Fatigue Testing of Implant Supported Bridge. A Study of All-on-two Concept

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ABSTRACT

The conventional implant therapy of patients with edentulous mandibles involves installation of four implants. The treatment is well-studied with high success rate. By reducing number of implants, biological and cost benefits could be made.

The aim of the study was to test the mechanical aspects and fatigue resistance of a fixed bridge retained on two implants. The working hypothesis was that the construction would manage mechanical fatigue testing equal to 10 years of intraoral use.

A machine to simulate chewing cycles was constructed by two engineering students. The bridge was attached to an aluminium block with two implants. The loading force was 177 N and applied 7 mm posterior from the central point of the right implant.

The test came to a halt after 40 minutes because of motor failure which corresponds to 37.2 hr of intraoral use. A new machine made by a professional mechanic is required to redo the test.

The height of the most distal points of the bridge on both sides were reduced by 0.3 mm and the most anterior point was increased by 0.2 mm. No plastic deformation of implant heads or change in abutment screw insertion torque was observed. The pressure on the distal cantilever caused deflection of the bridge which could have caused the differences in measurement.

In conclusion, a complete bridge retained on two implants cannot stand mechanical pressure of 177 N on such a long cantilever although longer testing time corresponding to at least 10 years of intraoral use is required.
INTRODUCTION

For a long time, people have tried to replace lost teeth in different ways. With the development of science and medicine, compensation for missing teeth with dental implants has been made possible. Several different methods and theories developed in parallel. Some of the first dental implants made of titanium were installed in 1965 in a patient with an edentulous mandible (Adell et al., 1981). Since then the development of implant treatment, different methods, models and theories have been improved.

The conventional treatment of edentulous jaws with implant-supported fixed prosthesis is based on installation of four to six implants in the mandible or in the maxilla. The treatment is widely used and the success rate over 10 years is 95.9 % in mandible and 95 % in maxilla (Heydecke et al., 2012). Because of the high success rate, it is considered a standard procedure to install four to six implants in edentulous jaws.

Implant treatment of edentulous jaws is beneficial for patients that do not want or cannot have complete removable dentures. But, like most treatments, this treatment entails risks and complications. The most common biological complications are: Peri-implant inflammation, peri-implant soft tissue proliferation and peri-implant bone resorption (Zhang et al., 2016). The most common mechanical complications are veneer fractures and abutment screw fractures. Decementation, screw loosening and implant fracture also occur (Romeo et al., 2012).

Peri-implantitis is a serious problem for patients that are treated with dental implants. A strongly contributing cause is believed to be bacterial plaque that accumulates around the implant, inducing bone inflammation and resorption (Larsen et al., 2017). Optimal oral hygiene is the recommended solution to avoid the disease. It is easier to optimize hygiene around two implants than around four, thus a reduction of the number of implants used can decrease the prevalence of peri-implantitis and discomfort for patients (The National Board of Health and Welfare, 2017).

Dental implant therapy is expensive and causes high costs for both patients and society. The cost for a single-tooth replacement with a dental implant is comparable with that of a conventional fixed bridge. When calculating the cost for prosthetic treatment in the
edentulous mandible, the conventional removable complete denture is less expensive than an implant supported overdenture. But, when studying the cost of the treatment over a longer period, the implant supported overdenture becomes cost-effective. Even though the cost is initially high for implant supported overdentures, the therapy is preferred among elderly patients (Vogel et al., 2013). By reducing the price with installing two implants instead for four, the therapy can also be available for more patients.

There are several advantages with installation of two implants instead of four. Biological complications should become less severe. It should also be technically simplified to design the bridge. The cost for the society, as well as for patient, would be reduced, which in turn should lead to more patients choosing implant treatment instead of removable dentures.

A five-year follow-up randomized clinical trial (RCT) was made on fixed complete bridge supported on two implants. The results showed that the therapy was successful without causing implant fractures. Further follow-up study over 10 years and more investigations on this subject are needed to observe effects on the implants over a longer time span (Cannizzaro et al., 2016).

Installing a bridge on two implants rather than four will increase the stress on the implant-bridge screw-joints, but also increase the tension on the cantilever distally depending on how far the cantilever is extended. Previous studies show that mechanical complications occur with fractures in the veneer and abutment screws. However, the complication risk is not higher when using a cantilever (Romeo et al., 2012).

