Mechanical and fatigue resistance of restorations supported by welded-framework and realized using computer-aided designed prosthetic shells: In vitro pilot study

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Abstract

Resin coating in implants rehabilitation cannot always be aesthetic, durable and comfortable for the patient mainly due to the limited dimensions of the final structure. Intraoral welding technique and computer-aided designed prosthetic shells may be a solution. This in vitro study evaluates the capacity of load and the weakest point of implant-supported provisional prosthesis using welded titanium framework. Twelve samples were produced to simulate an implant supported fixed prosthetic bridge. Two implants (Ankylos; Dentsply Sirona Implants; Germany) were inserted inside blocks of nanoceramic material produced with a stereolithographic 3D printer. A polymethylmethacrylate (PMMA) resin shell was performed with CAD/CAM and relined on welded framework. Six samples were produced with the same procedure reducing resin thickness. The samples were subjected to fatigue test (6,500,000 cycles) using ElectroForce 3310 fatigue machine (t_1); subsequently a mechanical compression test using a universal Shimadzu AGS-X 10 machine (t_2). The samples were analyzed with a photographic and radiographic documentation at t_0, t_1 and t_2. The samples survived mechanical fatigue test without evidence of failure. The radiographic and photographic evaluation revealed the fracture of resin coating after the mechanical compression test. The samples with minimal resin thickness fractured first. Adequate assessment of the resin thickness is mandatory to improve the longevity of these rehabilitations. CAD-CAM digital prosthetic design allows us to optimize the thicknesses and the prosthetic shapes, allowing us to obtain good degrees of resistance even in the presence of reduced prosthetic spaces.

Keywords

Welding, immediate loading, implant-supported dental prosthesis, mechanical stress, CAD/CAM design

Background

The treatment of edentulous jaw with dental implants represents a scientifically and clinically validated therapy modality. Osseo-integrated dental implants provide a predictable base for function and esthetics restorations in edentulous patients. However, the extended healing time without implant loading is a disadvantage from the patient perspective. Hence, reducing the healing period or time to loading would be of great benefit to the patient.[1]

In recent years, computer-guided implant (CGI) has been developed and is considered to be a treatment with maximum comfort and minimal patient morbidity.[2] The improved accuracy obtained with CGI surgery offers of course many advantages for the prosthodontist. It allows the use of a

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prefabricated Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) restorations which can be delivered immediately after implant placement to improve patient satisfaction including comfort, function and aesthetics.[3]

Degidi et al.[4] published a protocol for the immediate loading of multiple implants by welding a titanium bar to implant abutments directly in the oral cavity, so as to create a customized metal-reinforced provisional restoration. The intraoral welding technique subsequently proved to be a successful option in the full arch immediate restorations of the mandible and maxilla.[5,6] The welded titanium framework has a lot of advantages: a minimum size, it reduces the total volume required for rehabilitation, avoiding interference to the patient's speech. Albiero et al.[7–9] published a protocol for immediate loading of guided implants by using restorations supported by an intraoral welded titanium framework (guided-welded approach).

The advantages of combining CGI surgery with intraoral welding technique include correct passive fit implant prosthesis because of the possibility of titanium bar preshaping on the model cast by transferring implant positions from the surgical guide to the master model, with a consequent shorter time for intraoperative titanium bar shaping; optimized prosthetic procedure because of the chance of planning implant positions when considering the titanium bar encumbrance with respect to the provisional hollow prosthesis.[7]

In recent years, efforts have been made to increase the mechanical strength of the resin coating because it has been detected a lot of resin coating failure using welded prosthetic rehabilitation.

