In Vitro Analysis of the Comprehensive Strength of Two Dental Implant Internal Connection Designs

Ayar Sami Mohammed , Ahmad Fakrurrozi Mohamad, Paul Nahas

BDS(bachelor of dental surgery)
Advanced medical and dental institute
Master of Dental Science (Dental implantology)
University sains Malaysia (USM),Malaysia

DDS (doctor dental surgery) Craniofacial and biomaterial science cluster, advanced medical and dental institute (supervisor)
University Sains Malaysia (USM),Malaysia

BDS CES DSO
associate prof. faculty of dental medicine Lebanese
university sains Malaysia

Abstract:
Introduction: Dental implants are the most effective treatment for replacing missing teeth. This study compares the mechanical strength of a commonly used internal hexagonal connector with a newer octagonal internal connector design.
Materials and Methods: Two groups, each with 10 dental implant specimens, were established based on connector design: the Control group (hexagonal internal connector) and the Test group (octagonal internal connector). Static pressure was applied using a universal testing machine following ISO 14801 standards at angles between 25° and 30°. The force resistance was measured, and data were analyzed using a T-test with a significance level set at $p < 0.05$.
Results: The octagonal design exhibited an average force resistance of 685.9 N (±X N), compared to 650 N (±Y N) for the hexagonal design. The difference was not statistically significant ($p = 0.308$), leading to acceptance of the null hypothesis and rejection of the alternative hypothesis.
Conclusion: While the octagonal internal connector showed a higher average force resistance than the hexagonal connector, the difference lacked statistical significance. Both connector designs contribute to the durability and strength of dental implants, suggesting that either design may be effectively utilized in clinical practice.
Keywords: Dental implant, internal hexagonal connector, internal octagonal connector, mechanical strength, static force.

Introduction

Dental implants play a crucial role in modern dentistry, offering a viable solution for replacing missing teeth. Since their introduction for the restoration of totally edentulous patients in the late 1960s, dental implants have significantly evolved (Adell et al., 1981) Numerous studies confirm that masticatory forces in humans can exceed 800 N(Braun et al., 1995; Carr and Laney, 1987; Raadsheer et al., 1999). While early research focused on comparing external and internal joint designs of dental implants, internal connectors have become predominantly utilized in contemporary practice due to their superior mechanical stability and ease of use(Kofron et al., 2019).

Currently, internal connectors are the most commonly used type in dental implants. This study aims to compare two types of internal connectors for modern dental implants: the widely used hexagonal internal connector and the newest generation design, the octagonal internal connector. The increasing global utilization of dental implants, driven by advancements in marketing and the high demand for cosmetic dentistry, has positioned the dental implant market to reach an estimated value of $13 billion in 2023 (Alghamdi and Jansen, 2020). This growth underscores the need for continuous improvements in implant design to ensure durability and patient satisfaction.

The octagonal connector, featuring eight sides, was developed by Omniloc Sulzer to enhance mechanical stability and reduce the risk of mechanical failure under high masticatory forces .(Muley et al., 2012; Prithviraj et al., 2013; Ventura et al., 2012) By comparing the hexagonal and octagonal internal connectors, this study seeks to determine whether the advanced octagonal design offers significant improvements in mechanical strength, potentially influencing clinical decision-making and future implant designs.

Materials and method

Sample Size Calculation

The sample size was determined using the two-sample mean formula for a T-test and the Power Sample Size Program. Based on these calculations, a total of 20 specimens (10 hexagonal and 10 octagonal) were required for both groups, as outlined in the following table.

Specimen Selection and Preparation

All dental implant fixtures selected for this study were restored with metal crowns. The implants were categorized into two groups based on connector design:

- **Group A (Control):** 10 hexagonal internal connector implants (Ø 4.0-3.5 mm, 10 mm length; Bionnovation, Brazil)
- **Group B (Test):** 10 octagonal internal connector implants (Ø 4.1-3.7 mm, 10 mm length; Mode-Co., Turkey) Both groups were manufactured from Titanium Grade 4 to ensure consistency in material properties.

