Prosthetic Screw Detorque Values in Implants Retained as Cast Bar Superstructures or Bars Modified by the Cresco Ti Precision Technique–A Comparative In Vivo Study

Johannes Schmitt, DMD[a]/Stefan Holst, PhD, DMD[b]/Stephan Eitner, PhD, DMD[b]/
Andreas Schlegel, PhD, MD, DMD[c]/Manfred Wichmann, PhD, DMD[d]/Jörg Hamel, DMD[a]

Purpose: This prospective clinical trial investigated the effect of different fabrication techniques on screw-joint stability in implant-retained frameworks. ***Materials and Methods:*** Seventy-nine dental implants (39 Brånemark System and 40 Straumann) were inserted into 20 patients with an edentulous mandible. One of two fabrication techniques was randomly chosen as a definitive restoration, either a cast bar or a bar superstructure modified with the Cresco Ti Precision (CTiP) technique. The patients were divided into four groups depending on the type of implant and prosthetic superstructure: Straumann-conventional (Sc), Straumann-Cresco (SCr), Brånemark-conventional (Bc), and Brånemark-Cresco (BCr). Initial torque values and removal torque values were recorded with a custom-made digital torque controller both 1 week (T1) and 3 months (T2) after clinical function. ***Results:*** Statistical analysis revealed significant differences in absolute detorque values at T1 (P = .002) with 4.51 Ncm (SD = 3.80) for the Sc group, 10.65 Ncm (SD = 4.42) for SCr, 11.24 Ncm (SD = 4.00) for Bc, and 9.02 Ncm (SD = 3.81) for BCr. At T2 (P = .000) the median values of lost torque were 5.08 Ncm (SD = 4.05) for the Sc group, 10.51 (SD = 3.00) for SCr, 7.50 (SD = 5.86) for Bc, and 9.41 Ncm (SD = 4.54) for BCr. However, when correlation of detorque values to initial torque values was performed, no statistical differences were found between groups or time points. The percentage of lost torque at T1 (P = .849) and T2 (P = .058) was 28.60% (SD = 21.80) and 32.85% (SD = 24.65), 30.04% (SD = 12.49) and 30.80% (SD = 8.66), 32.11% (SD = 11.37) and 21.03% (SD = 16.53), and 25.33% (SD = 10.69) and 27.83% (SD = 12.57) for the Sc, SCr, Bc, and BCr groups, respectively. ***Conclusions:*** The screw-joint stability of passivated bars is not superior to cast superstructures. A general decrease of approximately 30% of initial torque values can be expected in clinical situations, independent of the implant system used.
Int J Prosthodont 2009;22:193–200

An important objective in implant dentistry is to achieve an optimal prosthesis fit to minimize biologic or mechanical complications. The unavoidable discrepancy between the implant and framework induces stress in the restoration, implants, and the surrounding bone.

Biologic complications may include adverse tissue reactions, pain, tenderness, marginal bone loss, and the possible loss of osseointegration.[1,2] Previous reports indicated that biologic implant failure is not related to the misfit of the prostheses.[3,4] Jemt and Book[4] reported that a certain biologic tolerance for misfit may be present and is clinically acceptable with regard to marginal bone loss.

Despite the fact that a relationship between biologic implant failure and prosthesis misfit has not been conclusively demonstrated,[4–6] mechanical complications such as loosening of prosthetic screws or fracture of components have been frequently reported in dental implant therapy.[7–10] Factors that may lead to screw joint

[a]*Assistant Professor, Department of Prosthodontics, Friedrich-Alexander-University Erlangen-Nuremberg, Erlangen, Germany.*
[b]*Associate Professor, Department of Prosthodontics, Friedrich-Alexander-University Erlangen-Nuremberg, Erlangen, Germany.*
[c]*Associate Professor, Department of Oral and Maxillofacial Surgery, Friedrich-Alexander-University Erlangen-Nuremberg, Erlangen, Germany.*
[d]*Dean and Clinical Director, Department of Prosthodontics, Friedrich-Alexander-University Erlangen-Nuremberg, Erlangen, Germany.*

Correspondence to: *Dr Johannes Schmitt, Department of Prosthodontics, Friedrich-Alexander-University Erlangen-Nuremberg, Glueckstr. 11, 91054 Erlangen, Germany. Fax: 09131/8536781. Email: johannes.schmitt@uk-erlangen.de*

instability are the misfit of implant-supported prostheses,[11] inadequate tightening force,[12,13] screw settling, and the diversity in screw material and design.[13,14]

Due to inaccuracies concerning clinical and laboratory procedures, achieving a passive fit is clinically unattainable.[15] Conventional impression procedures create a risk for error in the production of the final master cast.[16] One future possibility could be photogrammetry in conjunction with computer numerically controlled (CNC) milling techniques to eliminate any transfer errors.[17,18] Dimensional changes of the superstructure are related to the mixing ratio of the investment and casting technique.[19,20]