For example, it was proposed that the use of milled denture teeth were good alternatives to conventional denture teeth, however they showed lower wear resistance and higher fracture resistance than the prefabricated ones.[10,11] The 3D-printed teeth showed lower wear resistance and higher fracture resistance than the prefabricated ones. The fracture of the resin coating is the most common adverse prosthetic event to be expected in the early-medium term when using the intraoral welding technique.[12,13]

When the vertical dimension of occlusion is limited or when antagonist teeth are extruded, the implant-supported prosthesis has to be planned with a reduced restorative thickness. Literature about performance of this kind of rehabilitation is limited. By using CGI and CAD/CAM technology implants position and prosthetic shape could be evaluated in order to plan a correct prosthetic thickness even in the presence of sites of minor resistance such as near the access holes.

For this reason, the aim of this in vitro pilot study is to evaluate the capacity of load and the weakest point of implant-supported prosthesis welded titanium framework and like the thickness of resin influence the prosthetic failure.

Material and methods

Thermo-mechanical aging

An in vitro 12 samples were produced to simulate a fixed prosthetic bridge 1.4–1.7 with the insertion of implants in seats 1.4 and 1.6 by applying the intraoral welding protocol. The cantilever measured about 14 mm. Two implants 3.5 mm diameter and 11 mm length square threaded, grit-blasted and acid-etched implants with a tapered connection (Ankylos; Dentsply Sirona Implants; Germany) of commercially pure grade four titanium (ISO 5832-2: 1999) were used to create this sample, inserted at distance of 15 mm inside blocks of nanoceramic material (Vitra 413, DWS srl Thiene, VI, Italy), with elastic modulus between 1500 and 2550 MPa comparable with the elastic modulus of the trabecular bone, of dimensions $35.7 \times 12.5 \times 14\,mm^3$ produced with a stereolithographic 3D printer (XFAB; DWS, Milano, Italy). The conometric abutments (Balance Base Narrow GH 3 mm; Dentsply Sirona Implants; Germany) were screwed onto the implants with a controlled torque force of 25 Ncm with the use of a torque wrench. Subsequently on each of them were positioned and fixed with a fixing screw of the welding cylinders (Titanium coping Balance Base; Dentsply Sirona Implants; Germany) with a controlled torque force of 10 Ncm.

The next step was the welding phase, in which a 2 mm diameter and 30 mm long grade two titanium bar was welded on the top of the cylinders, through the use using an intraoral welder with Smart High program (WeldOne; Dentsply Sirona Implants; Germany). Once the electrodes of the welding machine clamp were positioned perfectly in contact with the bar and the welding cylinder, the electric discharge was activated in order to create the welded point. After a few seconds the forceps were removed from the sample. Subsequently, the titanium cylinders were sectioned 2 mm above the bar in order not to be encumbered with the application of prosthetic rehabilitation. Titanium frameworks were undergone to sandblasting at 4 bar (using 110 μm Al_2O_3 particles) and opaqued (Telio Lab C&B Material OP 1, Ivoclar Vivadent AG, Liechtenstein) to avoid metal light reflection through the acrylic resin. Six samples were performed with this procedure.

Each sample was scanned, the file was imported into the Exocad software with which the prosthetic shell was designed with CAD technique. At the end of the design, the file was sent to the milling machine software (CAM) with which the manufacture was made. The prosthetic shell obtained was milled from a BreCam block in A3 color resin material. Subsequently the resinous shell was relined on the welded framework using dual-curing resin cement (Bredent Combo.ling, Bredent Derbyshire, UK) and positioning the welded bar on buccal side was positioned. At the end each sample was finished and polished (group control).

