MEDICAL SCIENCES

A COMPARATIVE ANALYSIS OF DIFFERENT TYPES OF IMPLANT ABUTMENTS USED IN DENTAL IMPLANT TREATMENT

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https://doi.org/10.5281/zenodo.14679363

Abstract

Dental implant treatment has become a standard procedure for treating edentulous patients. Advances in technology have simplified treatment protocols; however, treatment planning remains the most critical and complex aspect. This article examines the advantages and disadvantages of various types of dental implant abutments and aims to provide clarity in selecting this essential component of implant therapy.

Keywords: dental implant, abutment, CAD/CAM, dentistry, prosthetic treatment

Introduction: The advancement of technology has led to significant progress in dental medicine. CAD/CAM technologies, intraoral scanning, and digitally guided implantology have made previously challenging procedures both accessible and popular, overcoming the limitations posed by outdated equipment.

In recent years, dental implant therapy has become a routine procedure. Despite the facilitation provided by specialized dental software, clinicians must meticulously plan and analyze every aspect of implant placement and subsequent prosthetic restoration. Particular emphasis is placed on the selection of prosthetic components upon which the final structures are mounted.

The dental implant abutment serves as the critical connecting link between the implant and the crown [1].

The aim of this literature review is to analyze the various types of implant abutments used in prosthetic treatments involving dental implants.

Titanium Abutments

Titanium abutments are regarded as the "gold standard" for application in all areas of the oral cavity [2, 3, 4, 5, 6]. The first prosthetic abutments (original Branemark abutment) were hollow cylinders with an internal hexagon and a fixation screw.

The commercial market offers a wide variety of implant abutments, with each manufacturer adopting its own standardized type of abutment available in several variations.

In the literature [7, 8, 9, 10, 11, 12, 13,14], they are generally classified as:

- Temporary abutments
- Permanent abutments (prefabricated and customized).

Prefabricated (standard) Abutments

Temporary standard abutments can be made of titanium, polymethyl methacrylate, or polyetheretherketone. These abutments allow for clinical customization to create an optimal design for the peri-implant mucosa. Permanent prefabricated abutments, on the other hand, can undergo modifications through reduction or reshaping.

Permanent prefabricated abutments are most commonly manufactured from titanium alloy but can also be made from zirconium dioxide. Standardized titanium abutments are the most widely used due to their ease of application and lower cost compared to other types [15, 16]. They are available in several standardized variations based on height, size, and shape.

Factory-produced abutments can be either straight or angled, with the angulation typically limited to a few options, most commonly 15 and 20 degrees. Modifications are often necessary to adapt the abutments as closely as possible to the specific clinical case. The height and width of the transmucosal portion are also predefined by the manufacturer in several variations.

Standard abutments can be designed with a gingival margin or without one, depending on the clinical needs.

Titanium Bases

Titanium bases are a type of prefabricated abutment with a specific geometric design, used in CAD/CAM technology for the fabrication of metal-free definitive restorations. These bases are also standardized in terms of diameter, height, and the dimensions of the transmucosal zone. They can be straight or angled.

The use of titanium bases allows for achieving a higher aesthetic outcome, making them a preferred choice in the anterior and premolar regions. Some authors highlight their advantages over zirconia abutments, which are associated with weaker connections and greater susceptibility to fracture [15, 17, 18, 19].

Another advantage of titanium bases is their extraoral adhesive fixation to the prosthetic restoration. This process enables precise control over excess cement around the implant superstructure, a critical factor in reducing peri-implant complications [20, 21, 22, 23].

Permanent Customized Abutments

This type of abutment can be fabricated from titanium alloy, zirconium dioxide, lithium disilicate, or a combination of different materials (known as hybrid abutments).

Characteristics of Customized Abutments

Customized abutments can be classified by the material used in their fabrication. They may be entirely titanium, zirconia, or a combination of titanium and other materials, referred to as hybrid abutments. Titanium customized abutments are milled entirely from titanium alloy, while hybrid abutments combine a titanium base with an adhesively bonded aesthetic material (zirconium dioxide or lithium disilicate). This aesthetic component mimics the shape of a tooth stump and transmucosally replicates the architecture of the peri-implant mucosal tissue (PIMT). In the literature, the aesthetic component of the hybrid abutment is often referred to as the "mesoabutment."