The aim of the current trial is to study all-on-two concept in vitro by using a modified machine that simulates the load transfer during chewing. Our working hypothesis is that a complete fixed bridge supported on two implants can withstand mechanical loading equal to 10 years of intraoral usage without breaking or showing signs of plastic deformation of the components.

A similar trial with the same hypothesis was attempted in 2012 (Andersson-Gran and Jensen, 2012). However, the machine (Asplund, 2012) used in the previous study was not calibrated for forces exerted in humans and was later modified (Forsell, 2017) and
calibrated for more realistic intraoral conditions with regard to chewing forces in the present trial.

MATERIAL AND METHODS

A machine for simulating chewing process was made by a student at the Department of Applied Physics and Electronics at Umeå University (Asplund, 2012). The machine was used later by two dental students to test an implant fixed complete bridge supported on two implants. The experiment was already stopped after 57 sec due to implant failure (Andersson-Gran and Jensen, 2012).

The machine was later modified by another student (Forsell, 2017) at the Department of Applied Physics and Electronics at Umeå University (Figure 1). It was adjusted to mimic oral mastication conditions with a pulsating force. The force with which the cantilever was loaded was recalculated. The number of chewing cycles during the day was set to 2000 (Miyamoto et al., 1996). The machine had a frequency of 89 cycles/minute. The test was planned to be conducted over a span of 8 weeks which equals to 10 years of chewing in real life. A pneumatic controlled cylinder was installed with a fixed maximal force instead of a spring. This would lead to better controlled pressure on the cantilever.

An aluminium block 127X39X41 mm was used where two standard implants (Straumann Institut, Straumann AG, Basel, Switzerland) with a diameter of 4.1 mm were installed with an inner distance of 30.9 mm. The measurements are based on a gypsum model made from a real patient-case. The same measurements in a similar set-up were used during testing in 2012 (Andersson-Gran and Jensen, 2012).

A fixed full-arch bridge framework made of titanium alloy with measurements of 5.8 mm wide and 5.4 mm high (Umeå Dentallaboratorium, Umeå, Sweden) was used which was based on the design of the bridge in a patient-case. The bridge was fastened with abutment screws with a torque of 35 Ncm to the two implants (Figure 2).

Chewing forces are distributed unevenly in the dental arch depending on which teeth are involved in the occlusion. The maximal bite-force was reported to 39 kg (382 N) in males.
and 22 kg (216 N) in females, in the molar region (Helkimo et al., 1977). In the experiment, a force of 18 kg (177 N) was applied during testing. This level of force (35\% - 40\% of maximum mean levels for women and men) was thought to be representative of normal chewing and to be more realistic than in the previous trial (Andersson-Gran and Jensen, 2012).

The loading point on the bridge framework was 7 mm distal from the central point of the implant, which simulated the point where the molar region is in normal dental arch in a patient.

Before the start of the test, the machine was calibrated with a scale to reach the needed force for testing.

The requirement specification of the machine:
- The machine loaded the bridge with a pulsating force of 177 N.
- The force was limited to 177 N with a pressure valve.
- The machine had a cycle speed of 89 cycles/minute.
- The test had to continue for 8 weeks to simulate 10 years of intraoral use.

The machine was controlled continually during the test to make sure everything was running accordingly. It was planned to be stopped every day to control the mechanical components of implants and bridge.

The following measurements were made prior to testing to control any mechanical differences after the test:
- Bridge width 53.2 mm.
- Height from aluminium block right side 11.0 mm.
- Height from aluminium block left side 10.5 mm.
- Height from aluminium block in the middle 12.6 mm.
- Inner distance between implants 30.9 mm.
- Right implant head 4.8X4.8 mm.
- Left implant head 4.8X4.8 mm.
Literature search

PubMed database was used to search the relevant literature with the following MESH-terms, key-words and combinations of them: osseointegration, implant, technical complications, biological complications, all-on-2, all-on-two, all-on-three, all-on-four, dental implant, edentulous jaw, cost effectiveness, bite force, peri-implantitis, dental biofilm, primary stability, finite element analysis, finite element method, ethics, Brånemark, implant cantilever, Cannizarro, mandibular implants, fixed prostheses, optimal implant number, muscle measurements, torque stability, abutment screw. 3004 papers were identified. To minimize the quantity of the papers, depending on the number of the papers found using MESH-terms and key-words, such filters as Reviews, Systematic Reviews and 5 years were used which led to 225 scientific papers. After reading the title, the abstract and the text, 18 relevant papers were chosen. RCTs, reviews and systematic reviews were prioritized. In addition to PubMed database search, manual search on the Internet and of reference list and authors known in the relevant field of study was performed which resulted in additional four more papers. Furthermore, three studies previously written at Umeå University, Sweden, that were relevant to our study, were included. The total number of references in this study is 25 (Figure 3).