Several methods to improve casting accuracy and framework fit have been described.[21–24] The most common way to correct misfit of a gold alloy framework is by sectioning and soldering, even if this method does not lead to an absolutely passive fit.[25] The spark erosion technique can improve the fit of cast titanium or gold alloy prostheses.[21,26] Eisenmann et al[21] reported mean gap widths of 31.63 µm for titanium frameworks and 12.72 µm for gold alloy frameworks prior to spark erosion. After spark erosion treatment, these widths reduced to 7.58 µm and 6.20 µm, respectively. The computer-aided design/computer-assisted manufacturing (CAD/CAM) milling technology in dentistry has evolved over the past 2 decades to improve framework fit for both natural teeth and implants.[27–29] Gap distances between gold alloy castings and the implant abutment of 42 to 74 µm, and 25 µm for Procera-machined and laser-welded superstructures, are described by Jemt and Lie[24] and Riedy et al.[30] Furthermore, the three-dimensional (3D) distortion of cylinders in CNC-milled titanium frameworks and gold alloy castings varies from 3 to 80 µm.[23] The level of a clinically acceptable fit of implant frameworks has been reported in the range of 10 to 150 µm.[24,31]

The Cresco Ti Precision (CTiP) method uses a conventional lost wax casting technique for titanium or gold alloy framework fabrication. In the second step, the cast framework is retained with plaster in a fixator, preserving the vertical and horizontal relationship between the master cast and framework. Prefabricated plastic cylinders for casting or machined titanium cylinders consistent with the implant system are screw-tightened to implant analogs in the master cast after framework retention. In the final step, the framework legs and cylinders are cut exactly in the same predetermined horizontal plane and assembled by laser-welding.[22] This approach permits an abutment-free fitting superstructure regardless of dental alloy for most implant systems on the market.[22,32,33] Divergence between implants up to 90 degrees can be compensated without the use of abutments, thus reducing the cost to patients. The result of a photoelastic experiment described by Helldén and Dérand[22] demonstrated a reduction of stresses in bone-model resin when passivated frameworks were mounted on the implants. Despite lacking absolute values of gap reduction between framework and implants by the CTiP method, a passivation of the framework to implant analogs in master casts is notable.[34]

Acceptable fit and correct torque values are essential for optimum preload and long-lasting screw-joint stability without loosening or breakage.[11,35] Proper preload will maximize the fatigue life of the screw while offering a reasonable degree of protection against loosening.[36] No clinical results comparing loss in preload of superstructures passivated by CTiP to conventional casting are available.

The purpose of the present study was to compare the screw-joint stability after clinical function between CTiP frameworks and conventional nonpassivated castings. It was hypothesized that passivated frameworks (CTiP) display a reduced loss in torque values when compared to cast bars.

Materials and Methods

The prospective randomized clinical investigation was conducted at Dental Clinic 2 – Prosthetic of the Friedrich-Alexander University Erlangen-Nuremberg. Patients were recruited from the interdisciplinary dental implant clinic, and two experienced surgeons and prosthodontists conducted the implant treatments. Inclusion criteria were as follows: must be at least 18 years old with a totally edentulous mandible, must have requested an implant-retained removable prosthesis, must possess no need for augmentation before implant placement, and must be physically and psychologically appropriate for implant therapy. Exclusion criteria included the presence of untreated periodontal disease in the maxilla, the presence of systemic diseases, patients irradiated in the head or neck region within 12 months before surgery, severe parafunctional habits (eg, bruxism), and poor oral hygiene and motivation.

All patients were asked to participate in the study, which was approved by the ethical committee of the FAU (no. 3084), and patients signed an informed consent form.

In the maxilla, 10 patients had a complete denture, six had a removable partial prosthesis on natural teeth, and two had a removable implant-supported prosthesis. Two patients had fixed partial dentures on natural dentition.

Twenty patients with an edentulous mandible were consecutively treated with four intraforaminal implants. The implants (Brånemark System, Noble Biocare; Standard Implant, Straumann) were placed in the region of the first premolar and second incisor at both

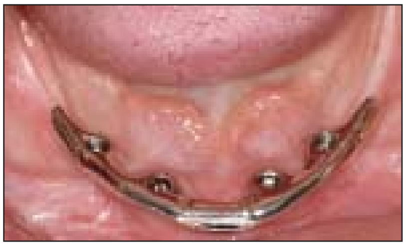


Fig 1 Cast bar of a Cresco group patient. Note screw heads with the slot.

Fig 2 Removable denture of a Cresco group patient on the day of insertion.

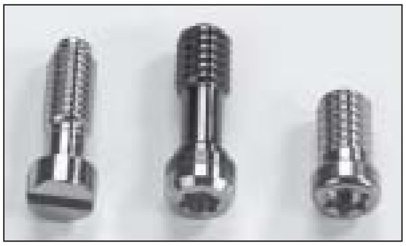


Fig 3 Prosthetic screws (from left to right: Cresco, Brånemark, Straumann).

mandible sites and healed submerged for at least 3 months. The Straumann and Brånemark groups consisting of 10 patients each were randomly divided into two sub-groups of five participants. These subgroups received either conventional or passivated CTiP bar superstructures (Figs 1 and 2). One patient of the Brånemark conventional group lost an implant during the healing period, and the bar was mounted on three implants. Custom impression trays were fabricated using light-curing resin plates (Palatray XL, Heraeus Kulzer). After insertion of the implant impression copings, a polyether (Impregum Penta, 3M ESPE) was used for the pick-up impression (open-tray technique). The implant laboratory replica was attached to the copings and a master cast with a silicone gingival cuff was fabricated.