The use of hybrid abutments aims to combine the advantages of titanium and zirconia abutments while eliminating their respective drawbacks [24]. Some authors suggest PEEK (polyetheretherketone) as a material for permanent prosthetics, arguing that it reduces the risk of implant overload and minimizes wear on adjacent teeth [25, 26, 27, 28, 29, 30].

The concept of Virtual Abutment Design (VAD), a part of CAD technology, is based on the idea that the shape of the abutment should be determined by the morphology of the restoration it will support [31].

As early as 1996, Marchack [32] presented a clinical case involving the prosthetic restoration of an upper central incisor using a customized titanium abutment. He noted several advantages of customized abutments over standardized ones. According to Marchack and other authors, customized abutments can eliminate many of the complications observed with prosthetic treatments that use prefabricated abutments [32, 33, 34, 35, 36].

The main advantages of customized abutments, as described in the literature, are:

- Creation of an optimally precise connection with the implant [37];
- Elimination or reduction of unfavorable implant angulation;
- Adequate compensation for the interdental space of the defect;
- Creation and maintenance of the design of the peri-implant mucosa [38, 39];
- Optimal transmission of chewing forces to the implant and surrounding periodontal tissues.

According to some authors, implant-supported individualized abutments can serve as a means to model the soft tissues around the restoration. Tselios et al. [40] utilize temporary individualized abutments, milled using CAD/CAM technology, in immediate implant prosthetics in the anterior region, with which they shape a better emergence profile and model the peri-implant mucosa. This approach eliminates subsequent aesthetic complications and leads to stable, predictable clinical outcomes. This protocol has also been described in other publications [41].

Other authors [42, 43] apply individualized abutments in cases where there are anatomical limitations, such as insufficient clearance from the antagonist and large interproximal spaces. Individualized abutments are also used in cases where parallelism between the individual implants involved in a common restoration cannot be achieved [44].

According to Tripodakis et al. and Furhauser et al. [45, 46], individualized abutments replicate the emergence profile of the natural tooth with maximal precision, eliminating the possibility of over-contouring the entire superstructure caused by the volumetric cylindrical cross-section of the standardized abutment and the thickness of the definitive prosthetic restoration. Parpaiola and Yildirim et al. [47, 48] emphasize the risk of peri-implantitis as a complication due to the deep marginal edge of the standardized implant abutment and residual cement subgingivally, which can lead to bone loss and an unsatisfactory treatment outcome.

Comparative Characteristics of Different Types of Abutments

A number of studies highlight the thickness of the mucosa as an important characteristic for aesthetics, particularly in the anterior region [32, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59]. One of the significant disadvantages of permanent titanium alloy abutments is the greying of the peri-implant mucosal tissue (PIMT) caused by their color [32, 60, 61, 62, 63, 64, 65]. To eliminate this drawback, zirconium dioxide abutments have been introduced into clinical practice.

Due to their colour, ceramic abutments are considered more suitable for restorations in the aesthetic zone [66], although other authors have found that the thickness of the gingiva is a leading factor, regardless of the abutment colour [17]. According to Sailer et al. [17], a thickness of attached gingiva less than 2 mm compromises aesthetics for both types of individualized abutments.

According to Smith and Turkyilmaz [7], zirconium dioxide abutments are not recommended as the first choice unless high aesthetics in the anterior region are the primary goal. The authors emphasize that their application should be limited due to the greater micro-crack formation and the potential for micro-leakage at the implant-abutment interface. Similar concerns are raised regarding individualized titanium abutments, which leads to the conclusion that standardized abutments are optimally applied in all areas of the oral cavity.

On the other hand, Yuzugullu and Avci [67] report that the vertical micro-crack in titanium and zirconium CAD/CAM abutments is similar, ranging from 2.5 to 3.2 μm, which is comparable to that observed in factory-made abutments. In contrast, Lopes et al. [68] express a different view, finding better accuracy in standardized abutments.

Micro-movement can often be a cause of fracture in zirconium dioxide abutments at the implant-abutment interface. For this reason, R. Kelly [69] recommends the use of titanium bases, which reduce the possibility of fractures and micro-leakage.

Fatigue and the risk of fractures are significant complications in implant prosthetic treatment. Foong et al. [70] investigate the fatigue of titanium alloy and zirconium dioxide abutments and determine that fatigue is greater in the latter. According to their findings, the failure rate is directly dependent on the material type and the design of the abutment.

The survival of zirconium dioxide abutments can be influenced by the manufacturing method, the thickness of the abutment, and the position of the implant.

