original research article

Fracture resistance of monolithic zirconia cantilevered frameworks in complete arch-prostheses supported by tilted or parallel implants

M. DE FRANCESCO[1], A. DI FIORE[1], G. BRUNO[2], M. GARGARI[3,4], M. MARTELLI[4], P. BARNABA[4], M. MARINO[2], A. QUERCIA[5], F.M. CERUSO[4]

[1] *Adjunct Professor, Department of Neurosciences, School of Dentistry, University of Padua, Padua, Italy*
[2] *Resident, Departments of Neurosciences, School of Dentistry, University of Padua, Padua, Italy*
[3] *Professor, Department of Clinical Science and Translational Medicine, University of Rome "Tor Vergata", Rome, Italy*
[4] *Department of Dentistry "Fra G.B. Orsenigo - Ospedale San Pietro F.B.F.", Rome, Italy*
[5] *UOC Radiology - Castel Franco Veneto - ASL 2 Treviso, Treviso, Italy*

SUMMARY

Aim. The aim of this *in vitro* study was to compare the loading force at the fracture of monolitithic zirconia cantilever substructure in complete arch-prostheses supported by tilted or parallel implants.
Material and methods. Ten anatomical models of edentulous mandible were fabricated. Five of these models had five screw-type implants embedded vertically in the intraforamica area (Brånemark protocols). The other five models had four screw-type implants in the intraforaminal area, two in front were placed vertically and two rear were tilted 30 degrees distally (All-on-4). Twelve superstructure in monolithic zirconia were fabricated, ten for the Brånemark protocols and ten All-on-4, with two cantilever for each superstructure. A static load was applied on the cantilever with a universal machine. The fracture load was monitored and the sites of fracture were identified.
Results. No statistical significant difference was found between the two techniques. Mean fracture load values was 998 N (SD 83N) for Brånemark protocols while 905 N (SD 37N) for All-on-4. Most fractures occurred at the mesial connector attack to the last abutment.
Conclusion. Zirconia cantilevered frameworks on vertical implants may tolerate higher occlusal forces before fracturing.

Key words: cantilever, zirconia, tilted implants, fracture resistance.

Introduction

Dental implants represent since many years an evidence-based treatment in the rehabilitation of the edentulous maxilla and mandible. However, there are some unfavourable conditions such as atrophy of the alveolar bone caused by previous periodontal disease that may determine an insufficient bone volume for a correct placement of the implants due to the proximity of the inferior alveolar nerve (1). In literature, a huge variety of complex implant techniques has been described: autologous and heterologous bone grafts, transposition of the inferior dental nerve, guided bone regeneration (2). On the other hand all these techniques are associated with a high cost, high morbidity and poor patient acceptance. To avoid these complicated surgical procedures, different therapeutic protocols have been proposed, such as the use of short implants (3) and/or elongate the prosthetic rehabilitation using a distal cantilever (4). However, the use of short implant is particularly limited in the posterior region presenting bone atrophy with a residual height shorter than 5 mm. In the last years, an innovative protocol based on only four implants, the All-on-4, has been proposed as a therapeutic alternative (5). The All-on-4 on the lower arch consists in four implants to rehabilitate a completely edentulous mandible with a minimal bone volume, two implants are inserted in an anterior position vertically following the jaw anatomy direction and the other two implants are inserted just anterior to the foramina and tilted distally about 30 degrees relative to the occlusal plane (5). The use of implant tilting in the maxilla and in the mandible has been demonstrated to be a valid alternative to bone grafting in alveolar bone defects (6) and there is no significance difference in the marginal bone loss between tilted and axially positioned implants (7). While bone loss has been widely studied, in literature few studies described the prosthetic complications with tilted or parallel implants. Cantilevers were used to extend implant supported full arch fixed dental prostheses (FDP) since the early applications of the Brånemark protocols and literature show promising results in the short and long run (8). Since then, using cantilevers in full arch, in multiple unit or even in single unit FDP have been relatively common in implant reconstructions. In a cohort of patients affected by periodontal disease treated and maintained by the University of Berne, implant-supported cantilever FDPs represented 8.6% of all FDPs and 27.78% of implant-supported FDPs (9).The extension of FPDs with cantilevers can not only reduce the cost of the reconstruction but also it allows for more masticatory units in cases of compromised bone conditions and, at the same time, to avoid additional surgical procedures and morbidity associated with bone grafting in both arches and sinus lift. Furthermore, the use of single implant cantilever FDP may help in solving compromising clinical situations, for example of an insufficient mesio-distal dimension in the aesthetic region. In this situation, the recommended inter-implant distance longer than 3 mm for minimising crestal bone loss between two implants is often not achievable. The use of cantilevers, however, has not been without controversy. Different Authors suggested that occlusal forces on cantilevers may be amplified by leverage action which might result in a potential damage of the structure. Finite element analysis showed that FDPs develop the highest stress at the neck of the distal tilted implant and in presence of cantilever the stress could increase up to 100% (10). Literature lack of univocal agreement for traditional titanium and Cr-Co substructures, even lower evidence can be found for zircornium dioxide structures since only a few *in vitro* and retrospective studies have been conducted on this recent material (11). The purpose of this *in vitro* study was to compare the loading force at the fracture of monolithic zirconia cantilever substructure in complete arch-prostheses supported by parallel (Brånemark protocols) or tilted implants (All-on-4).