The other six samples were performed with the same procedure reducing at minimum vertical prosthetic space by placing the welding titanium bar at the base

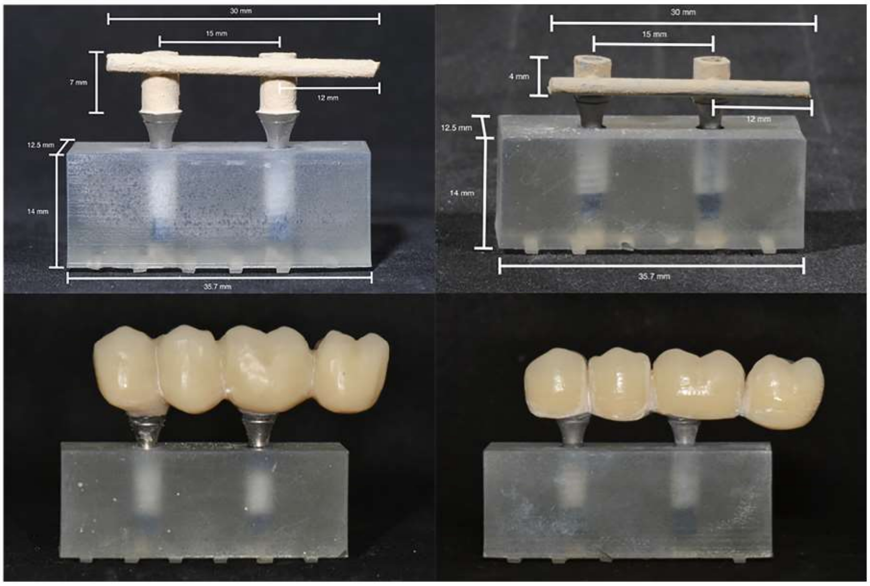

Figure 1. Photographic evaluation of ideal resin thickness samples, group control (a) and minimum resin thickness samples, group test (b) at t_0.

of welding cylinders and consequently reducing the resin thickness (group test). In sagittal section the resin thickness was reduced on average from 70 to 50 mm^2 between 1.4 and 1.5, from 70 to 35 mm^2 between 1.5 and 1.6 and at cantilever connector from 50 to 30 mm^2 between 1.6 and 1.7. Figure 1 illustrated the dimensions of the samples of group test and group control.

In addition, a steel antagonist was planned and produced in which two hemispheres were designed to perfectly occlude prosthetic rehabilitation in order to have a balanced load application over the entire structure.

Each sample was analyzed with photographic and radiographic documentation at t_0.

Dynamic mechanical aging: fatigue test

Three samples of the group test and three samples of the group control were subjected to fatigue test. 6,500,000 cycles were performed with the ElectroForce 3310 fatigue machine (TA Instruments—Waters LLC, ElectroForce System Group, 9625 West 76th Street, Eden Prairie, Minnesota 55344, USA). Equivalent to 97 and a half months (approximately 8 years) of clinical service according to a study carried out by Rosentritt et al.[14] according to which an adult performs an average of 800,000 chewing cycles per year. Each cycle involved the application of an alternating uniaxial compression load between 50 and 800 N according to a sinusoidal function with a frequency of 5 Hz. Each sample was analyzed with photographic and radiographic documentation at t_1 (after 6,500,000 cycles).

Evaluation of the load at failure

At the end of the fatigue tests all samples were subjected to a mechanical compression test with an increasing uniaxial compression load using a universal Shimadzu AGS-X 10 machine. The load-displacement curves were recorded until the structure failed (t_2). The antagonist used for this test was the same used in the mechanical fatigue test. A 50 N preload was applied to the samples in order to be able to adjust the antagonist's supports. At the end of the preload phase, the instrument applied the compression load with a speed equal to 1 mm/min until the complete fracture of the sample. Each sample was analyzed with photographic and radiographic documentation at t_2.

The study design is outlined in Figure 2.

Results

Dynamic mechanical aging: evaluation after fatigue test

The samples survived the mechanical fatigue test without evidence of failure or screw loosening. It is possible to compare the photographic documentation of the samples at t_0 and t_1 it is possible to see the presence of minimal wear zone on the resin shell. No differences were observed radiographically.

Evaluation of the load at failure after dynamic stress

The radiographic and photographic evaluation of the samples revealed how the fracture or detachment of the composite resin coating occurs more frequently in the palatal area, where the titanium bar is not present.

Furthermore, three samples demonstrate a failure at the level of the implant seat on 1.4 (Figure 3).