For conventional bar fabrication on Straumann implants, SynOcta abutments (1.5 mm in height) were applied. Any other bars were shaped directly at the implant level. Rotation-symmetric, machine-made gold cylinders were embedded into the framework wax-up in the conventional Straumann (Sc) and Brånemark (Bc) groups. After embedding, pressure die casting was performed with a reduced gold alloy (61 Z^6, Teamziereis).

For the passivated bars in the Straumann-Cresco (SCr) and Brånemark-Cresco (BCr) groups, plastic cylinders were screw-tightened on the implant analogs and wax-up and casting of the bars with a reduced gold alloy (61 Z^6) was completed. Additionally, prefabricated plastic cylinders consistent with the implant system were embedded and cast with the same alloy. The master cast with the attached framework was then mounted in a fixator and the framework was dipped in plaster in a fixed vertical and horizontal position. The framework unit was separated from the master cast and the cast cylinders with identical surfaces to the implants were tightened to the implant analogs. These cylinders and the corresponding framework legs were cut in the same horizontal plane and assembled by laser-welding, resulting in a superstructure with a passivated fit to the analogs. Manufacturing of both types of frameworks was accomplished by one accredited dental laboratory.

Prior to placement of the conventional bars on Straumann implants, the SynOcta abutments were tightened using 35 Ncm. This joint was not solved throughout the entire term.

A custom-made electronic torque wrench with strain gauges and a precision of 0.1 Ncm was used to tighten the abutment screws. The torque wrench was connected to a computer to record the data using custom-made software.

Except for the bars of the Sc group, which were screwed on using 15 Ncm at the abutment level, all other bars (Bc, SCr, and BCr) were directly screwed with 35 Ncm to the implants. In the SCr and BCr groups, screws with a slotted head made of titan grade V were applied. The titan grade V screw for the Bc group had an internal hexagon slot as well as a titan grade IV screw, which joined the bars in the Sc group to the SynOcta abutments (Fig 3). Prior to definitive tightening, the bolts were screwed once and released to smooth the mating surfaces. Loosening torque was measured both 1 week (T1) and 3 months (T2) after insertion of the prosthetic superstructure, and the screws were retightened to recommended values.

All statistical data were processed with SPSS 14.0 for Windows. The differences in reduced torque were compared using the Kruskal-Wallis nonparametric test at a significance level of .05. Due to varying recommended torque values depending on the system used, the percentage of lost torque was assessed for each system in addition to the absolute values of lost torque.

Results

All patients completed the study and the loosening torque of 79 prosthetic retaining screws was assessed. The patients of the test groups, Straumann-conventional (Sc), Straumann-Cresco (SCr), Brånemark-conventional (Bc), and Brånemark-Cresco (BCr), presented different median detorque values (Table 1). The detorque values for the test groups showed statistically significant differences for both T1 and T2 observation periods ($P = .002$ and $P = .000$, respectively) (Figs 4a and 4b), according to the Kruskal-Wallis test.

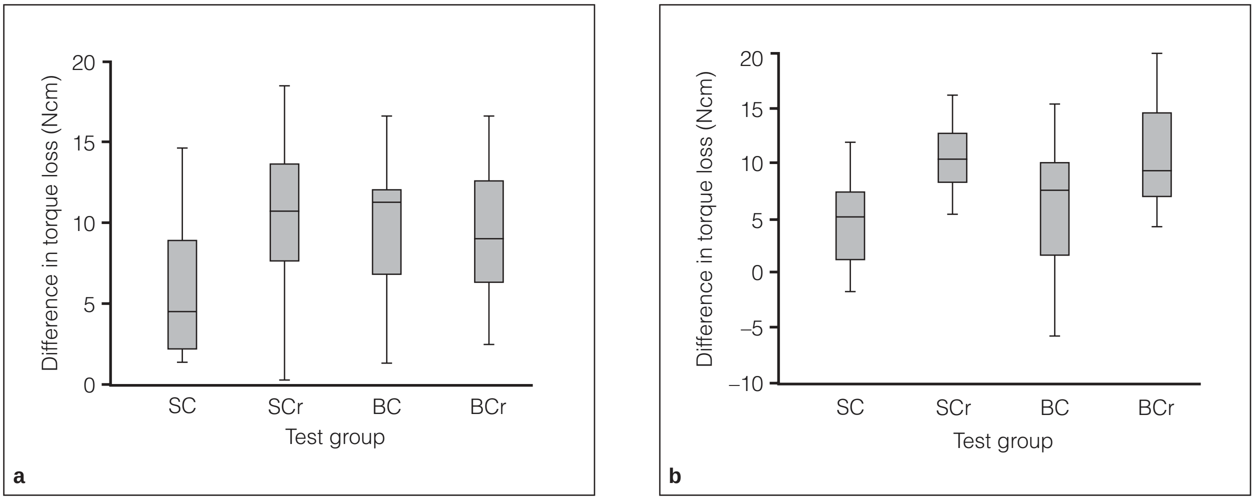


Fig 4 Values of lost torque for each implant group (**a**) 1 week (T1) and (**b**) 3 months (T2) after reconstruction.