Material and methods

A cone beam computed tomography of an edentulous lower jaw was selected. The Cad software (3Diagnosys) was used to project different implant supported rehabilitation: Brånemark protocols with five axially oriented implants positioned in the intraforamina zone parallel to the midline and an All-on-4 with two axially orientated anterior implants parallel to the midline positioned anteriorly and two distal implants tilted of 30° respect the midline always in the intraforamina zone (Figure 1). After the projecting phase, a resin-stone model of the mandible was printed (ZPrinter 310 Plus). Ten anatomical models of edentulous mandible were fabricated. Five of these models had five screw-type implants embedded vertically in the intraforaminal area (Brånemark protocols). The other five models had four screw-type implants in the intraforaminal area, two in front were placed vertically and two rear were tilted 30 degrees distally (All-on-4). The implant site preparation was already

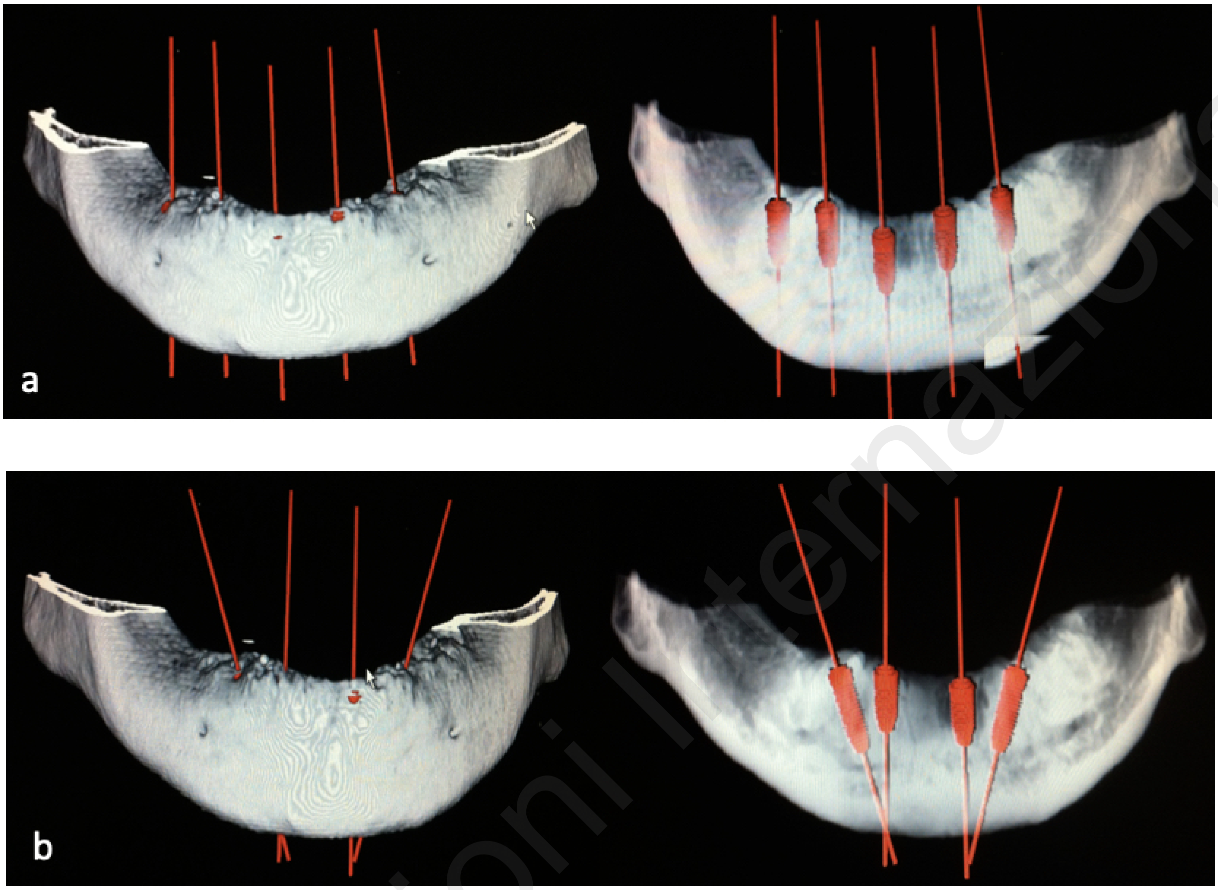

Figure 1
Different Cad projects performed for the Brånemark protocols (a) and the All-on-4 (b).