According to several in vitro studies, zirconium dioxide abutments are more prone to fractures compared to those made of titanium alloy [2, 71, 72, 73]. Lin et al. [38] define the connection between titanium implants and zirconium abutments as unsatisfactory, which has been confirmed by other studies as well [74].

In their in vitro study, Stimmelmayr et al. [75] analyze wear resistance under electron microscopy and find that zirconium abutments exhibit 10 times higher values than titanium abutments.

The application of hybrid abutments aims to combine the advantages of titanium and zirconium abutments while eliminating their disadvantages.

Elsayed et al. [15] subjected implant superstructures made of lithium disilicate to fatigue testing. The team applied dynamic loading of 1.2 million chewing cycles and found fractures only in the zirconium dioxide abutment group.

In another study [76], the authors note the limited application of hybrid abutments solely in the anterior region due to the risk of fractures in distal areas.

Various laboratory studies report a high survival rate for test specimens with titanium abutments, while others report a 43.8% failure rate when testing the same superstructures [55, 15, 77].

The creation of an individualized design for the transmucosal part and positioning of the margin preparation in individualized implant abutments is used as a tool to prevent complications resulting from residual cement in the subgingival area, which can lead to inflammatory changes in the soft tissues and negatively affect the prosthetic treatment [78]. Korsch and Walther [79] clinically investigate metal factory-made and individualized abutments in single implant restorations and find a 0% loosening of the fixing screw with individualized abutments and 7.7% with standardized ones. Hosseini et al. [80] compare single implant abutments made of zirconium dioxide with prosthetic restorations of the same material and metal abutments with metal-ceramic crowns in the premolar region based on biological, mechanical, and aesthetic criteria. The results show no significant difference in the parameters studied. No colour change in the peri-implant gingiva was observed, and patient feedback indicates no aesthetic difference between the materials, although professional aesthetic assessments noted such differences.

Sailer et al. [63] also compare individualized zirconium dioxide and titanium abutments based on the characteristics mentioned above and find no significant difference between the two materials. The authors report that more plaque was found on structures with zirconium dioxide abutments. Zembic et al. [81] reach the same conclusion after investigating the same criteria over a three-year period.

Bosch et al. [82] compare the biomechanical behavior of zirconium dioxide implant superstructures and metal-ceramic crowns with titanium abutments. They conclude that both studied groups exhibit similar qualities, with statistically insignificant differences in the evaluated parameters. In their publication, Otero et al. [83], supported by Rompen et al. [84], conclude that individualized abutments with a concave profile have a positive effect on the stability of peri-implant mucosal tissue (PIMT). Bompolaki et al. [42] report a higher number of functional complications with implant superstructures featuring factory-made abutments compared to hybrid abutments with lithium disilicate.

According to Schepke et al. [85], the advantages of individualized over factory-made abutments remain unclear. The team compared standardized and individualized zirconium abutments and found no statistically significant differences over a one-year period. Long et al. [86] express the opinion that individualized abutments, milled using CAD/CAM technology, exhibit good survival rates compared to conventional abutments.

Our laboratory studies on fatigue and fracture resistance show twice the mechanical strength in implant superstructures, which are a combination of monolithic zirconium dioxide and a titanium base, compared to individualized titanium abutments with the same type of crown [87]. The same test groups were subjected to clinical examination to assess their biomechanical behavior. The results demonstrated excellent survival rates for all types of abutments but also highlighted the previously mentioned advantages of individualized titanium alloy abutments [88].

Conclusion: The selection of the appropriate implant abutment based on the individual characteristics of each patient is a leading factor in achieving high aesthetic outcomes. Prosthetic treatment with a correctly chosen abutment ensures functional stability and is directly linked to maintaining the soft tissue profile and aesthetics.

Despite the trend towards unifying and standardizing prosthetic treatments, factory-made solutions often fail to meet the individual needs and personal requirements of each patient. In some clinical cases, the standard abutment cannot provide the optimal positioning for the future restoration and gingival architecture.

Asknowledgements: The materials necessary to implement this scientific research were provided under GRANT No. 165/03.08.2023 project.