The radiographic evaluation of the samples revealed that at the welded joint failure did not occurred. However, comparing the radiographic images at t_0 and at t_2 of each sample with Image J program (NIH,

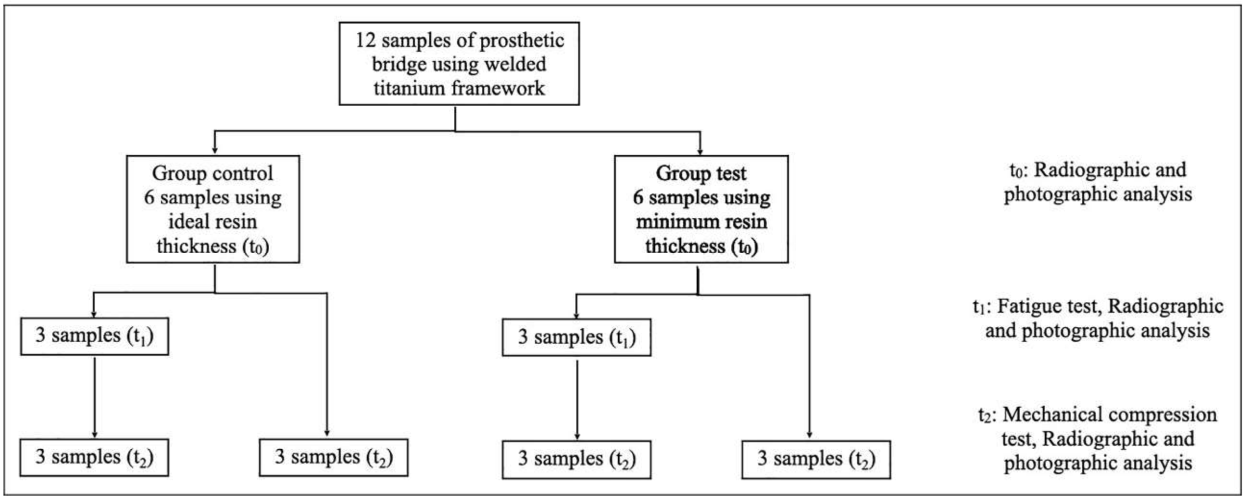

Figure 2. Study design.

Figure 3. Photographic evaluation of sample minimum resin thickness samples at t_2.

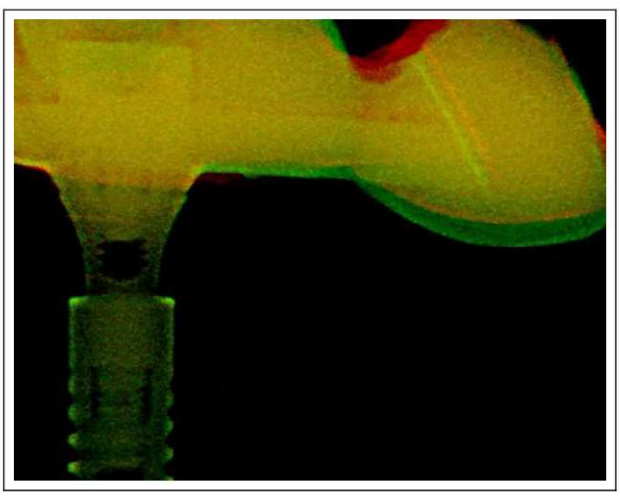

Figure 4. Radiographic comparison of sample minimum resin thickness samples before and after tests processing with ImageJ program.

USA) it was possible to detect a deformation of the titanium bar in the cantilever area (Figure 4).