included in the lower jaw model. Implants analogues (Biotek-BTK) were used with a sticking technique. A length of 10 mm for the axially positioned implants was used while a length of 13 mm was chosen for the tilted ones. External hexagon connection with diameter of 3.75 mm was selected for the study (Figure 2). The implant shoulder was placed at the bone level. Multi unit abutment (mua) (Biotek-BTK) was connected to the implant tilted with an inclination of 30 degrees to parallel with the axis of the other implant. Mua without inclination was connect with the two axially orientated anterior implants parallel to the midline. Mua screws were tightened at 15 Ncm with a manual dynamometer. The scan-abutment was screwed to the implants analogues on the model using a standard torque of 15 Ncm with a manual dynamometer. The digital implant impression was captured with a digital scanner (Imetric D103i) without spraying powder. After the acquisition of the two model zirconia structures were projected using a CAD software (Exocad). Two different projects were performed for the Brånemark protocols and the All-on-4 (Figure 3). Ten structures for Brånemark protocols and ten structures for All-on-4 were milled from zirconia blocks (Zenostar T). The frameworks had cross-sectional area connector dimensions of 10.5 mm^2 with a diameter between 3.6 mm and 3.8 mm. The cantilever length was of 10 mm. The same structural dimensions were used for both the techniques. Finally, structures

