported by periodontium [Lindhe et al. 2008a]. This gives the tooth the ability to migrate in response to applied force, for example, adjusting to an ill-fitting framework [Cho & Chee 1992; Garcia & Oesterle 1998; Sahin & Cehreli 2001]. As the implant lacks this ability [Lindhe et al. 2008b], any misfit will result in stresses within the implant-reconstruction complex [Watanabe et al. 2000; Sahin & Cehreli 2001; Karl et al. 2004; Abduo et al. 2010]. Ceramics are brittle materials and ill-equipped to tolerate tensile forces [Anusavice 2012]. If misfit occurs and leads to tensile forces within the restoration, it is likely that the veneering porcelain will act as the weak link and fracture. This factor may influence the occurrence of veneer fractures, and there seems to be no difference between cement and screw-retained implant FDP [Sailer et al. 2015]. There are, however, few studies available that examine the possible effect of misfit on risk of veneer fractures.

### Aim

The aim of this study was to investigate whether misfit between a restoration and the supporting implant may affect the risk of veneer fractures in screw-retained implant-supported metal-ceramic FDPs.

The hypothesis was that misfit would increase the risk of veneering porcelain fractures in metal-ceramic implant-supported FDPs.

### Materials and Methods

Twenty-five unit implant-supported metal-ceramic FDPs were manufactured, all with the same simplified design and geometry. The FDPs were screw-retained on implant level [Nobel Bränemark System RP, Göteborg, Sweden].

A mastermodel with implant analogs was set up in plaster (Vel-Mix Stone, Kerr Nordic, Tranås, Sweden) at standardised distance for a five-unit FDP with premolar-sized teeth was made. The implants were placed to act as two anterior end abutments and one posterior end abutment with two pontics in-between. A simplified framework design was then built up on the mastermodel using a resin material [Dura-Lay, Reliance Dental MFG Co, Worth, IL, USA] and wax-up sleeves [Nobel Biocare AB, Göteborg, Sweden]. The design was scanned in a NobelProcera 2G scanner (Nobel Biocare AB), and 20 identical milled titanium frameworks [NobelProcera Implant Bridge Titanium, Nobel Biocare AB] were ordered. To achieve a reproducible, uniform veneering porcelain layer, a two-piece putty mold (Provil Novo Putty, Heraeus Kulzer GmbH, Hanau, Germany) was constructed to guide the dental technician. The veneering porcelain [GC Initial Ti, GC Europe, Leuven, Belgium] was built up in five layers: one bonder, two opaquer layers, and two dentine layers according to the manufacturer’s instruction and fired under vacuum in a ceramic furnace [Ivoclar Programat P500; Ivoclar Vivadent AG, Schaan, Liechtenstein]. The same dental technician performed all steps in the process and produced all FDPs. No in vitro study could be found with adequate relevance to provide data for a power calculation, given the fact that the settings and design of this study are rather unique [prosthesis design, implant distribution, and microgap size], as well as the studied outcome [microcracks, chipping]. Nevertheless, extrapolating from Pjetursson et al. 2012, we assumed that an approximate incidence of veneer fractures in similar FDPs for a clinical load period corresponding to 2 million cycles is around 10%. Assuming that an incidence of 45% in the test group [misfit] would constitute a clinically important difference, the necessary sample size of the test group was calculated to be 8 (alpha 0.05, beta 0.2, power 0.8).