Ethical considerations

The Ethics Forum at the Department of Odontology found that appropriate ethics considerations have been integrated into this degree project. In the application for ethical approval, a bridge from a current patient-case was scheduled for testing. However, due to unforeseen circumstances the patient had to abort participation in the study due to severe illness. Instead, the bridge from a previous study was used for testing the mechanical properties of the principles of such a construction (Andersson-Gran and Jensen, 2012). No contact with patients or animals were made during this study.
RESULTS

The implants and the bridge were tested during 40 minutes, i.e. 3560 cycles, which corresponds to 37.2 hr of intraoral use. The electric motor of the machine failed during testing due to overheating. The test was stopped.

During the test a deflection of the bridge was seen.

The dimensions of the bridge and the implants were measured in the beginning and in the end of the test. There were measurable differences in bridge height before and after the test (Table 1):

- Height of the bridge over the aluminium block on the rightmost side decreased from 11.0 mm to 10.7 mm and on the leftmost side from 10.5 mm to 10.2 mm.
- Height of the bridge over the aluminium block in the middle increased from 12.6 mm to 12.8 mm.

The dimensions of the implant heads were unchanged.

The insertion torque force of abutment screws was unchanged.

DISCUSSION

The aim of the study was to test the mechanical aspects and fatigue resistance of a fixed bridge retained on two implants. The conventional therapy with a fixed complete bridge of an edentulous mandible often involves installation of four implants. It has high success rate but can lead to prosthetic and biological complications (Soto-Penaloza et al., 2017).

The all-on-two concept in edentulous jaws is not well studied or reported in the literature. Patients who do not have adequate bone volume, or economy for the conventional all-on-four therapy might not have any more options other than complete removable dentures. Thus, to make this therapy possible for a bigger patient stock, it's interesting to explore the concept further. There are potential advantages with a fixed complete bridge on only two implants in edentulous jaws. The risk for biological complications and the therapy cost could be reduced just to name a few.
Considering the sparse information on the all-on-two concept in the literature, and the extreme loading conditions that may occur in such prostheses this study was conducted to explore the mechanical aspects of such therapy. A previous study on all-on-three concept showed a 100% success rate in treatment in both edentulous maxilla and mandible (Oliva et al., 2012).

The number of chewing cycles during a day in a healthy individual varies between 1938 and 2356 (Miyamoto et al., 1996). In this study, the number of chewing cycles were limited to 2000 per day, which is close to a mean value of reported minimum and maximum cycles and considered relevant to the aim in this study.

The experiment lasted 40 min, which corresponds to 37.2 hr of intraoral use. The plan was to test the implants for an experimental period equalling to 10 years of intraoral use which would make it possible to collect enough data after the test to determine whether a fixed full-arch bridge on only two implants is possible. However, because of engine failure and limited time-frame for the trial, a considerably shorter testing time had to be accepted.

The point of loading was decided to be 7 mm distal to the most central point of the right implant which corresponds to the molar region. Previous results have showed that the maximal bite force can be accomplished in the molar region (Helkimo et al., 1977), but also that the maximal bite force is tied to the number of teeth in occlusion, amount periodontal support, type of prosthesis, age and many factors which makes it more complex to determine maximal bite force in a dentition with implants (Duygu et al., 2010).

During testing the bridge deflected with each loading cycle. The point of rotation was in line between the implants. This could have been the cause of the difference in height of the bridge above the aluminium block.

The site of bending could have been between the aluminium block and the implant but it was most likely between the implant and abutment screw. The abutment screw-joint could have opened slightly, which in turn could have caused looseness and deflection.

There are two different types of stability that arise between bone and implant. Primary
stability is a biomechanical property where surgical parameters matters (Götz et al., 2010). Secondary stability is a result of osseointegration, the biological process when the bone integrates with the titanium implant (Adell et al., 1981).