Table 1 Median Values of Lost Torque of All Implant Groups Both 1 Week (T1) and 3 Months (T2) After Reconstruction

	T1		T2	
	Median (Ncm)	SD	Median (Ncm)	SD
Sc	4.51	3.80	5.08	4.05
SCr	10.65	4.42	10.51	3.00
Bc	11.24	4.00	7.50	5.86
BCr	9.02	3.81	9.41	4.54

SD = standard deviation.

Table 2 Median Values of the Percentage of Lost Torque of All Implant Groups Both 1 Week (T1) and 3 Months (T2) After Reconstruction

	T1		T2	
	Median (%)	SD	Median (%)	SD
Sc	28.60	21.80	32.85	24.65
SCr	30.04	12.49	30.80	8.66
Bc	32.11	11.37	21.03	16.35
BCr	25.33	10.69	27.83	12.57

SD = standard deviation.

The smallest loss in absolute detorque values 1 week after insertion was in the Sc group, which showed a median of 4.51 Ncm. By comparison, the Bc group showed the greatest absolute reduction in torque values, with a median of 11.24 Ncm (Table 1).

After 3 months (T2), the Sc group again presented the lowest decrease in absolute detorque values (median: 5.08 Ncm).

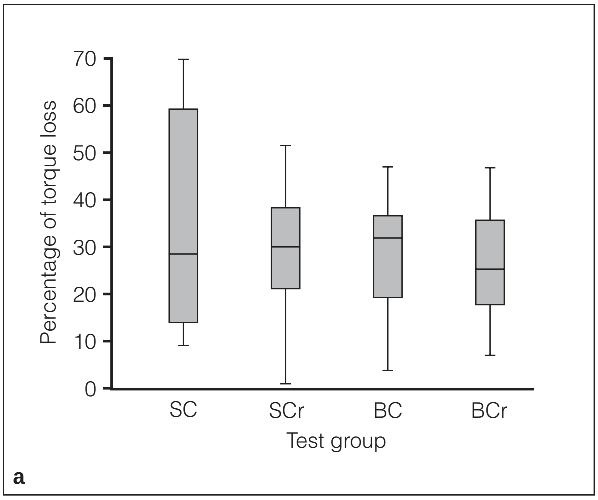
However, when assessing the percentage of lost torque for the different groups with respect to the different initial torque values, no statistically significant differences for time or system were found (Figs 5a and 5b). At T1, the median values for the percentage of lost torque were 28.60% for Sc, 30.04 % for SCr, 32.11% for Bc, and 25.33% for BCr ($P = .849$). Three months after insertion of the prostheses, the median values for the percentage of lost torque were 32.85% for Sc, 30.80% for SCr, 21.03% for Bc, and 27.83% for BCr ($P = .058$) (Table 2).

Discussion

The purpose of the present study was to assess the screw joint stability of CTiP passivated frameworks after clinical function compared to conventional non-passivated castings.

In the literature, in vitro studies without loading the implant abutment connection report loosening torque values ranging from 70% to 90% of initial tightening torque.[13,37–39] In a clinical situation, mastication-induced forces are transferred through the prosthesis onto the implant and the bone[40]; also, the screw joint is loaded and preload forces may decrease.

Taking into account the different torque values of 15 Ncm versus 35 Ncm of the prosthetic screws, the percentage of lost torque was assessed and preferred over the absolute values of lost torque. In the present clinical study, percentage of lost torque ranged from 21.03% to 32.85%. This is in accordance with other in



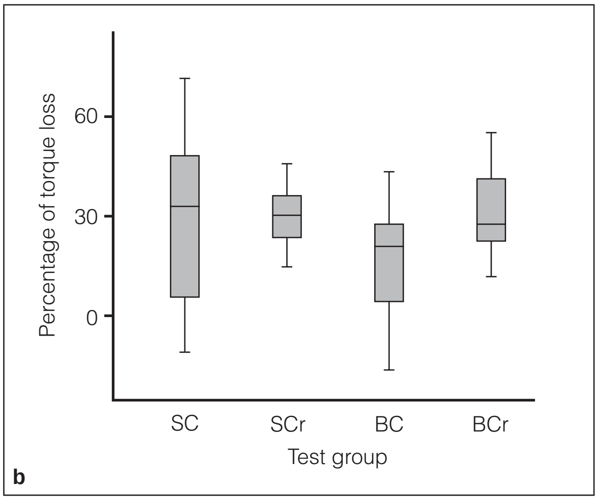


Fig 5 Percentage of lost torque for each implant group (**a**) 1 week (T1) and (**b**) 3 months (T2) after reconstruction.

vitro studies.[13,37,38] Stress on the screws induced by masticatory forces after short-term clinical service seemed to be within the elastic range, because no further torque was lost additional to in vitro results without putting a strain on the joint where detected.[13,37,38] No statistically significant differences concerning the median percentage in lost torque for the groups at T1 and T2 were detected. For each observation period, equivalent percentages of lost torque values were detected. Therefore, the working hypothesis proposing that screw-joint stability of CTiP frameworks after clinical function would be superior to conventional non-passivated castings was disproved, and instead, the passivated superstructures did not show superior results compared to the conventional cast bars. These findings are in accordance with Hjalmarsson and Smedberg, whose clinical retrospective study of prosthesis retention screw stability of Cresco frameworks did not yield superior results compared to conventional castings.[35]