References:

1. Selz, C. F., Vuck, A., & Guess, P. C. (2016). Full-mouth rehabilitation with monolithic CAD/CAM-fabricated hybrid and all-ceramic materials: Acase report and 3-year follow up. Quintessence International, 47, 115–121

2. Fenner N, Hämmerle CH, Sailer I, Jung RE. Long-term clinical, technical, and esthetic outcomes of all-ceramic vs. titanium abutments on implant supporting single-tooth reconstructions after at least 5 years. Clin Oral 169 Implants Res. 2016 Jun;27(6):716-23. doi: 10.1111/clr.12654. Epub 2015 Jun 18. PMID: 26086947.

3. Cehreli M, Duyck J, De Cooman M, Puers R, Naert I. Implant design and interface force transfer. A photoelastic and strain-gauge analysis. Clin Oral Implants Res 2004;15:249-57

4. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Schärer P. Experimental zirconia abutments for implant-supported single-tooth restorations in es-

thetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont. 2004 May-Jun;17(3):285-90. PMID:15237873.

5. Kraus R D, Epprecht A, Hämmerle C HF, Sailer I, Thoma D S. Cemented vs screw-retained zirconia-based single implant reconstructions: a 3-year prospective randomized

6. Mada S, Smith M, Smith L, Midha P, Overview of passive and active vision techniques for hand-held 3D data acquisition, Proc. SPIE 4877, OptoIreland2002: Optical Metrology, Imaging, and Machine Vision.

7. Smith, N. A., & Turkyilmaz, I. (2014). Evaluation of the sealing capability of implants to titanium and zirconia abutments against Porphyromonas gingivalis, Prevotella intermedia, and Fusobacterium nucleatum under different screw torque values. J Prosthet Dent, 112(3), 561- 567

8. Shafie Hamid R. Clinical and Laboratory Manual of Dental Implant Abutments, (First Ed. by Hamid R. Shafie), Wiley-Blackwell, ISBN 10:1119949815, ISBN 13: 978-1-119-94981-7, ISBN: 111892665X, 2014, 17-22

9. Scutella F, Weinstein T, Lazzara R, Testori T. Buccolingual implant position and vertical abutment finish line geometry: two strictly related factors that may influence the implant esthetic outcome. Implant Dent. 6 2015;24(3): 343-8.

10. Sclar AG. Strategies for management of single-tooth extraction sites in aesthetic implant therapy. Journal Of Oral And Maxillofacial Surgery. 2004;62: 90-105

11. Mijiritsky, Eitan. Plastic Temporary Abutments with Provisional Restorations in Immediate Loading Procedures: A Clinical Report. Implant Dentistry 2006;15.3: 236-240

12. Hirayama H, Kang KH, Oishi Y. The modification of interim cylinders for the fabrication of cement-retained implant-supported provisional restorations. J Prosthet Dent 2003;90: 406-9.

13. Bilhan, Hakan, Onur Geckili, and Emre Mumcu. The Use of Definitive Implant Abutments for the Fabrication of Provisional Crowns: A Case Series. Journal of Periodontal and Implant Science 2011;41.5: 248-252.

14. Azer SS. A Simplified Technique for Creating a Customized Gingival Emergence Profile for Implant-Supported Crowns. Journal of Prosthodontics. 2010;19.6: 497-501.

15. Elsayed A, Wille S, Al-Akhali M, Kern M. Effect of fatigue loading on the fracture strength and failure mode of lithium disilicate and zirconia implant abutments. Clin Oral Implants Res. 2018 Jan;29(1):20-27. doi: 10.1111/clr.13034. Epub 2017 Jun 30. PMID: 28664585

16. Yogesh K, Veena J, Shyam S, Ch. Vinayak B, Dheeraj K and Manish K. Influence of different forms and materials (zirconia or titanium) of abutments in peri-implant soft-tissue healing using matrix metalloproteinase-8: A randomized pilot study. Journal of Prosthetic Dentistry 2017;118: 475-480.

17. Sailer I, Zembic A, Jung RE, Siegenthaler D, Holderegger C, Hämmerle CH. Randomized controlled clinical trial of customized zirconia and titanium implant abutments for canine and posterior single-tooth implant reconstructions: preliminary results at 1 year of function. Clin Oral Implants Res. 2009 Mar;20(3):219-25.

18. Chiu A, Chen YW, Hayashi J, Sadr A. Accuracy of CAD/CAM Digital Impressions with Different Intraoral Scanner Parameters. Sensors (Basel). 2020 Feb 20;20(4):1157. doi: 10.3390/s20041157.