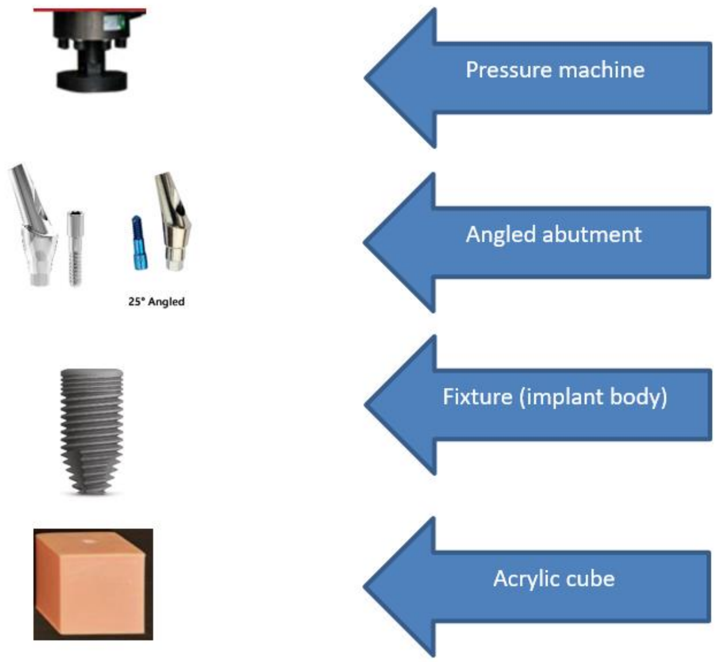


Figure 1 stages of material assembly

Figure 2 illustrates the samples for both groups

Experimental Procedure

Each implant fixture was securely mounted in a standardized testing apparatus to ensure uniformity during testing. A universal testing machine applied static pressure to each specimen. The testing angle was maintained between 25° and 30°, adhering to the international standard ISO 14801. The force resistance of each implant was measured, and data were recorded for subsequent statistical analysis.

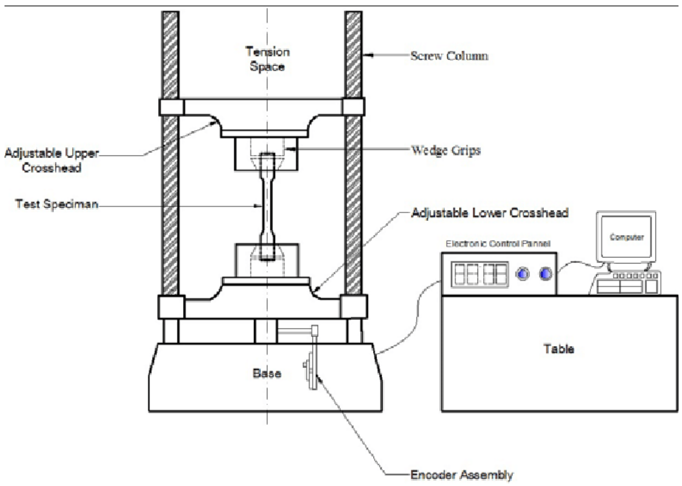
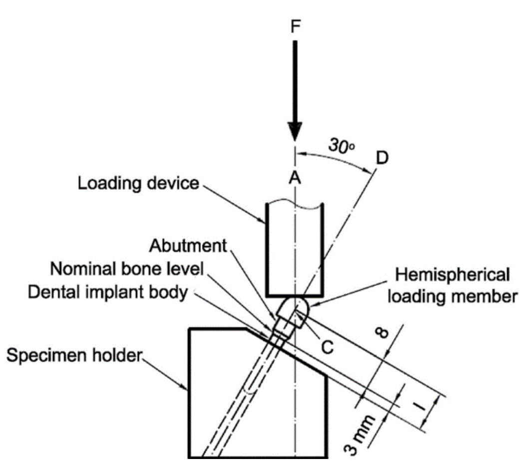
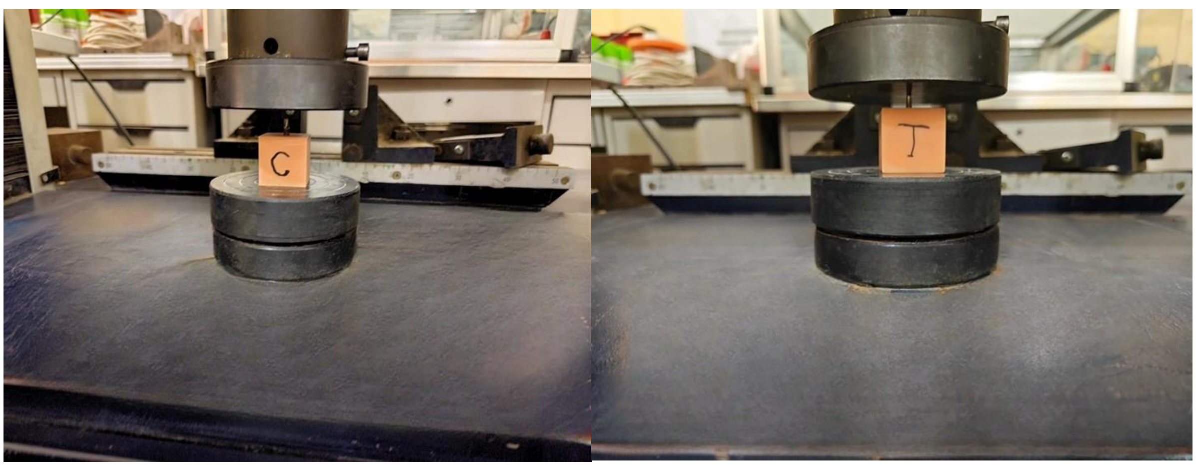