The passivation of prosthetic superstructures is a critical clinical goal since severe discrepancies between the implants and superstructure may lead to mechanical failures of the restoration, implants, or biologic complications of the surrounding tissues.[31,41] Excessive mechanical stress could lead to failures, including loosening of the prosthetic and abutment screws or fracture of various system components.[42,43] Since a master cast is the basis for the CTiP technique, absolute passive fit is not possible. However, frameworks fabricated with the CTiP technique are proclaimed to be of better fit compared to conventional castings.[22,34,44]

In any laboratory joining technology, whether laser-welding or soldering, attention must be paid to the interface. Even though finite element (FEM) analysis suggests that a 0.64-mm-thick laser-weld joint exhibits enough strength to withstand biomechanical stress factors, it is a weak point over time since maximum stresses are concentrated at the framework-weld interface.[45,46] Throughout this examination, no fracture of the superstructures in either group took place.

One-piece casting results in extremely stable reconstructions and offers the benefit of reducing the risk for fracture of the frameworks compared to welded frameworks.[47,48] However, adequate precision of the one-piece full-arch implant framework is not easily attainable when applying the lost wax technique.[49] To correct an unacceptable fit of gold alloy castings, they must be sectioned and soldered many times. Some authors disprove a better fit of fixed partial dentures (FPDs) after such proceedings.[25,47] In addition, the tensile stress at the solder joint accounts for failure, mainly at the distal cantilever extensions of bars.[50] In the present study, no bars required separating and joining.

When inserting implant-retained restorations, using a torque controller instead of manual tightening is a mandatory requirement to obtain the optimal preload. Hand tightening does not result in adequate forces of the implant components.[51] To obtain comparable preload values in this study, a calibrated torque device was used. Component fit, lubrication, the applied torque, and its velocity influence the coefficient of friction. Therefore, the torque was applied in a steady and repeated manner.[39] To reduce microroughness of the mating surfaces, increase the preload, and minimize settling effects of the screw joint, the screws were screwed once and released prior to definitive tightening. After repeated tightening and loosening cycles, friction decreased and preload increased.[13,39] Component fit and precision also influenced the attainable preload. The use of prefabricated cylinders offers an advantage over plastic patterns in both preload magnitude and precision.[37,52] Therefore, the values of lost torque of the Cresco frameworks may be affected worse by the casting process of the plastic cylinders compared to the machine-made gold cylinders in the groups with the conventional bars.

Upon further examination, the dentition of the maxilla and the position of the prosthetic screw to the fulcrum line could be considered. Mastication-induced forces also depend on opposing dentition and type of restoration.[53,54] Therefore, forces on the prosthetic screws will differ by diverse occlusal support. Moreover, anterior and posterior prosthetic screws in a full-arch bar are submitted to different loads.[55,56] Al Jabbari et al detected a pronounced galling rate and higher fracture rate at the anterior retaining screws in fixed detachable hybrid prostheses after long-term use in vivo.[57,58]

It has been recommended that patients return for regular clinical and radiographic check-ups to maintain the clinical success of any restoration.[2,59] Since screw loosening, screw deformation, and fracture are the most common complications in prosthetic implant dentistry, it is of major clinical concern to schedule patients at adequate recall intervals.[42] Overall, the analysis after 3 months suggests a sufficient preload of the screws, independent from the system used. A retorquing of the retaining screws after the first 6 months to compensate for short-term relaxation seems to be advisable.[57]

At both observation periods the least percentage of lost torque was detected in groups where the bars were directly shaped at the implant level, whereas after 3 months the lost torque in the Straumann group with the use of SynOcta abutments was the highest. If implant angulation and internal connection shape do not require abutment use, the additional benefit of bar-retained overdentures is not remarkable. For exact appreciation, further examination with equal numbers of bars with and without the use of abutments is necessary.

Geometric designs such as thread length and diameter, microstructure, and major alloy constituents influence the preload of retaining screws.[57,60] Unfortunately, there is a lack of written specifications for prosthetic implant components.[58] All screws consisted of a titanium alloy with a flatted head, granting safe retention of the restorations.[61] The Straumann conventional prosthetic screw with the lowest torque value revealed the highest percentage of lost torque. Its major shank diameter and small total length prevent fatigue fracture in the load-bearing shank area.[62] Perhaps an increasing torque value could be beneficial for the stability between the framework, SynOcta abutments, and the implants.[60]

The authors' findings after 3 months indicate that the smallest reduction for screw preload values was found for the conventional casting group. One explanation for the conventional bar showing the best result is that slotted screws were used in the CTiP groups as provided by the manufacturer, compared to the screws for joining the conventional bars to the implants, which were internal hexagon slots. Based on the assumption that frameworks fabricated with the CTiP technique are of better fit compared to conventional castings, the design of the screw is one of the deciding factors for achieving ideal torque values.[44] In a retrospective clinical study, Kallus and Bessing noted that screw heads with internal hexagon slots were preferable, as these were frequently observed to be tighter than slotted screws.[10] This is most likely due to the force transfer not being ideal when tightening a slotted screw because of a higher probability of slippage and screwdriver angulation from the slot. Furthermore, a slotted screw accepts only one torque wrench placement as opposed to an internal hexagon's six slot positions, which complicate torque application through restricted deep access holes and poor visibility.[51] If implants are angulated in the abutment-free CTiP method, only a certain portion of the screwdriver mates with the slot, resulting in reduced torque and leading to an insufficient preload.