After construction, the FDPs were randomized into two groups, one test group and one control group [Fig. 1]. To achieve a completely passive fit between implant and FDP in the control group, implant dummies [Nobel Bränemark System Groovy Mk III RP 3.75 × 13 mm, Nobel Biocare AB] were first fixed to the FDPs with original abutment screws [Abutment Screw Bränemark System RP, Nobel Biocare AB] using hand force. The implant dummies were then fixed in pre-drilled PMMA [Plexilite Plastprodukter AB, Malmo, Sweden] blocks with epoxy [EpoFix, Struers, Copenhagen, Denmark] and left to cure for 24 h. The same procedure was repeated in the test group with the exception that spacers cut from a 150-μm steel sheet were placed between the FDPs and implant analogs at position 5 [Fig. 2]. After curing, all FDPs were dismounted and inspected. In the test group, the spacers were removed and the misfits created at position 5 were controlled to be 150 ± 5 μm by visual inspection [Fig. 3] in light microscopy [Wild M3, Wild Heerbrugg, Switzerland]. All FDPs were then remounted to the models with a torque of 35
Ncm using a manual torque wrench (Manual Torque Wrench Prosthetic, Nobel Biocare AB). Sheffield test approach was followed (Jemt 1991). The cast framework was carefully seated on the implants by first tightening down completely the terminal gold screw on the opposite side of the misfit (positions 1, 2). A poor fit was revealed as a gap opening between the framework and the terminal implant on the other side (position 5). Screw access holes were closed with silicon string (Kuntze & Co AB, Hägersten, Sweden) and dental restorative composite (Tetric Evo-Ceram, Ivoclar Vivadent AG, Schaan, Liechtenstein). The same operator performed all steps in the process. Standardized digital periapical radiograph with optimal parallelity was taken before and after tightening of the position 5 abutment screw (Fig. 4a, b). The images were analyzed with ImageJ (National Institute of Health, USA) to investigate possible framework distortion. Measurements were conducted after calibrating the images with the known length in mm of the implant shoulder. A straight line was drawn from the shoulder of the implant in position 5 and a parallel line passing from the most apical point of the bridge pontic in position 4 for both radiographs. The distance between the two lines was measured before [a] and after [b] the complete seating of the bridge (Fig. 5a, b).

Both FDP groups were then subjected to a cyclic loading test of 30–300 N at 2 Hz for 100,000 cycles in a cyclic loading machine (MTI Engineering AB, Lund/Pamaco AB, Malmö, Sweden). The load was applied by a 2.5-mm stainless steel ball in the middle of the occlusal surface at position 3. A thin plastic foil was placed between the indenter and the restoration surface (PE-Baufolie, Pro-Bau, Mannheim, Germany). The FDPs were mounted at a 10° angle to the force direction and were covered by water during loading (Fig. 6). To record visible veneer cracks and chip-off fractures, all FDPs were controlled with the aid of a LED white light source (Ronvig Dental Mfg, Daugaard, Denmark) at five occasions: before loading and after 10, 10,000, 50,000, and finally after 100,000 cycles. FDPs that presented chip-off fractures at any occasion were excluded from further testing. Fixed dental prostheses that presented with cracks were kept in testing to check for further crack propagation and/or chipping. Composite plugs were removed after completion of cyclic loading, and all screws were controlled for loosening by retorque with a retorque meter (Tohnichi digital torque gauge model BTGE-G, Tohnichi MFG Co, Tokyo, Japan). The same operator performed all registrations during the process.

Statistical analysis
The difference between test and control group regarding occurrence of visible cracks and chip-off fractures at the different intervals was analyzed by Fisher’s exact probability test. The difference between test and control group regarding retorque value was analyzed by independent groups t-test of the means at the different positions. Calculations were made in collaboration with a statistician. The SPSS software (SPSS 18.0; SPSS Inc, Chicago, IL, USA) was used to perform calculations. Differences were considered statistically significant at $P < 0.05$.

Results
No immediate cracks or chip-off fractures occurred at the start of cyclic load and the 10-cycle check. Visible cracks within the porcelain veneer occurred significantly more often in the test group compared to the control group: at 10,000 ($P < 0.033$), 50,000 ($P < 0.003$), and 100,000 ($P < 0.001$) cycles. After 100,000 cycles of loading, nine of ten FDPs in the test group presented with visible cracks, compared to one of ten in the control group. [Figs 7 and 8]. The location of the cracks differed between test and control group. Although most cracks
occurred between implant position 2 and the pontic, cracks in the test group were also found in various other positions (Fig. 9a,b). In one of the test bridges, two cracks occurred in positions 1 and 5.

Three chip-off fractures were recorded in the test group, none in the control group. (Fig. 10) This difference was not statistically significant. One fracture occurred at 50,000 cycles. This FDP was excluded from further testing.

The difference in mean retorque value was greatest at the position of introduced misfit, position 5. No statistically significant differences were, however, found neither between the groups nor between positions. Mean values, calculated on the nine FDPs that underwent 100,000 load cycles, were as follows: position 1: 27.11 Ncm (test) and 26.44 Ncm (control); position 2: 24.71 Ncm (test) and 25.22 Ncm (control); position 5: 24.00 Ncm (test) and 25.77 Ncm (control) (Fig. 11).