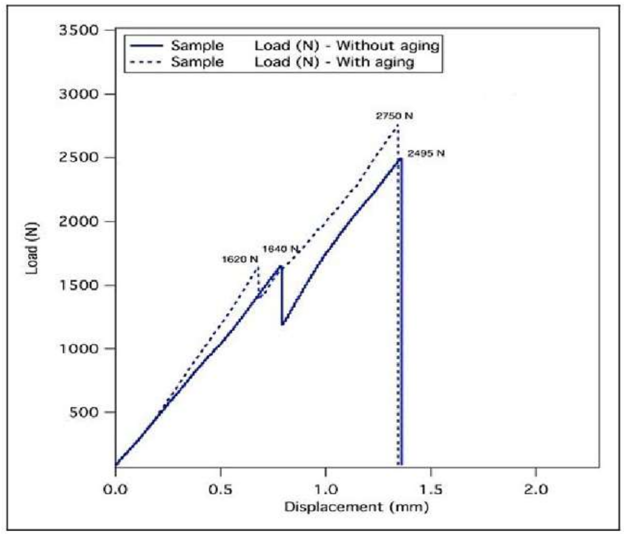

Figure 5. Load displacement of the samples ideal resin thickness samples.

From the load-displacement graphs (Figures 5 and 6) obtained during the mechanical compression test it was possible to highlight how the most samples produced with ideal resin thickness reached the framework failure to higher values compare to the samples produced with minimum resin thickness. In the Figure 1 about the two samples of the group control, the previous fatigue test does not seem to have significantly influenced the overall strength of the composite resin since the samples show the first fractures at close strength values. Furthermore, from the Figure 6 it is evident that the resistance has been negatively affected by the previous mechanical fatigue test.

It is evident that the toughness of the coating material was also negatively influenced by the mechanical fatigue test for the group test. The sample produced with minimum resin thickness and subjected to fatigue test has in fact an area under the load-displacement cures lower than the same sample that was not subjected, this has led to more frequent fractures of the

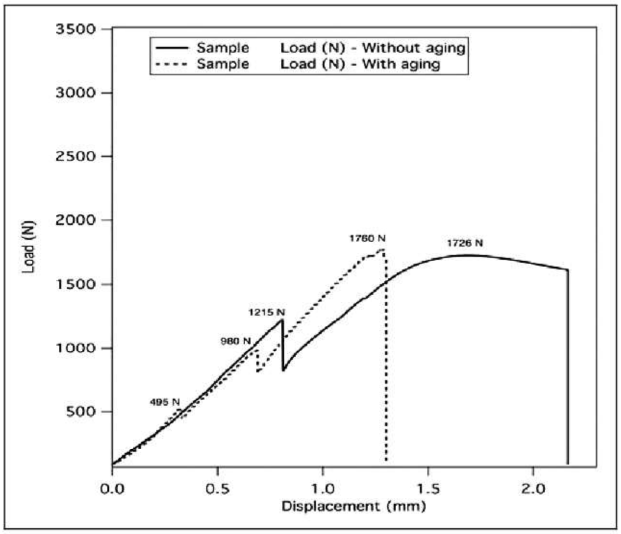

Figure 6. Load displacement of the samples minimum resin thickness samples.

coating material of the first sample. This condition was not highlighted in the samples produced with ideal resin thickness where the two areas are almost equal.

Discussion

Since the early studies on implant osseointegration, the presence of movement and overload at the bone-implant interface has been identified as one of the major failure factors of an implant-based treatment plan.[15,16] In cases of immediate loading the passive fit avoiding micromovements more than 150 μm is most important for the implant osseointegration.

The intra-oral welding technique allowed a quick and adequate rigid splinting of multiple implants for same-day immediate loading, resulting in a predictable fixation of implants in the early stages of bone healing with a significant reduction of the micromovement problem.[17] Welding the framework directly in the patient's mouth allows the creation of a precise and passive structure, without needing any correction or further components, such as those often necessary for CAD CAM-manufactured frameworks.[18]

In vivo the implant rehabilitations are subjected to chewing load, which is a cyclic load. For this reason, on in vitro tests it is important to consider cyclic mechanical loading when evaluating the long-term behavior of implant-supported rehabilitation.