Hence, a screw with an internal hexagon slot and minimal angulation of the screwdriver to the slot provide for proper preload. Together with passivation of the prosthetic superstructure, this will lay the foundation for a reliable screw joint under clinical wear. Regardless of the more or less passive fit, annual retorquing of the screws after the first year in service is essential.[57]

Conclusion

Based on the proposition that Cresco Ti Precision bars are of better fit compared to cast bars, the following conclusions can be drawn:

- The improvement of cast bar fit with the Cresco Ti Precision technique is not able to reduce the unavoidable decrease of preload of the abutment screw.
- A general decrease of approximately 30% of initial torque values can be expected in clinical situations, independent of the implant system used.
- Using a torque controller, reliable implant bar connections can be achieved.
- Prosthetic screws with internal hexagon slots provide better force transfer of the applied tightening torque.

References

1. Berglundh T, Persson L, Klinge B. A systematic review of the incidence of biological and technical complications in implant dentistry reported in prospective longitudinal studies of at least 5 years. J Clin Periodontol 2002;29 (suppl 3):197–212.
2. Kiener P, Oetterli M, Mericske E, Mericske-Stern R. Effectiveness of maxillary overdentures supported by implants: Maintenance and prosthetic complications. Int J Prosthodont 2001;14:133–140.
3. Duyck J, Vrielinck L, Lambrichts I, et al. Biologic response of immediately versus delayed loaded implants supporting ill-fitting prostheses: An animal study. Clin Implant Dent Relat Res 2005;7:150–158.
4. Jemt T, Book K. Prosthesis misfit and marginal bone loss in edentulous implant patients. Int J Oral Maxillofac Implants 1996;11:620–625.
5. Carr AB, Gerard DA, Larsen PE. The response of bone in primates around unloaded dental implants supporting prostheses with different levels of fit. J Prosthet Dent 1996;76:500–509.
6. Jemt T. In vivo measurements of precision of fit involving implant-supported prostheses in the edentulous jaw. Int J Oral Maxillofac Implants 1996;11:151–158.
7. Behr M, Lang R, Leibrock A, Rosentritt M, Handel G. Complication rate with prosthodontic reconstructions on ITI and IMZ dental implants. Internationales Team für Implantologie. Clin Oral Implants Res 1998;9:51–58.
8. Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: A study of treatment from the time of prosthesis placement to the first annual checkup. Int J Oral Maxillofac Implants 1991;6:270–276.
9. Jemt T, Lindén B, Lekholm U. Failures and complications in 127 consecutively placed fixed partial prostheses supported by Brånemark implants: From prosthetic treatment to first annual checkup. Int J Oral Maxillofac Implants 1992;7:40–44.
10. Kallus T, Bessing C. Loose gold screws frequently occur in full-arch fixed prostheses supported by osseointegrated implants after 5 years. Int J Oral Maxillofac Implants 1994;9:169–178.
11. al-Turki LE, Chai J, Lautenschlager EP, Hutten MC. Changes in prosthetic screw stability because of misfit of implant-supported prostheses. Int J Prosthodont 2002;15:38–42.
12. Gross M, Kozak D, Laufer BZ, Weiss EI. Manual closing torque in five implant abutment systems: An in vitro comparative study. J Prosthet Dent 1999;81:574–578.
13. Haack JE, Sakaguchi RL, Sun T, Coffey JP. Elongation and preload stress in dental implant abutment screws. Int J Oral Maxillofac Implants 1995;10:529–536.
14. Laney WR, Jemt T, Harris D, et al. Osseointegrated implants for single-tooth replacement: Progress report from a multicenter prospective study after 3 years. Int J Oral Maxillofac Implants 1994;9:49–54.
15. Hecker DM, Eckert SE. Cyclic loading of implant-supported prostheses: Changes in component fit over time. J Prosthet Dent 2003;89:346–351.
16. Holst S, Blatz MB, Bergler M, Goellner M, Wichmann M. Influence of impression material and time on the 3-dimensional accuracy of implant impressions. Quintessence Int 2007;38:67–73.
17. Jemt T, Bäck T, Petersson A. Photogrammetry—An alternative to conventional impressions in implant dentistry? A clinical pilot study. Int J Prosthodont 1999;12:363–368.
18. Reiss B, Walther W. Clinical long-term results and 10-year Kaplan-Meier analysis of Cerec restorations. Int J Comput Dent 2000;3:9–23.
19. Augthun M, Zyfuss M, Spiekermann H. The influence of spruing technique on the development of tension in a cast partial denture framework. Int J Prosthodont 1994;7:72–76.
20. Yang CC, Yang HH, Ding SJ, Huang TH, Kao CT, Yan M. Characteristics of commercial quick-heating phosphate-bonded investments for the accelerated casting technique. Quintessence Int 2007;38:e271–e278.
21. Eisenmann E, Mokabberi A, Walter MH, Freesmeyer WB. Improving the fit of implant-supported superstructures using the spark erosion technique. Int J Oral Maxillofac Implants 2004;19:810–818.
22. Helldén LB, Dérand T. Description and evaluation of a simplified method to achieve passive fit between cast titanium frameworks and implants. Int J Oral Maxillofac Implants 1998;13:190–196.
23. Jemt T, Bäck T, Petersson A. Precision of CNC-milled titanium frameworks for implant treatment in the edentulous jaw. Int J Prosthodont 1999;12:209–215.
24. Jemt T, Lie A. Accuracy of implant-supported prostheses in the edentulous jaw: Analysis of precision of fit between cast gold-alloy frameworks and master casts by means of a three-dimensional photogrammetric technique. Clin Oral Implants Res 1995;6:172–180.
25. Zervas PJ, Papazoglou E, Beck FM, Carr AB. Distortion of three-unit implant frameworks during casting, soldering, and simulated porcelain firings. J Prosthodont 1999;8:171–179.
26. Sartori IA, Ribeiro RF, Francischone CE, de Mattos Mda G. In vitro comparative analysis of the fit of gold alloy or commercially pure titanium implant-supported prostheses before and after electroerosion. J Prosthet Dent 2004;92:132–138.
27. Mörmann WH. The evolution of the CEREC system. J Am Dent Assoc 2006;137 suppl:7S–13S.
28. Ortorp A, Jemt T, Bäck T, Jälevik T. Comparisons of precision of fit between cast and CNC-milled titanium implant frameworks for the edentulous mandible. Int J Prosthodont 2003;16:194–200.
29. Witkowski S, Komine F, Gerds T. Marginal accuracy of titanium copings fabricated by casting and CAD/CAM techniques. J Prosthet Dent 2006;96:47–52.
30. Riedy SJ, Lang BR, Lang BE. Fit of implant frameworks fabricated by different techniques. J Prosthet Dent 1997;78:596–604.
31. Kan JY, Rungcharassaeng K, Bohsali K, Goodacre CJ, Lang BR. Clinical methods for evaluating implant framework fit. J Prosthet Dent 1999;81:7–13.
32. Hedkvist L, Mattsson T, Hellden LB. Clinical performance of a method for the fabrication of implant-supported precisely fitting titanium frameworks: A retrospective 5- to 8-year clinical follow-up study. Clin Implant Dent Relat Res 2004;6:174–180.
33. Helldén LB, Ericson G, Olsson CO. The Cresco Bridge and implant concept: Presentation of a technology for fabrication of abutment-free, passively fitting superstructures. Int J Periodontics Restorative Dent 2005;25:89–94.
34. Calderini A, Maiorana C, Garlini G, Abbondanza T. A simplified method to assess precision of fit between framework and supporting implants: A preliminary study. Int J Oral Maxillofac Implants 2007;22:831–838.
35. Hjalmarsson L, Smedberg JI. A 3-year retrospective study of Cresco frameworks: Preload and complications. Clin Implant Dent Relat Res 2005;7:189–199.
36. Burguete RL, Johns RB, King T, Patterson EA. Tightening characteristics for screwed joints in osseointegrated dental implants. J Prosthet Dent 1994;71:592– 599.
37. Kano SC, Binon P, Bonfante G, Curtis DA. Effect of casting procedures on screw loosening in UCLA-type abutments. J Prosthodont 2006;15:77–81.
38. Norton MR. Assessment of cold welding properties of the internal conical interface of two commercially available implant systems. J Prosthet Dent 1999;81:159–166.
39. Tzenakis GK, Nagy WW, Fournelle RA, Dhuru VB. The effect of repeated torque and salivary contamination on the preload of slotted gold implant prosthetic screws. J Prosthet Dent 2002;88:183–191.