19. Al-Thobity AM. Titanium Base Abutments in Implant Prosthodontics: A Literature Review. Eur J Dent. 2022 Feb;16(1):49-55. doi: 10.1055/s-0041-1735423. Epub 2021 Nov 18.

20. Berroeta E, Zabalegui I, Donovan T, Chee W. Dynamic abutment: a method of redirecting screw access for implant-supported restorations: technical details and a clinical report. J Prosthet Dent. 2015;113(06):516–519.

21. .Bidra AS, Rungruanganunt P. Clinical outcomes of implant abutments in the anterior region: a systematic review. J Esthet Restor Dent. 2013

22. Kraus R D, Epprecht A, Hämmerle C HF, Sailer I, Thoma D S. Cemented vs screw-retained zirconia-based single implant reconstructions: a 3-year prospective randomized controlled clinical trial. Clin Implant Dent Relat Res. 2019;21(04):578–585.

23. Tabesh M, Alikhasi M, Siadat H. A Comparison of implant impression precision: Different materials and techniques. J Clin Exp Dent. 2018 Feb 1;10(2):e151-e157. doi: 10.4317/jced.54457.

24. Baldissara, P.; Llukacej, A.; Ciocca, L.; Valandro, L.F.; Scotti, R. Translucency of zirconia copings made with different CAD/CAM systems. J. Prosthet. Dent. 2010, 104, 6–1

25. Elsayed A, Farrag G, Chaar MS, Abdelnabi N, Kern M. Influence of Different CAD/CAM Crown Materials on the Fracture of Custom-Made Titanium and Zirconia Implant Abutments After Artificial Aging. Int J Prosthodont. 2019 Jan/Feb;32(1):91-96.

26. Heintze, S.; Reinhardt, M.; Peschke, A. Fatigue resistance of CAD/CAM all-ceramic molar crowns of reduced thickness. Dent. Mater. 2017, 33, e38.

27. Magne, P., Silva, M., Oderich, E., Boff, L.L., Enciso, R., 2013. Damping behavior of implant-supported restorations. Clin. Oral Implants Res. 24, 143–148.

28. Menini M, Conserva E, Tealdo T, Bevilacqua M, Pera F, Signori A, Pera P. Shock absorption capacity of restorative materials for dental implant 180prostheses: an in vitro study. Int J Prosthodont. 2013 Nov-Dec;26(6):549-56.

29. Mörmann WH, Stawarczyk B, Ender A, Sener B, Attin T, Mehl A. Wear characteristics of current aesthetic dental restorative CAD/CAM materials: two-body wear, gloss retention, roughness and Martens hardness. J Mech Behav Biomed Mater. 2013 Apr;20:113-25.

30. Wohrle PS. Single-tooth replacement in the aesthetic zone with immediate provisionalization: Fourteen consecutive cases reports. Prac Periodontics Aesthet Dent 1998;10: 1107–1114.

31. Parpaiola A, Norton MR, Cecchinato D, Bressan E, Toia M. Virtual abutment design: a concept for delivery of CAD/CAM customized abutments-- report of a retrospective cohort. Int J Periodontics Restorative Dent. 2013 Jan-Feb;33(1):51-8. doi: 10.11607/prd.1272. PMID: 23342347

32. Marchack CB. A custom titanium abutment for the anterior single-tooth implant. J Prosthet Dent. 1996 Sep;76(3):288-91. doi: 10.1016/s0022-3913(96)90173-0. PMID: 8887802

33. Agustín-Panadero Rubén et al. Mechanical Behavior of Provisional Implant Prosthetic Abutments. Med Oral Patol Oral Cir Bucal 2015;20(1):e94-102

34. Bilhan, Hakan, Onur Geckili, and Emre Mumcu. The Use of Definitive Implant Abutments for the Fabrication of Provisional Crowns: A Case Series. Journal of Periodontal and Implant Science 2011;41.5: 248-252.

35. Andersson B, Taylor A, Lang BR, et al. Alumina ceramic implant abutments used for single-tooth replacement: A prospective 1- to 3-year multicenter study. Int J Prosthodont. 2001;14: 432.

36.Azer SS. A Simplified Technique for Creating a Customized Gingival Emergence Profile for Implant-Supported Crowns. Journal of Prosthodontics. 2010;19.6: 497-501.

37. Byrne D, Houston F, Cleary R, Claffey N. The fit of cast and premachined implant abutments. J Prosthet Dent. 1998 Aug;80(2):184-92. doi: 10.1016/s0022-3913(98)70108-8. PMID: 9710820.