The measurements on the radiographs confirmed the bending of the framework with (a) being 3.40 mm while (b) was 3.29 mm. Microscope photograph of the implant in being 3.40 mm while (b) was 3.29 mm. Microscope photograph of the implant in (Fig. 12).

Discussion

The results from the present study suggest that misfit between a restoration and the supporting implant significantly affects the occurrence of fractures of the porcelain veneer. The most likely explanation is the fact that implant framework misfit alters the biomechanical situation (Abduo & Judge 2014). The rigid connection of the implants to the bone means that stress is transferred to the implant components and/or built up within the frameworks (Abduo & Judge 2014). It is likely that compressive as well as tensile stress develops. For metal-ceramic FDPs, areas where tensile stress is concentrated are potential crack-initiation sites and prone to fracture, as ceramics are ill-equipped to tolerate tensile forces (Anusavice 2012).

Implant-supported restorations rarely exhibit perfect passive fit (Abduo et al. 2011). When producing an implant-supported FDP, there are numerous steps where the fit can be affected: from the impression to final production and adjustment, and it is well known that a certain amount of misfit is unavoidable, irrespective of production technique. (Abduo et al. 2011). The potential influence of misfit on technical complications such as veneer fractures should therefore not be overlooked.

Several authors have discussed the levels of misfit and attempted to define passive fit or an acceptable level of fit (Bränemark 1983; Jemt 1991; Sahin & Cehreli 2001; Karl et al. 2004; Abduo et al. 2010). One suggestion has been to define any distance between abutment and FDP as misfit. A distance ranging from 10 μm up to 150 μm has been discussed, while other authors define passive fit as no space between abutment and FDP (Bränemark 1983; Jemt 1991; Watanabe et al. 2000). Another definition of passive fit is no tension within the framework, after delivery (Sahin & Cehreli 2001). However, all proposed definitions are hypothetical (Abduo et al. 2010). In the present study, misfit was set as a distance of 150 μm between implant and FDP. This is in the higher range of what is discussed in the studies mentioned above, and stress increases with increasing misfit (Abduo et al. 2010). It is, however, evident from clinical reports that misfit of this magnitude exists (Jokstad & Shokati 2015). It has also been proven in laboratory studies that discrepancies of up to 500 μm will disappear after screw tightening (Clelland et al. 1995). In the present study, it was possible to close the 150-μm gap by tightening the bridge screws purely by hand before using the torque wrench. This finding is in accordance with another study that demonstrated that misfits could be closed by tightening prosthetic screws to 10 Ncm (Clelland et al. 1995).

The implant placement and distribution were adapted to clinical situations. It may be preferable to distribute the load of the restoration on more than two implants when making a five-unit FDP. It is not uncommon to find anatomical limitations in the posterior parts of the jaws – therefore, two anterior implants were placed and one posterior. To place the misfit at the distal abutment in the test group could be said to represent a “worst case scenario,” whereas the control group represents the ideal situation. In vitro studies have shown the distal abutment to be the area of the maximum distortion in implant-supported FDPs (Mitha et al. 2009). It is possible that a centrally placed misfit might not have created deflection and tensile stress of a similar extent. The clinical situation may present misfit at any position. Future studies
should include alternative designs of the subgroups. The localization of cracks differed between test and control groups where cracks in the test group occurred in various places. This is not easy to interpret, but is likely attributed to the misfit causing a shift from linear stress distribution to more complex stress patterns [Glantz et al. 1984]. The present study was not meant to tackle the issue of stress distribution. Future studies, for example, finite element analysis, could enhance our understanding.

The consequences of stress are exacerbated by dynamic loading [Sahin & Cehreli 2001]. The present study therefore chose to load the FDPs cyclically. A thin plastic foil was used between indenter and FDP to ensure even distribution of load on the surface of the restoration [Kelly 1999]. No thermocycling was performed. It is often used when evaluating effects on the cement and risk of loss of retention, whereas this study evaluated screw-retained restorations [Gale & Darvell 1999]. It may, however, also affect fracture resistance of ceramic FDPs in vitro, at least at temperatures of 50°C [Rosentritt et al. 2006]. No concrete evidence that failures in clinical practice occur because of thermal stresses exists though [Gale & Darvell 1999]. Water was, however, present during cyclic load as it is considered to aggravate stress corrosion and lead to strength degradation [Jung et al. 2000].