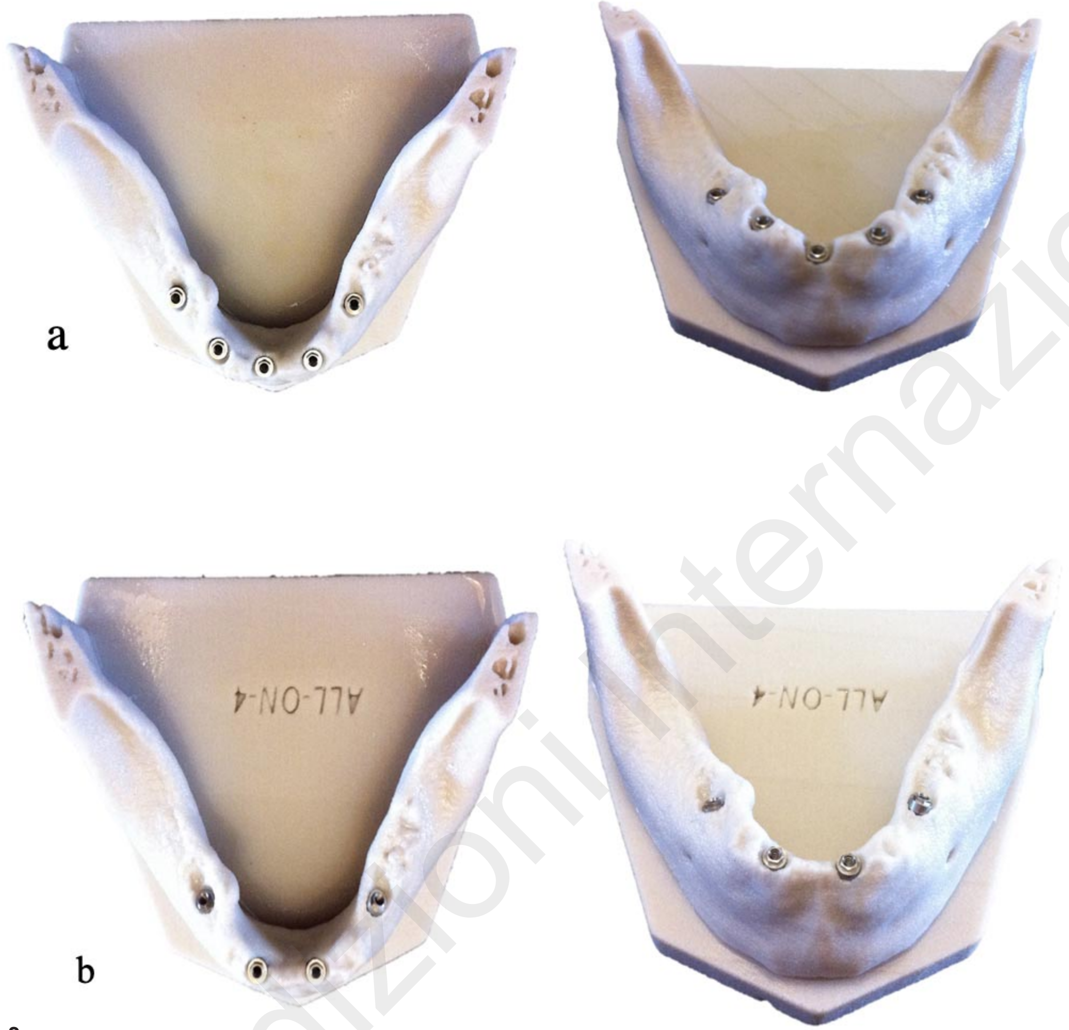

Figure 2
Resin-stone model of the mandible. a) Brånemark protocols; b) All-on-4.

were synterized for 12 hours at 1450°C following the manufacturing instructions. The vertical micro gap between the zirconia framework and model was evaluated with the Sheffield test (12). Static load tests were performed on the element of the cantilever using a universal fatigue testing machine (Instron 3366). The load was applied with a titanium sphere (diameter 1 cm) at a crosshead speed of 1.0 mm/min with a 90-degree angle on the occlusal surface until the specimen fractured to determine fracture load. A silver foil (thickness 1 mm) was placed between the occlusal surface and the titanium sphere in order to spread the loading force avoiding the concentration of the pressure on single points. The silver foil was replaced with new ones for each test. After the fracture load had been measured, the fracture site was checked. The Wilcoxon sum-rank one-tailed test was used for the statistical analysis of the data collected. The level of statistical significance was set as $\alpha = 0.05$ and with a statistical power of 80%. Descriptive and comparative statistical analysis was performed using statistical software SPSS 16.0.