38. Lin WS, Harris BT, Zandinejad A, Martin WC, Morton D. Use of prefabricated titanium abutments and customized anatomic lithium disilicate structures for cement-retained implant restorations in the esthetic zone. J Prosthet Dent. 2014 Mar;111(3):181-5. doi: 10.1016/j.prosdent.2013.07.013. Epub 2013 Dec 18. PMID: 24360007.

39. Wittneben J-G, Buser D, Belser UC, Brägger U. Peri-implant soft tissue conditioning with provisional restorations in the esthetic zone: the dynamic compression technique. The International Journal Of Periodontics & Restorative Dentistry. 2013;33(4): 447-45.

40. Tselios N, Parel SM, Jones JD. Immediate placement and immediate provisional abutment modeling in anterior single-tooth implant restorations using a CAD/CAM application: a clinical report. J Prosthet Dent. 2006 Mar;95(3):181-5. doi: 10.1016/j.prosdent.2006.01.014. PMID: 16543013

41. Canullo L. Clinical outcome study of customized zirconia abutments for single-implant restorations. Int J Prosthodont. 2007 Sep-Oct;20(5):489-93. PMID: 17944337.

42. Bompolaki D, Punj A, Fellows C, Truong C, Ferracane JL. Clinical Performance of CAD/CAM Monolithic Lithium Disilicate ImplantSupported Single Crowns Using Solid or Predrilled Blocks in a Fully Digital Workflow: A Retrospective Cohort Study With Up To 33 Months of Follow Up. J Prosthodont.

43. Martinez-Rus F, Ferreiroa A, Ozcan M, Pradies G. Marginal discrepancy of monolithic and veneered all-ceramic crowns on titanium and zirconia implant abutments before and after adhesive cementation: a scanning electron microscopy analysis. Int J Oral Maxillofac Implants. 2013 MarApr;28(2):480-7. doi: 10.11607/jomi.2759. PMID: 23527350

44. Lemos CAA, Verri FR, Bonfante EA, Santiago Júnior JF, Pellizzer EP. Comparison of external and internal implant-abutment connections for implant supported prostheses. A systematic review and meta-analysis. J Dent. 2018 Mar;70:14-22. doi: 10.1016/j.jdent.2017.12.001. Epub 2017 Dec 6. PMID: 29221955.

45. Tripodakis, A.P.D., Strub, J.R., Kappert, H.F. & Witkowski, S. (1995) Strength and mode of failure of single implant all-ceramic abutment restorations under static load. International Journal of Prosthodontics 8: 265–272.

46. Furhauser, R., Florescu, D., Benesh, T., Haas, R., € Mailath, G. & Watzek, G. (2005) Evaluation of soft tissue around single-tooth implant crowns: the pink esthetic score. Clinical Oral Implants Research 16: 639–644

47. Yuzbasioglu E, Kurt H, Turunc R, Bilir H. Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. BMC Oral Health. 2014 Jan 30;14:10. doi: 10.1186/1472-6831-14-10. PMID: 24479892; PMCID: PMC3913616

48. Parpaiola A, Sbricoli L, Guazzo R, Bressan E, Lops D. Managing the peri-implant mucosa: a clinically reliable method for optimizing soft tissue contours and emergence profile. Journal of Esthetic And Restorative Dentistry 2013;25(5): 317-323.

49. Jemt, T. (1986) Modified single and short-span restorations supported by osseointegrated fixtures in the partially edentulous jaw. Journal of Prosthetic Dentistry 55: 243–247.

50. McCartney, J.W., Vermilyea, S.G. & Fosdal, T. (1993) Modification of angulated abutments to avoid unesthetic display of metal. Journal of Prosthetic Dentistry 69: 439–441

51. Thongthammachat S, Moore BK, Barco MT, Hovijitra S, Brown DT, Andres CJ. Dimensional accuracy of dental casts: influence of tray material, impression material, and time. Journal of Prosthodontics. 2002;11:98-108.

52. Rosentritt, M., Hahnel, S., Engelhardt, F., Behr, M., Preis, V., 2017. In vitro performance and fracture resistance of CAD/CAM-fabricated implant supported molar crowns. Clin. Oral Invest. 21, 1213–1219.

53. Yi Y, Heo S-J, Koak J-Y, Kim S-K. Comparison of CAD/CAM abutment and prefabricated abutment in Morse taper internal type implant after cyclic loading: axial displacement, removal torque, and tensile removal force. J Adv Prosthodont. 2019;11(06):305–312.