Figure 3 schematic diagram of universal testing machine(“Fig. 5,” n.d.)



("Fig. 2 Schematic of test setup according to The ISO 14801 recommendations," n.d.)



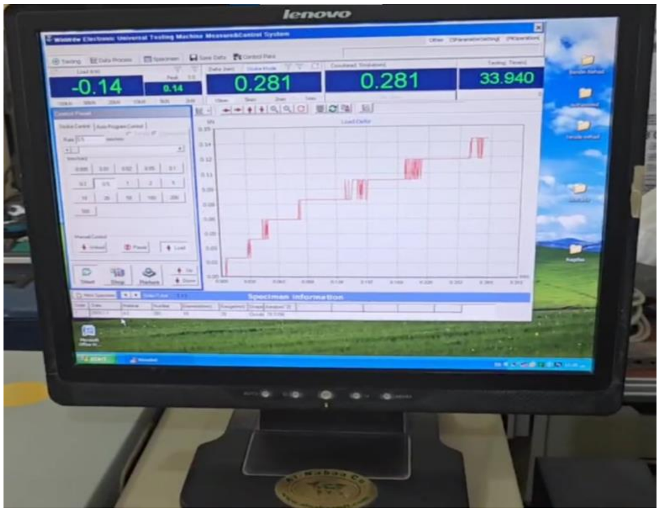


Figure 5 laboratory experiments

Statistical Analysis

Data were analyzed using an independent T-test to compare the mean force resistance between the hexagonal and octagonal internal connector groups. The significance level was set at $p < 0.05$. All statistical analyses were performed using [Specify Software, e.g., SPSS Version X.0].

Result

The compressive force resistance of dental implant internal connectors was evaluated for both hexagonal and octagonal designs. The octagonal internal connector group exhibited a higher average compressive force (**MEAN = 685.9 N**) compared to the hexagonal internal connector group (**MEAN = 650 N**). However, this difference was not statistically significant (**p = 0.308**), as the p-value exceeded the conventional threshold for significance (**p < 0.05**) (Table 1). Consequently, the null hypothesis was accepted, and the alternative hypothesis was rejected.

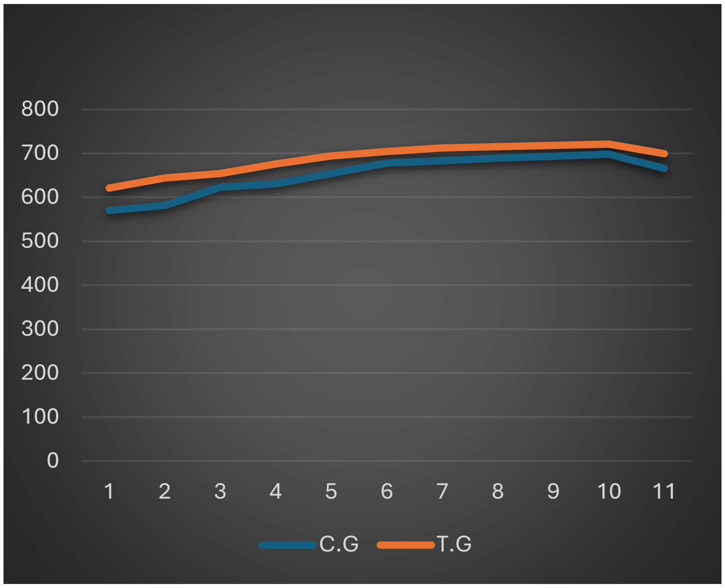


Table 1: Comparison of compressive strength (N) between test group and control group.