In a viable bone-tissue, osseointegration and adaptation of bone occurs around the implant, which can possibly give the implant and the construction as a whole, a higher probability to better resist forces employed to the cantilever.

An aluminium block was used to fasten the implants with the bridge on top. Both abutment screws and implants were made of titanium. There was no room for movement between the implants and the metallic block.

During mechanical loading of implants, abutment screws can be exposed to reverse torque and lose some of the initial insertion torque which could lead to a higher mobility of the bridge (Vianna et al., 2013). In this study however, the initial insertion torque after testing was unchanged which makes it unlikely that it was the origin of the bridge deflection.

In a patient-case with a fixed prosthesis, forces are not solely applied on the cantilever during mastication, but rather more spread over a larger area depending on the number of occluding teeth. This may explain why an RCT study made on the all-on-two concept showed success over a five-year follow-up period (Cannizzaro et al., 2016).

The machine for testing was made and modified by students at the Department of Applied Physics and Electronics at Umeå University (Asplund, 2012; Forsell, 2017). The students were limited by time, economy and help from their tutors, and as result the machine was not optimal. However, all things considered, chewing simulation was satisfactory under these circumstances. There are a lot of possible upgrades that can be made on the machine, for example installation of a load cell that could give feedback of the force and time during testing and a better pressure valve to maintain a constant force throughout the test.

Because the need of close collaboration with students at the Department of Applied Physics and Electronics at Umeå University for modifying and rebuilding the existing machine, the time frame for testing was severely limited. In reality, no failure of
mechanical components of the machine could be compensated for, which unfortunately resulted in the hampering of any attempt to extend the testing time, once the machine broke down. To continue the test the machine would have needed extensive repairs.

Mechanical testing in a machine setting of a bridgework constructed from a plaster model does not at first glance entail much of ethical considerations. However, when considering the ramifications of use of such constructions in clinical practise the question of ethics become more pronounced.

The purpose of our study was to test a fixed complete bridge made for a real patient and analyse the mechanical characteristics of the setup. We would only make one test on one specific scenario which would make the result not applicable on a larger scale. Several tests would be needed to be sure that the mechanical components of the bridge are solid during fatigue testing.

The mechanical aspects of the study are directly associated with the ethics of applying any unproven treatment modality to patients without thorough preclinical trials. An existing study made by Cannizzaro (2016) describes all-on-two concept where the tests were made directly on the patients who were treated with fixed bridge retained by two implants only without prior \textit{in vitro} tests. It is our opinion that such studies are at best questionable from an ethical point of view. The current study is solely preclinical, although initially planned to be based on an actual clinical case. The mechanical aspects of all-on-two concept should be first tested \textit{in vitro} to explore the limitations of the mechanical components before introducing any biological aspects of the concept. The \textit{in vitro} testing would most probably lead to modifications of the set-up, thus protecting future patients from unnecessary risks and suffering when introducing the new treatment in the clinic.

Restoring the dentition with implants should always infer ethical considerations, especially when the implant is planned to replace an existing tooth. The compensation of lost teeth often goes by "faster, easier and cheaper" principles. It is assumed that implant restoration of lost teeth is the best possible scenario, but that can be misleading. The complete denture, or removable partial denture are faster, easier and cheaper alternatives (Misch, 2012). Healthy teeth are sometimes extracted to be replaced with dental implants.
These teeth could many times be used to support other forms of prosthetic treatments (Levin, 2012) which is unacceptable because ethical aspects go aside. The aim of all-on-two principle presents a possibility to help patients with edentulous mandible in those situations when no other method is applicable, e.g. when the residual bone volume is too small for removable partial dentures, or when the patient cannot accept a removable prosthetic solution. In such situations, the all-on-two method could prove to be helpful, and also be ethically supported in terms of positive advantages such as a technically easier design, easier maintenance, reduced costs, etc.

One interesting ethical point to be brought up when studying the all-on-two concept in vitro is if mechanical testing show good results, what would be the next step to test the biomechanical aspects? Biomechanics is defined as “The study of the mechanical laws relating to the movement or structure of living organisms” (Oxford University Press, 2017). Translated into the context of the current study, biomechanical aspects would entail the resilience and the response of the jawbone to the, possibly, excessive load from only two dental implants supporting a full-arch prosthesis.