Degidi et al.[4] demonstrate that the frameworks made with the resistance welding approach lead to a mechanical response that is well comparable to that of the traditional frameworks. To maximize tensile strength, the design of the titanium framework can evolve using the application of secondary bars and additional titanium retentions.[19] However, this preliminary experimental in vitro study allowed us to state that the load capacity of welded frameworks implant supported rehabilitation may be greater than the maximum occlusal forces in posterior tooth (180-847N).

Degidi et al.[10] demonstrate that none of the titanium welded joints evidenced radiological signs of fracture or impairment in the 6-year follow-up period after full occlusal load. In this study the strength of the welded framework was confirmed, indeed the welded joint resisted forces higher than 2500 N. There was no evidence of fracture or detachment of the titanium bar at the level of the welded joints, but it is detected a deformation of the titanium bar in the cantilever area was detected, due to the application of high loads, at mechanical compression test.

Besides, it is possible to state that these prosthetic rehabilitations, also in minimum resin thickness, are sufficiently resistant for the period of time tested (6,500,000 cycles, i.e., 8 years), which is greater than the times for temporary rehabilitation is usually used. Nevertheless, higher thicknesses of composite resin correspond to higher resistance values.

The fracture of the resin coating was the most disadvantage reported by Degidi et al.[12] in his 10-year report on implant-supported full-arch maxillary prostheses. Another in vivo study about intraoral welding technique observed failure of the resin coating 4 years after implant placement.[10]

The samples demonstrate the most failure at the level of the implant seat on 1.4. This complication has been associated with the access to the connecting screw which involves an interruption of the resin's shell. The zone is directly under the load of the antagonist without the possibility of flexing compare to implant seat on 1.6. The fracture of the resin shell occurs more frequently in the palatal area, where the titanium bar is not present. The titanium framework provides better resistance to rehabilitation than the composite resin alone.

Another way to maximize the tensile strength, Degidi et al.[19] advised to use composite instead of common acrylic resin. Composite resin has a more rigid tridimensional structure and in clinical use has proved itself less prone to fracture than common acrylic.

Based on studies in literature and the results obtained in this study, is possible to state that the weak point of this type of rehabilitation is the resin coating. In recent years, fiber-reinforced composite materials (FRCs) have been proposed as a reinforcement of a prosthetic structure. The twisted fibers seem to increase the resistance of resin and to prevent propagation of the fracture.[20] In an in vitro study by Hamza et al.[21] it was observed that the use of fibers can improve temporary resin restorations mechanical properties (flexural and fracture resistance).

PMMA acrylic resin is used as a prosthetic material, however it demonstrates low fatigue resistance. It is possible to reinforce PMMA rehabilitation using welded titanium framework. It may be possible the use of FRCs as a reinforcement of the resin coating in implant-supported welded rehabilitation.

Conclusions

Cyclic loading does not affect the loading capacity and toughness of the samples at both reduced and ideal thicknesses. The most frequent complication is the fracture of the resin coating and there are preferential areas of resin fracture in this type of implant-prosthetic rehabilitation. Higher resin thicknesses correspond to higher toughness values. For this reason, the CAD-CAM digital prosthetic design allows us to optimize the thicknesses and the prosthetic shapes, allowing us to obtain good degrees of resistance even in the presence of reduced prosthetic spaces. The resistance of implant rehabilitation with electro-welded frameworks appears to be greater than the maximum occlusal forces detected in the oral cavity, even at minimum thicknesses and for a longer period than the time that is usually necessary for provisional prosthetic rehabilitation Despite the limitations of this study, represented by the small sample size, the results appear to be promising for this electro-welded prosthetic rehabilitation as a "durable" implant-supported restoration. The resin is the weak point/spot of the rehabilitation and it is possible to hypothesize a study evaluating the load capacity of implant-supported welded rehabilitation using FRCs.

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