54. Henriksson, K. & Jemt, T. (2003) Evaluation of custom-made procera ceramic abutments for single-implant tooth replacement: a prospective 1-year follow-up study. International Journal of Prosthodontics 16: 626–630.

55. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Schärer P. Experimental zirconia abutments

for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont. 2004 May-Jun;17(3):285-90. PMID: 15237873.

56. Kraus R D, Epprecht A, Hämmerle C HF, Sailer I, Thoma D S. Cemented vs screw-retained zirconia-based single implant reconstructions: a 3-year prospective randomized controlled clinical trial. Clin Implant Dent Relat Res. 2019;21(04):578–585.

57. Ortega-Martínez J, Delgado LM, Ortiz-Hernández M, Punset M, CanoBatalla J, Cayon MR, Cabratosa-Termes J. In vitro assessment of PEEK and titanium implant abutments: Screw loosening and microleakage evaluations under dynamic mechanical testing. J Prosthet Dent. 2022 Mar;127(3):470- 476. doi: 10.1016/j.prosdent.2020.09.033. Epub 2020 Dec 9. PMID:33309211.

58. Park SE, Da Silva JD, Weber HP, Ishikawa-Nagai S. Optical phenomenon of peri-implant soft tissue. Part I. Spectrophotometric assessment of natural tooth gingiva and peri-implant mucosa. Clin Oral Implants Res. 2007 Oct;18(5):569-74. doi: 10.1111/j.1600-0501.2007.01391.x. Epub 2007 Jul 26. PMID: 17655713

59. Piattelli A, Scarano A, Paolantonio M, Assenza B, Leghissa GC, Bonaventura GD, et al. Fluids and microbial penetration in the internal part of cement-retained versus screw-retained implant-abutment connections. J Periodontol 2001;72:1146-50.

60. Jung RE, Sailer I, Hämmerle CH, Attin T, Schmidlin P. In vitro color changes of soft tissues caused by restorative materials. Int J Periodontics Restorative Dent. 2007 Jun;27(3):251-7. PMID: 17694948.

61. Menini M, Conserva E, Tealdo T, Bevilacqua M, Pera F, Signori A, Pera P. Shock absorption capacity of restorative materials for dental implant 180 prostheses: an in vitro study. Int J Prosthodont. 2013 Nov-Dec;26(6):549-56. doi: 10.11607/ijp.3241. PMID: 24179969

62. Lops D, Meneghello R, Sbricoli L, Savio G, Bressan E, Stellini E. Precision of the Connection Between Implant and Standard or ComputerAided Design/Computer-Aided Manufacturing Abutments: A Novel Evaluation Method. Int J Oral Maxillofac Implants. 2018 Jan/Feb;33(1):23- 30. doi: 10.11607/jomi.5411. PMID: 29340342.

63. Sailer I, Sailer T, Stawarczyk B, Jung R. In vitro study of the influence of the type of connection on the fracture load of zirconia abutments with internal and external implant-abutment connections. Int J Oral Maxillofac Implants. 2009;24:850–858

64. Joda T, Brägger U. Complete digital workflow for the production of implant-supported single-unit monolithic crowns. Clin Oral Implants Res. 2014 Nov;25(11):1304-1306. doi: 10.1111/clr.12270. Epub 2013 Oct 8. PMID: 25040237

65. Kokat AM, Akca K. Fabrication of a screw-retained fixed provisional prosthesis supported by dental implants. J Prosthet Dent. 2004;91(3): 293-7.

66. Kerstein, R.B., Castellucci, F. & Osorio, J. (2000) Ideal gingival form with computer-generated permanent healing abutments. Compendium 21: 793–801.

67. Yüzügüllü B, Avci M. The implant-abutment interface of alumina and zirconia abutments. Clin Implant Dent Relat Res. 2008 May;10(2):113-21. doi: 10.1111/j.1708-8208.2007.00071.x. Epub 2008 Jan 24. PMID: 18218054

68. Lops D, Meneghello R, Sbricoli L, Savio G, Bressan E, Stellini E. Precision of the Connection Between Implant and Standard or ComputerAided Design/Computer-Aided Manufacturing Abutments: A Novel Evaluation Method. Int J Oral Maxillofac Implants. 2018 Jan/Feb;33(1):23-30. doi: 10.11607/jomi.5411. PMID: 29340342.