Table 2: Mean Compressive Force Resistance of Hexagonal and Octagonal Internal Connectors

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
CF in N	Control Group	10	650.00	46.921	14.838
	Test Group	10	685.90	35.382	11.189

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CF in N	Equal variances assumed	1.101	.308	-1.932	18	.069	-35.900	18.583	-74.942	3.142
	Equal variances not assumed			-1.932	16.734	.070	-35.900	18.583	-75.155	3.355

.

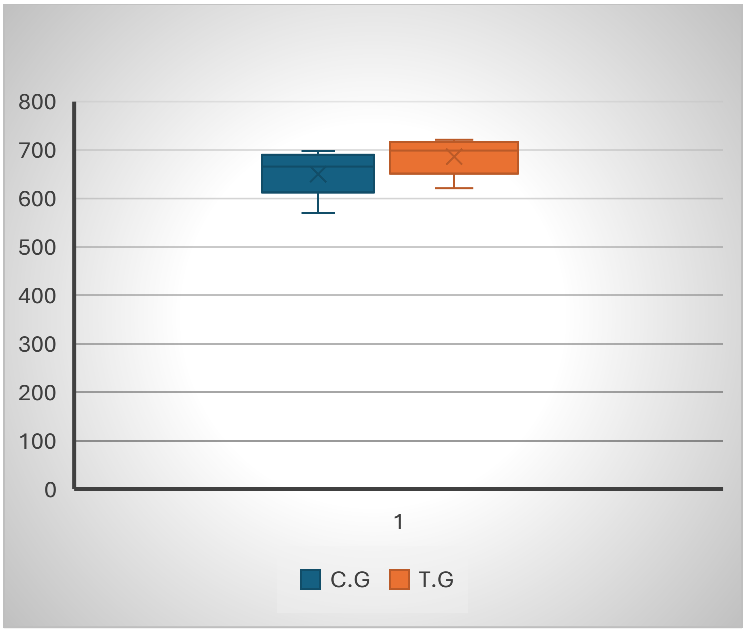


Table 3 Box plot shows the differences between the control group and the test group

Discussion

Numerous studies have explored the comparative advantages and disadvantages of these two design features.

One of the key benefits of the hexagonal internal connection is its potential for improved load distribution and stress transfer between the implant and the surrounding bone. The hexagonal design is thought to provide a more stable and secure interface, potentially leading to better long-term implant performance. Additionally, the hexagonal shape may offer better resistance to rotational forces, which could be important in certain clinical scenarios.

On the other hand, the octagonal internal connection has been proposed as an alternative that may offer improved aesthetics and a more natural emergence profile. Some research has suggested that the octagonal design may allow for a more precise and consistent fit between the implant and the abutment, potentially reducing the risk of micromovement and improving overall stability .

Ultimately, the decision between hexagonal and octagonal internal connections should be based on a careful evaluation of the specific clinical situation, the patient's oral anatomy and biomechanical requirements, as well as the surgeon's preference and experience. Long-term clinical studies with robust methodologies are still needed to definitively determine the optimal implant design for different clinical scenarios.

Previous studies have consistently confirmed that implant failure related to screw loosening ranges from 2% to 45%, particularly in single restored crowns, which are more susceptible to this complication(Goodacre et al., 1999). Unfortunately, information provided by dental implant manufacturers regarding complications related to implant connections is scarce, and the data on Dental Implant Connections (DIC) is limited (Cressie and Whitford, 1986).

Clinically, the jawbone varies significantly among patients due to several conditions, influencing implant stability and success(Balik et al., 2012). Titanium remains the most widely used material for fabricating dental implants due to its excellent osseointegration properties with bone, despite the availability of various titanium grades (Janeček et al., 2015). Advances in materials used for DIC have the potential to enhance implant stability, particularly mechanical stability (Park et al., 2016).

Some companies have begun modifying DIC designs to improve stability and reduce the incidence of screw loosening. For example, Astra Tech Dent has focused on enhancing connector stability to make implants more resistant to loosening (Richter, 1995). Studies have reported that the maximum load values on implants range from 299 N to 847 N, depending on the area of the jaw (incisors or molars) (Roohafza et al., 2016).