The choice of 30- to 300-N loads is within what has previously been used for in vitro tests [Rosentritt et al. 2008]. In vivo mean masticatory forces generally range between 20 and 70 N, and a 50- to 200-N test load has been established to create cracking and fracture of porcelain veneer [Rosentritt et al. 2008] (Jung et al. 2000). One Lakh cycles were performed. There is no consensus on what number of cycles is adequate. One regularly cited study claims that as much as 800,000 chewing cycles may be performed per year [Rosentritt et al. 2006]. If this estimate is true, it would mean that 100,000 cycles are the equivalent of a couple of months of chewing. The authors did, however, not perform any measurements; instead, a provisory survey was made among dental students and assistants. The validity and reliability of those results may be unreliable.
Another study found significant degradation of porcelain to occur already at 10,000 cycles (Jung et al. 2000).

In the present study, the differences concerning the occurrence of cracks within the veneer were clearly significant already after 50,000 cycles. This is in accordance with a statement that ceramic failure is predicted to occur mostly within the first days after insertion and should therefore be able to be detected at early stages of cyclic loading (Kelly 1999). It cannot, however, be ruled out that the prevalence of fractures within the veneer might differ with increasing number of cycles, as a fracture in the control group only occurred at the end of the test. Future studies should increase the number of cycles performed. There were no significant differences in retorque values of the abutment screws. Other investigators have shown that misfit significantly decreases the loosening torque values of implant FDP prosthetic screws after cyclic loading of 1,000,000 cycles (Farina et al. 2012). It might be possible that the abutment screws would have loosened in the present study if cyclic load had been continued beyond 100,000 cycles.

Differences between the groups are unlikely to be attributed to the veneering technique. All feasible efforts to standardization of the manufacturing process have been taken. The restorations were standardized and produced in the same way throughout, by one and the same dental technician. The technique has been previously used and displays predictable results (Mahmood et al. 2016). It is anticipated that randomization would eliminate any risks from any inevitable diversity. Further studies with slicing of the reconstructions and/or micro-CT analysis might be helpful to reveal further cracks and indicate the patterns of stress/strain induced.

The present study is a pilot trial comprising relatively few FDPs. The number of specimens might also influence whether differences noted reach statistical significance or not – as, for example, concerning the occurrence of chip-off fractures which differed numerically between groups. Further studies are necessary and should include an increased number of specimens.

As technical complications are more common in implant-supported than tooth-supported restorations, it is of great interest to evaluate possible factors behind complications in order to gain knowledge and understanding on how to prevent complications. Future studies should also include and compare different materials. Less stiff materials, such as titanium used in the present study, or high-noble alloys, exhibit less stress within the frameworks compared to stiffer framework materials, such as cobalt–chromium and zirconia (Abduo et al. 2012). On the other hand, stiffer frameworks cause less stress within the ceramic veneer.

From a clinical point of view, one might wonder if a misfit of 150 μm would be detectable in clinical settings in a similar reconstruction. After seating of the reconstruction with 35 Ncm, the gap appears to close, so clinical detection through, for example, probing appears impossible. Nevertheless, in the in vitro setting, an optimally parallel periapical radiograph (Fig. 8) indicates the presence of the misfit. Whether such an optimalparallelity and contrast, however, are likely to be achieved in clinical settings is questionable.

The present study used titanium as framework material. The occurrence of veneer fractures has been reported to be higher on titanium than high-noble alloys but more limited than for zirconia frameworks (Jemt et al. 2003) (Pjetursson et al. 2015). The choice of titanium was made as it is more commonly used today compared to high-noble alloys due to cost, biocompatibility, and modern manufacturing techniques. Future studies should, however, include and compare different materials for the reasons discussed above.

Conclusion

Within the limitations of this in vitro study, it is suggested that misfit between a restoration and the supporting implant may increase the risk of cracking and/or chipping of the veneering porcelain for metal-ceramic FDPs. Further studies are required to investigate possible outcomes for different levels of misfit, increased periods of cyclic load, and different materials.

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Conflict of interest

The authors declare no conflict of interest.

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