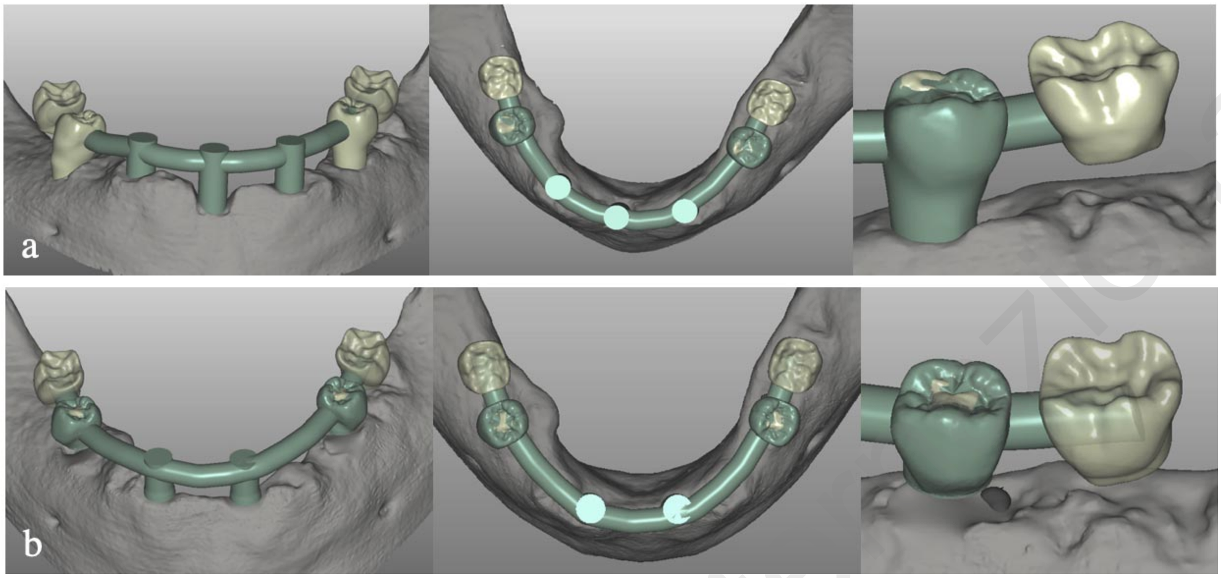

Figure 3
Zirconia structures projected using a CAD software with two different a) Brånemark protocols and b) All-on-4.

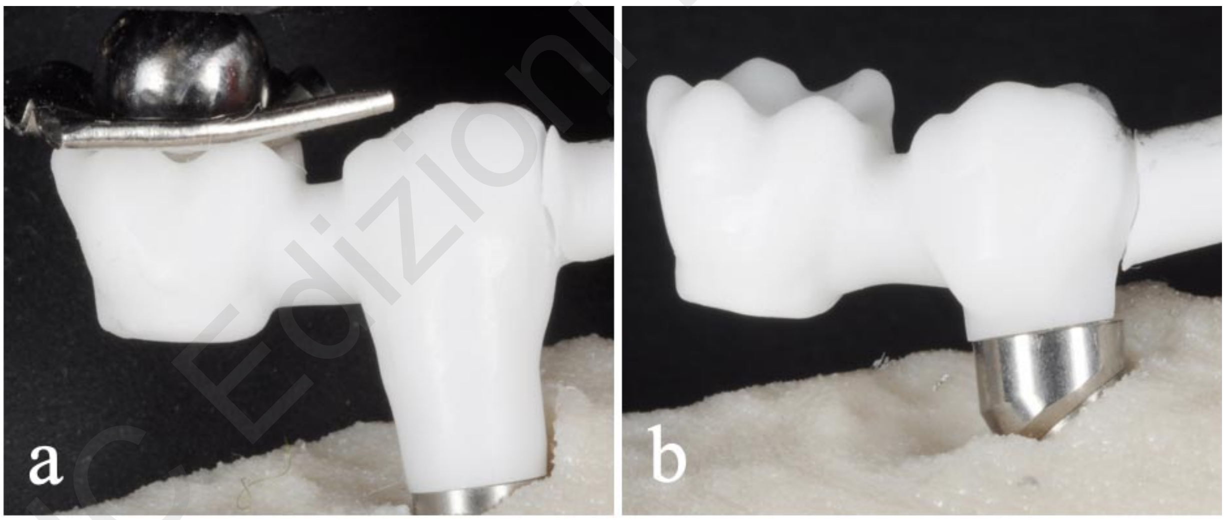

Figure 4
Fracture at the mesial terminal abutment wall with crack propagation along this wall to the connector region. a) Brånemark protocols and b) All-on-4.