Previous research has primarily focused on comparing external dental implant connectors with internal ones. Additionally, some studies have examined other connector types, such as the Morse taper, with findings suggesting that more tapered connectors are more durable compared to hexagonal connectors. However, other studies have found no significant differences between these designs. In recent times, some companies have begun producing implants that incorporate both hexagonal and Morse-taper designs, aiming to combine the advantages of both connector types.

Our study compared the hexagonal internal joint design with the octagonal internal joint design in dental implants, as the octagonal design represents a newer advancement. The octagonal connector, featuring eight sides, was developed to enhance mechanical stability and reduce the risk of screw loosening(Prithviraj and Muley, 2012). Although the octagonal design demonstrated a higher average compressive force resistance (MEAN = 685.9 N) compared to the hexagonal design (MEAN = 650 N), this difference was not statistically significant ($p = 0.308$). This finding aligns with some previous studies that reported no significant differences between certain internal connector designs (Richter, 1995).

The lack of statistical significance in our results may be attributed to the limited sample size, which could affect the study's power to detect subtle differences between the connector designs. Additionally, in vitro testing conditions may not fully replicate the complex biomechanical environment present in the oral cavity. Future research should consider larger sample sizes and in vivo studies to better assess the clinical performance of different internal connector designs.

Despite the non-significant difference, the trend towards higher compressive force resistance in octagonal connectors suggests a potential for improved mechanical stability. This could have clinical implications, as enhanced stability may reduce the likelihood of screw loosening and implant failure, thereby increasing the longevity of dental implants. Manufacturers may consider further refining octagonal designs or exploring hybrid connector types to maximize the benefits of both hexagonal and Morse-taper systems.

In conclusion, while the octagonal internal connector showed a higher average compressive force resistance, the difference was not statistically significant in our study. Nevertheless, the ongoing development and improvement of internal connector designs are crucial for advancing dental implant technology and ensuring long-term success in clinical applications.

Conclusion

The choice of implant neck design has long been a subject of discussion in the field of dental Implantology. Two commonly used connector geometries are the hexagon and the octagon, each with its own set of advantages and considerations.

Hexagonal internal connections have been a mainstay in the industry, providing a stable and reliable interface between the implant fixture and the prosthetic components. Their symmetrical shape allows for precise rotational orientation and even distribution of forces, which is crucial for the long-term success of the implant-supported restoration. In contrast, octagonal connections offer an increased number of rotational positions, potentially providing greater flexibility in component positioning and enhanced esthetic outcomes.

However, the implications of these differing geometries on biomechanical performance and clinical outcomes are not fully clear. A study comparing the stress distribution patterns in 3-unit fixed partial dentures supported by implants with hexagonal and octagonal collars found that the octagonal design exhibited slightly lower stresses in the surrounding bone and prosthetic components(Merİç et al., 2011). This suggests that the additional rotational positions offered by the octagon may marginally improve load distribution.

Conversely, some research has indicated that the hexagonal configuration may provide a more secure connection, potentially reducing the risk of abutment or screw loosening over time.

This study, along with previous research, focused on comparing different types of implant connectors within dental implants, including external versus internal connectors and various internal designs such as hexagonal and octagonal shapes. The primary aim was to identify designs that could minimize future complications and enhance implant durability. Our findings indicated a higher average compressive force resistance for the octagonal internal connector compared to the hexagonal design. However, this difference was not statistically significant ($p = 0.308$). Despite the lack of statistical significance, the trend favoring the octagonal design suggests potential benefits in mechanical stability. These insights contribute to the ongoing development of dental implants by evaluating connector designs to ensure their strength and longevity. Future research with larger sample sizes and in vivo studies is recommended to explore further the efficacy of octagonal connectors and their clinical implications.

My main supervisor, Dr. Ahamad Fakrurrozi Bin Mohamad, deserves special gratitude for his support, guidance, patience, and encouragement throughout the research.

I would also like to express my warmest gratitude to my co-supervisor Associate Professor Dr. Paul Nahas for continuously guiding me throughout this project with insightful feedback. In addition, I would like to extend my gratitude to Dr Ameer A.Kadhim, for helping me during data collection and laboratory requirements.

Reference

Adell, R., Lekholm, U., Rockler, B., Brånemark, P.-I., 1981. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int. J. Oral Surg. 10, 387–416.