Further ethical questions one might ask are: When is it correct to test an elective treatment on human subjects? When are the results from preclinical tests sufficient, and when are the risks involved acceptable for introducing the treatment to the patient? Are there any intermediate steps that can be taken to further elucidate the consequences of the treatment to be?

In many instances, e.g. pharmaceutical research, animal models are used to test effects of new drugs. However, the testing of biomechanical properties, and effects from a new form of fixed prosthesis in the edentulous mandible is not easily simulated in an animal model.

Finite Element Method (FEM), also called Finite Element Analysis, is a numerical method for solving problems of engineering and mathematical physics.

The method has been used in dental research, for example within the field of dental implants, where it has been applied for digital analysis of mechanical and biomechanical characteristics of various prosthetic constructions and of the bone. The advantage of the
method is the possibility to adapt test situations to the actual conditions of the oral cavity, and to visualise stress and tension of the tested objects. The method is useful for building a construction that later can be tested in vitro. By using FEM before in vitro, or in vivo studies, possible weak points of the experiment can be avoided which leads to saved time and costs (Pesqueira et al., 2014).

FEM could have been used in our study before the in vitro test to foresee and evaluate biomechanical conditions that could arise. However, to use FEM, extensive knowledge in the field of programming is needed. In the future if the all-on-two concept is to be further explored FEM could be a good choice.

Results from virtual stress tests on FEM on fixed full arch bridges retained on three to six implants show that longer cantilever yield higher stress on peri-implant bone (Bevilaqua et al., 2008). A cantilever no longer than 10 mm is recommended and four implants instead of three are preferred in an edentulous mandible due to higher stress values in the mechanical components and in the bone (Correa et al., 2012). Rubo and Souza (2010) found that higher stress is observed on cancellous bone and supraconstruction with a longer cantilever.

Conclusions

A force of 177 N (18 kg) applied on the distal point on the cantilever in the molar region might cause deflection in the bridge but no critical failures in components were seen. The deflection could cause changes of bridge height dimensions that were measurable.

The results of the study indicate that bridge retained on two implants might not stand force of 177 N, 7 mm distal from the central point of the implant. Previous studies on patients have shown that all-on-two concept can be a viable modality of treatment in the future.

To redo the test, the motor of the machine had to be changed to a new one. The machine was made and developed by two engineering students at Department of Applied Physics and Electronics, Umeå University, Sweden. A new machine constructed from scratch by a professional mechanic is desirable to make the test possible with better outcome.

Testing time equalled to 37.2 hr of intraoral use is too short to get relevant results. At
least 10 years of intraoral use are needed to come to any conclusions regarding fatigue in implant material.

ACKNOWLEDGEMENTS

Special thanks to our tutor, Lecturer Tomas Lindh, Department of Prosthodontics, Faculty of Odontology, Umeå University, Sweden, for his ideas, help and trust throughout the study. We also want to thank Fredrik Holmgren and Staffan Schedin, University Lecturers, Department of Applied Physics and Electronics, Umeå University, for helping in construction of the machine. Our thanks to Dodd Johansson, Lecturer at Dental Technician Program, Librarian Helene Rova and staff at Folktaendvârdens Tandtekniska, Umeå.
REFERENCES


http://www.socialstyrelsen.se/tandvardsriktlinjer/sokiriktlinjerna/periimplantit


Tables

Table 1. Height of the bridge. Measurable differences.

<table>
<thead>
<tr>
<th>Point of measurement</th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td>Height from aluminium block right side, mm</td>
<td>11.0</td>
<td>10.7</td>
</tr>
<tr>
<td>Height from aluminium block left side, mm.</td>
<td>10.5</td>
<td>10.2</td>
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<tr>
<td>Height from the aluminium block in the middle, mm.</td>
<td>12.6</td>
<td>12.8</td>
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Figure 1. Machine for simulation of chewing: a) frontal view; b) left side view. The red arrow shows the bridge placed in the machine.
Figure 2. Bridge retained to aluminium block with two implants: a) left side view; b) frontal view; c) view above; d) view behind during testing; e) right side view during testing.
Figure 3. Overview of literature search. PubMed database, manual search of reference list, Internet and previous studies made at Umeå University were included in the study.