40. Sahin S, Cehreli MC, Yalçin E. The influence of functional forces on the biomechanics of implant-supported prostheses—A review. J Dent 2002;30:271–282.
41. Skalak R. Biomechanical considerations in osseointegrated prostheses. J Prosthet Dent 1983;49:843–848.
42. Naert I, Quirynen M, van Steenberghe D, Darius P. A study of 589 consecutive implants supporting complete fixed prostheses. Part II: Prosthetic aspects. J Prosthet Dent 1992;68:949–956.
43. Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants: The Toronto study. Part III: Problems and complications encountered. J Prosthet Dent 1990;64:185–194.
44. Helldén LB, Dérand T, Johansson S, Lindberg A. The CrescoTi Precision method: Description of a simplified method to fabricate titanium superstructures with passive fit to osseointegrated implants. J Prosthet Dent 1999;82:487–491.
45. Uysal H, Kurtoglu C, Gurbuz R, Tutuncu N. Structure and mechanical properties of Cresco-Ti laser-welded joints and stress analyses using finite element models of fixed distal extension and fixed partial prosthetic designs. J Prosthet Dent 2005;93:235–244.
46. Wang RR, Welsch GE. Joining titanium materials with tungsten inert gas welding, laser welding, and infrared brazing. J Prosthet Dent 1995;74:521–530.
47. de Oliveira Correa G, Henriques GE, Mesquita MF, Sobrinho LC. Over-refractory casting technique as an alternative to one-piece multi-unit fixed partial denture frameworks. J Prosthet Dent 2006;95:243–248.
48. Henriques GE, Consani S, Rollo JM, Andrade e Silva F. Soldering and remelting influence on fatigue strength of cobalt-chromium alloys. J Prosthet Dent 1997;78:146–152.
49. Al-Fadda SA, Zarb GA, Finer Y. A comparison of the accuracy of fit of 2 methods for fabricating implant-prosthodontic frameworks. Int J Prosthodont 2007;20:125–131.
50. Waddell JN, Payne AG, Swain MV. Physical and metallurgical considerations of failures of soldered bars in bar attachment systems for implant overdentures: A review of the literature. J Prosthet Dent 2006;96:283–288.
51. Goheen KL, Vermilyea SG, Vossoughi J, Agar JR. Torque generated by handheld screwdrivers and mechanical torquing devices for osseointegrated implants. Int J Oral Maxillofac Implants 1994;9:149–155.
52. Carr AB, Brunski JB, Hurley E. Effects of fabrication, finishing, and polishing procedures on preload in prostheses using conventional "gold' and plastic cylinders. Int J Oral Maxillofac Implants 1996;11:589–598.
53. Haraldson T, Karlsson U, Carlsson GE. Bite force and oral function in complete denture wearers. J Oral Rehabil 1979;6:41–48.
54. Ono T, Kumakura I, Arimoto M, et al. Influence of bite force and tongue pressure on oro-pharyngeal residue in the elderly. Gerodontology 2007;24:143–150.
55. Duyck J, Van Oosterwyck H, Vander Sloten J, De Cooman M., Puers R, Naert I. Magnitude and distribution of occlusal forces on oral implants supporting fixed prostheses: An in vivo study. Clin Oral Implants Res 2000;11:465–475.
56. Zarone F, Apicella A, Nicolais L, Aversa R, Sorrentino R. Mandibular flexure and stress build-up in mandibular full-arch fixed prostheses supported by osseointegrated implants. Clin Oral Implants Res 2003;14:103–114.
57. Al Jabbari YS, Fournelle R, Ziebert G, Toth J,Iacopino AM. Mechanical behavior and failure analysis of prosthetic retaining screws after long-term use in vivo. Part 1: Characterization of adhesive wear and structure of retaining screws. J Prosthodont 2007;17:168–180.
58. Al Jabbari YS, Fournelle R, Ziebert G, Toth J, Iacopino AM. Mechanical behavior and failure analysis of prosthetic retaining screws after long-term use in vivo. Part 4: Failure analysis of 10 fractured retaining screws retrieved from three patients. J Prosthodont 2008;17:201–210.
59. Mericske-Stern R, Grütter L, Rösch R, Mericske E. Clinical evaluation and prosthetic complications of single tooth replacements by non-submerged implants. Clin Oral Implants Res 2001;12:309–318.
60. Siamos G, Winkler S, Boberick KG. Relationship between implant preload and screw loosening on implant-supported prostheses. J Oral Implantol 2002;28:67–73.
61. Jemt T, Lekholm U, Gröndahl K. 3-year followup study of early single implant restorations ad modum Brånemark. Int J Periodontics Restorative Dent 1990;10:340–349.
62. Jaarda MJ, Razzoog ME, Gratton DG. Ultimate tensile strength of five interchangeable prosthetic retaining screws. Implant Dent 1996;5:16–19.