Results

The mean fracture load value for Brånemark protocols structures was 998 N with a standard deviation of 83 N (Min = 859 N Max= 1190 N). Mean fracture-load value for All-on-4 was 905 N with a standard deviation of 37 N (Min = 820 N Max= 955 N). The Wilcoxon sum-rank one-tailed test showed a no statistically significant difference between the two procedures (W-value = 61.5 p-value=0.055). The mode of fracture for all speci-

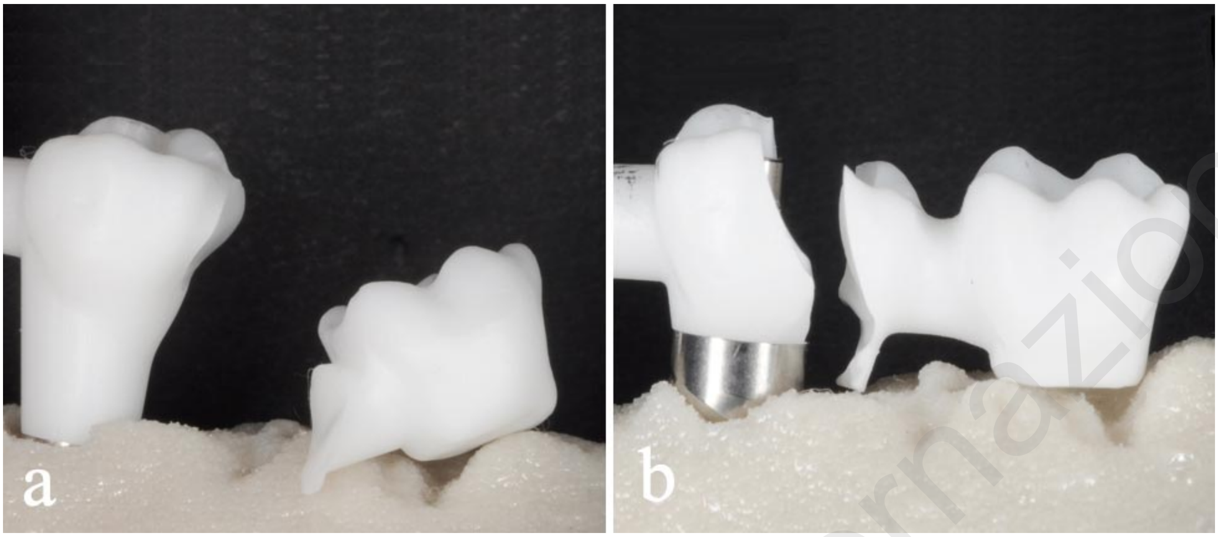

Figure 5
Fracture at the level of the cantilever with the crack extended through the distai terminal abutment wall toward the connector region. a) Brånemark protocols and b) All-on-4.

mens was different. Eleven frameworks were fractured at the mesial terminal abutment wall with crack propagation along this wall to the connector region (3 Brånemark protocols and 8 All-on-4) (Figure 4). Seven frameworks were fractured at the level of the cantilever (5 Brånemark protocols and 2 All-on-4) with the crack extended through the distal terminal abutment wall toward the connector region (Figure 5). Two frameworks designed with Brånemark protocols were fractured at level of the base of abutment (Figure 6).

Figure 6
Two frameworks designed with Brånemark protocols were fractured at level of the base of abutment.