Alghamdi, H.S., Jansen, J.A., 2020. The development and future of dental implants. Dent. Mater. J. 39, 167–172.

Balik, A., Karatas, M.O., Keskin, H., 2012. Effects of different abutment connection designs on the stress distribution around five different implants: a 3-dimensional finite element analysis. J. Oral Implantol. 38, 491–496.

Braun, S., Bantleon, H.-P., Hnat, W.P., Freudenthaler, J.W., Marcotte, M.R., Johnson, B.E., 1995. A study of bite force, part 1: Relationship to various physical characteristics. Angle Orthod. 65, 367–372.

Carr, A.B., Laney, W.R., 1987. Maximum occlusal force levels in patients with osseointegrated oral implant prostheses and patients with complete dentures. Int. J. Oral Maxillofac. Implants 2.

Cressie, N.A.C., Whitford, H.J., 1986. How to use the two sample t-test. Biom. J. 28, 131–148.

Fig. 2 Schematic of test setup according to The ISO 14801 recommendations [WWW Document], n.d. . ResearchGate. URL https://www.researchgate.net/figure/Schematic-of-test-setup-according-to-The-ISO-14801-recommendations_fig2_330367685 (accessed 1.9.24).

Fig. 5: Schematic diagram of Tensile Testing Machine [WWW Document], n.d. . ResearchGate. URL https://www.researchgate.net/figure/Schematic-diagram-of-Tensile-Testing-Machine_fig5_289029747 (accessed 2.18.25).

Goodacre, C.J., Kan, J.Y., Rungcharassaeng, K., 1999. Clinical complications of osseointegrated implants. J. Prosthet. Dent. 81, 537–552.

Janeček, M., Nový, F., Harcuba, P., Stráský, J., Trško, L., Mhaede, M., Wagner, L., 2015. The very high cycle fatigue behaviour of Ti-6Al-4V alloy. Acta Phys. Pol. A 128, 497–502.

Kofron, M.D., Carstens, M., Fu, C., Wen, H.B., 2019. In vitro assessment of connection strength and stability of internal implant-abutment connections. Clin. Biomech. 65, 92–99.

Merİç, G., Erkmen, E., Kurt, A., Eser, A., Özden, A.U., 2011. Biomechanical effects of two different collar implant structures on stress distribution under cantilever fixed partial dentures. Acta Odontol. Scand. 69, 374–384. https://doi.org/10.3109/00016357.2011.572287

Muley, N., Prithviraj, D., Gupta, V., 2012. Evolution of external and internal implant to abutment connection. Int J Oral Implant. Clin Res 3, 122–129.

Park, S.-J., Lee, S.-W., Leesungbok, R., Ahn, S.-J., 2016. Influence of the connection design and titanium grades of the implant complex on resistance under static loading. J. Adv. Prosthodont. 8, 388–395.

Prithviraj, D., Muley, N., 2012. Evolution of External and Internal Implant to Abutment Connection. Int. J. Oral Implantol. Clin. Res. 3, 122–129. https://doi.org/10.5005/JP-Journals-10012-1079

Prithviraj, D.R., Gupta, V., Muley, N., Sandhu, P., 2013. One-Piece Implants: Placement Timing, Surgical Technique, Loading Protocol, and Marginal Bone Loss. J. Prosthodont. 22, 237–244. https://doi.org/10.1111/j.1532-849X.2012.00928.x

Raadsheer, M., Van Eijden, T., Van Ginkel, F., Prahl-Andersen, B., 1999. Contribution of jaw muscle size and craniofacial morphology to human bite force magnitude. J. Dent. Res. 78, 31–42.

Richter, E.-J., 1995. In vivo vertical forces on implants. Int. J. Oral Maxillofac. Implants 10.

Roohafza, H., Afshar, H., Keshteli, A.H., Shirani, M.J., Afghari, P., Vali, A., Adibi, P., 2016. Masticatory ability with depression, anxiety, and stress: Does there exist any association? Dent. Res. J. 13, 211.

Ventura, P.R.R., Poiate, I.A.V., Junior, E.P., de Vasconcellos, A.B., 2012. Evaluation of Stress Distribution in Implant-Supported Restoration Under Different Simulated Loads, in: Finite Element Analysis-From Biomedical Applications to Industrial Developments. IntechOpen.