Literature Abstract

Tilting of splinted implants for improved prosthodontic support: A two-dimensional finite element analysis

The use of tilted implants is becoming increasingly popular in order to avoid vital structures, such as the maxillary sinuses and the mental foramina. This study evaluated the stress distribution around the neck of tilted and splinted implants and whether using this scheme is superior to using a distal cantilever design with straight implants. A 2-D model for finite element analysis was developed using two Brånemark 3.75 × 13-mm implants splinted by a titanium beam, 16 × 3 mm. The implants were embedded in bone blocks, simulating different bone properties. A small crater was created in the marginal bone around the tilted implant to simulate physiologic bone remodeling. A 7 mm distal cantilever model was compared to a distal implant (13 or 19 mm) which was tilted 45 degrees and supported the distal end of the cantilever. Also, different tilts were used to evaluate the stress around the cervical portion of the implant (0, 10, 20, 30, and 45 degrees). A force of 50 N was applied via the beam. The assumption was made that the implants had complete integration. The stress was identical at the neck of the implant irrespective of the angle of tilt. The use of cantilevers resulted in higher stress in the marginal bone around the implants. This stress was reduced to "normal" levels when the cantilever arm was eliminated by the distal implant being apically inclined to support the distal end of the cantilever. The use of a longer implant only reduced the stress marginally. This study supports the use of the all-on-4 concept developed by Nobel Biocare. Nonetheless, it is a finite element analysis study, and the results should be considered with precaution.

Zampelis A, Rangert B, Heijl L. *J Prosthet Dent* 2007;97:S35-S43. **References:** 34. **Reprints:** Dr Antonios Zampelis, Specialist Clinic for Periodontics (SPA), Medicinaregatan 12C, Goteborg, Sweden. Fax: 30-210-7758 381. E-mail: odoanz@odontologi.gu.se—*Majd Al Mardini, Hamilton, Ontario, Canada*