Discussion

The use of zirconia in dentistry is becoming an increasingly common practice due to its hardness, resistance and high aesthetics. Only a few studies have been conducted to compare fracture performance of zirconia structures of different implant supported rehabilitations, particularly on distal cantilever (11). No significant statistical difference was found between fracture resistance of monolithic zirconia cantilevered frameworks in complete arch-prostheses supported by tilted (All-on-4) or parallel (Brånemark protocols) implants. The mean fracture load value for parallel implants was greater than the value obtained for the tilted implants. However, the mean bite forces in the molar region were of 847 N for men and 597 N for woman (13) and the maximum occlusal forces for cantilever fixed partial dentures were reported between 150 N and 700 N (14). Thus, both prosthetic rehabilitations are clinically acceptable and the zirconia can be a valid alternative to titanium or Cr-Co structures. In literature different studies showed a success rate for zirconia structure between the 73.4% and 93% (15); other Authors evaluated the influence of the cantilever length on marginal bone loss (16), but no research showed the way of fracture in complete arch-prostheses supported by tilted or parallel implants. Fractures often occur in the posterior region because of the shape a thickness of the structures. The effect of the cross-sectional area connector dimensions of zirconia fixed dentures on the fracture load has been studied (17, 18). CAD software often set the connector thickness at least at 5 mm^2, even if this value seems too small for an appropriate mechanical resistance of the structure. Oh et al. (19) suggested a minimum area for the connector of 6.25 mm^2. Other Authors investigated the impact of variations in the cross-sectional dimension of connector and cantilever length on zirconia implant frameworks. Chong et al. (17) concluded that zirconia implant frameworks loaded 7 mm from the distal abutment failed at higher fracture loads than specimens loaded 10 mm from the distal abutment and the specimens with cross-sectional area connector dimensions of 3x5 mm failed at higher fracture loads than specimens with cross-sectional area connector dimensions of 3x4 mm. In this study the frameworks had cross-sectional area connector dimensions of 10.5 mm^2 (diameter between 3.6 mm and 3.8 mm) with the cantilever length of 10 mm for both type of rehabilitations. The main variable that influences the resistance of the structures and the mode of fracture is the implant inclination with the presence of the multi unit abutment in the "All-on-4" technique. Seven frameworks were fractured at the level of the cantilever (5 Brånemark protocols and 2 All-on-4) with the crack extended through the distal terminal abutment wall toward the connector region, eleven were fractured at the mesial terminal abutment wall with crack propagation along this wall to the connector region (3 Brånemark protocols and 8 All-on-4) and two frameworks designed with Brånemark protocols were fractured at level of the base of abutment. Our results showed three different types of fractures. The distal fracture of the terminal abutment can be considered the most favorable mechanical complication respect the mesial fracture. However, the mesial fracture was manifested in 11 cases on 20. Thus, particular attention should be paid to the design, construction and size of the mesial connector to the terminal abutment, especially for the "All-on-4" techniques. The fractures at level of the base of abutment were showed only in two cases with Brånemark protocols. These results can be explained by the absence of Mua. However, the most mechanical complications in FDP with cantilevers included veneer fractures, screw loosening and loss of retention (20-22). It is also necessary to keep in mind the degradation of the structure due to aging, cyclic fatigue and the wet environment of oral cavity that can contribute to a premature failure of the rehabilitation. Actual knowledge highlights that aging may decrease mechanical properties of zirconia structures however showing loading values at fracture clinically acceptable (23, 24). The limitations of this study included the not completely simulate the masticatory forces, but a traditional load to failure test. However, the evidence emerged in this study needs further validation with prospective clinical investigations.

Conclusions

No significant statistical difference was found between fracture resistance of monolithic zirconia cantilevered frameworks in complete arch-prostheses supported by tilted (All-on-4) or parallel (Brånemark protocols) implants. However, the zirconia structures on vertical implants (Brånemark protocols) may tolerate higher occlusal forces before fracture.

References

1. Chiapasco M, Autelitano L, Rabbiosi D, Zaniboni M. The role of pericranium grafts in the reduction of post-operative dehiscences and bone resorption after reconstruction of severely deficient edentulous ridges with autogenous onlay bone grafts. Clin Oral Implants Res. 2013;24(6):679-87.
2. Chiapasco M, Zaniboni M, Boisco M. Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. Clin Oral Implants Res. 2006;17(S2):136-59.
3. Sivolella S, Stellini E, Testori T, Di Fiore A, Berengo M, Lops D. Splinted and Unsplinted Short Implants in Mandibles: A Retrospective Evaluation With 5 to 16 Years of Follow-up. J Periodontol. 2012;84(4):1-13.
4. Minoretti R, Triaca A, Saulacic N. Unconventional implants for distal cantilever fixed full-arch prostheses: a long-term evaluation of four cases. Int J Periodontics Restorative Dent. 2012;32(2):e59-67.
5. Maló P, Rangert B, Nobre M. All-on-4 immediate-function concept with Brånemark System implants for completely edentulous maxillae: a 1-year retrospective clinical study. Clin Implant Dent Relat Res. 2005;7 Suppl 1:S88-94.
6. Krekmanov L, Kahn M, Rangert B, Lindström H. Tilting of posterior mandibular and maxillary implants for improved prosthesis support. Int J Oral Maxillofac Implants. 2000;15(3):405-14.
7. Koutouzis T, Wennström JL. Bone level changes at axial- and non-axial-positioned implants supporting fixed partial dentures. A 5-year retrospective longitudinal study. Clin Oral Implants Res. 2007;18(5):585-90.
8. 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(6):949-56.
9. Brägger U, Hirt-Steiner S, Schnell N, et al. Complication and failure rates of fixed dental prostheses in patients treated for periodontal disease. Clin Oral Implants Res. 2011;22(1):70-7.
10. Silva GC, Mendonça JA, Lopes LR, Landre J. Stress patterns on implants in prostheses supported by four or six implants: a three-dimensional finite element analysis. Int J Oral Maxillofac Implants. 2010;25(2):239-46.
11. Chong KKH, Palamara J, Wong RHK, Judge RB. Fracture force of cantilevered zirconia frameworks: An in vitro study. J Prosthet Dent. 2014;112(4):849-56.
12. Di Fiore A, Meneghello R, Savio G, Sivolella S, Katsoulis J, Stellini E. In Vitro Implant Impression Accuracy Using a New Photopolymerizing SDR Splinting Material. Clin Implant Dent Relat Res. 2015;17:e721-9.
13. Waltimo A, Kononen M. A novel bite force recorder and maximal isometric bite force values for healthy young adults. Scand J Dent Res. 1993;101:171-5.
14. Lundgren D, Laurell L. Occlusal force pattern during chewing and biting in dentitions restored with fixed bridges of cross-arch extension. II. Unilateral posterior two-unit cantilevers. J Oral Rehabil. 1986;13:191-203.
15. Tartaglia GM, Maiorana C, Gallo M, Codari M, Sforza C. Implant-Supported Immediately Loaded Full-Arch Rehabilitations. Implant Dent. 2016;25(1):74-82.
16. Bevilacqua M, Tealdo T, Menini M, Pera F, Mossolov A, Drago C, Pera P. The influence of cantilever length and implant inclination on stress distribution in maxillary implant-supported fixed dentures. J Prosthet Dent. 2011 Jan;105(1):5-13.
17. Chong KK, Palamara J, Wong RH, Judge RB. Fracture force of cantilevered zirconia frameworks: an in vitro study. J Prosthet Dent. 2014 Oct;112(4):849-56.
18. Gargari M, Ottria L, Morelli V, Benli M, Ceruso FM. Conservative Zirconia-Ceramic bridge in front teeth. Case report. ORAL& Implantology. 2014;7(4):93-8.
19. Oh W, Götzen N, Anusavice KJ. Influence of Connector Design on Fracture Probability of Ceramic Fixed-partial Dentures. J Dent Res. 2002;81(9):623-7.
20. Pjetursson BE, Tan K, Lang NP, Br.gger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after a observation period of at least 5 years. Clin Oral Implants Res. 2004;15:625-42.
21. Gargari M, Lorè B, Ceruso FM. Esthetic and function rehabilitation of severely worn dentition with prosthetic-restorative approach and VDO increase. Case report. Oral & Implantology. 2014;7:40-5.
22. Gargari M, Prete V, Pujia A, Ceruso FM. Full-Arch Maxillary Rehabilitation Fixed On 6 Implants. ORAL& Implantology. 2013;6:1-4.
23. Manicone PF, Rossi Iommetti P, Raffaelli L. An overview of zirconia ceramics: Basic properties and clinical applications. J Dent. 2007;35(11):819-26.
24. Ceruso FM, Barnaba P, Mazzoleni S, Ottria L, Gargari M, Zuccon A, Bruno G, Di Fiore A. Implant-abutment connections on single crowns: a systematic review. Oral Implantol. 2017 Oct-Dec;10(4):349-53.

Correspondence to:
Francesco Ceruso
Department of Neurosciences School of Dentistry
University of Padua, Padua, Italy
E-mail: hello_982@yahoo.it