69. Kelly JR, Rungruanganunt P. Fatigue Behavior of Computer-Aided Design/Computer-Assisted Manufacture Ceramic Abutments as a Function of Design and Ceramics Processing. Int J Oral Maxillofac Implants. 2016 May-Jun;31(3):601-9. doi: 10.11607/jomi.4698. PMID: 27183069

70. Foong J KW, Judge R B, Palamara J E, Swain M V. Fracture resistance of titanium and zirconia abutments: an in vitro study. J Prosthet Dent. 2013;109(05):304–312.

71. Vélez J, Peláez J, López-Suárez C, Agustín-Panadero R, Tobar C, Suárez MJ. Influence of Implant Connection, Abutment Design and Screw Insertion Torque on Implant-Abutment Misfit. Journal of Clinical Medicine. 2020; 9(8):2365.

72. Ramalho I, Witek L, Coelho PG, Bergamo E, Pegoraro LF, Bonfante EA. Influence of Abutment Fabrication Method on 3D Fit at the ImplantAbutment Connection. Int J Prosthodont. 2020 Nov/Dec;33(6):641-647. doi: 10.11607/ijp.6574. PMID: 33284906.

73. Gehrke P, Dhom G, Brunner J, Wolf D, Degidi M, Piatelli A. Zirconium implant abutments: fracture strength and influence of cyclic loading on retaining-screw loosening. Quintessence Int 2006;37:19-26.

74. Alikhasi M, Monzavi A, Bassir SH, Naini RB, Khosronedjad N, Keshavarz S. A comparison of precision of fit, rotational freedom, and torque loss with copy-milled zirconia and prefabricated titanium abutments. Int J Oral Maxillofac Implants. 2013 Jul-Aug;28(4):996-1002. doi: 10.11607/jomi.2937. PMID: 23869357.

75. Stimmelmayr M, Edelhoff D, Güth JF, et al., Wear at the titaniumtitanium and the titanium zirconia implant-abutment interface: a comparative in vitro study. Dent Mater. 2012;28:1215- 374 1220.

76. Elsayed A, Wille S, Al-Akhali M, Kern M. Comparison of fracture strength and failure mode of different ceramic implant abutments. J Prosthet Dent. 2017 Apr;117(4):499-506. doi: 10.1016/j.prosdent.2016.06.018. Epub 2016 Oct 18. PMID: 27769518.

77. Kaweewongprasert, P.; Phasuk, K.; Levon, J.A.; Eckert, G.J.; Feitosa, S.; Valandro, L.F.; Bottino, M.C.; Morton, D. Fatigue Failure Load of Lithium Disilicate Restorations Cemented on a Chairside Titanium-Base. J. Prosthodont. 2019, 28, 973–981.

78. Gehrke P, Bleuel K, Fischer C, Sader R. Influence of margin location and luting material on the

amount of undetected cement excess on CAD/CAM implant abutments and cement-retained zirconia crowns: an in-vitro study. BMC Oral Health. 2019 Jun 14;19(1):111. doi: 10.1186/s12903-019-0809-2. PMID: 31200680; PMCID: PMC6567410.

79. Korsch M, Walther W. Prefabricated Versus Customized Abutments: A Retrospective Analysis of Loosening of Cement-Retained Fixed ImplantSupported Reconstructions. Int J Prosthodont. 2015 Sep-Oct;28(5):522-6. doi: 10.11607/ijp.4307. PMID: 26340014.

80. Hosseini M, Worsaae N, Schiodt M, Gotfredsen K. A 1-year randomised controlled trial comparing zirconia versus metal-ceramic implant supported single-tooth restorations. Eur J Oral Implantol. 2011 Winter;4(4):347-61. PMID: 22282731

81. Zembic A, Bösch A, Jung RE, Hämmerle CH, Sailer I. Five-year results of a randomized controlled clinical trial comparing zirconia and titanium abutments supporting single-implant crowns in canine and posterior regions. Clin Oral Implants Res. 2013 Apr;24(4):384-90. doi: 10.1111/clr.12044. Epub 2012 Oct 2. PMID: 23025514.

82. Bösch A, Jung RE, Sailer I, Goran B, Hämmerle CH, Thoma DS. SingleTooth Replacement Using Dental Implants Supporting All-Ceramic and Metal-Based Reconstructions: Results at 18 Months of Loading. Int J Periodontics Restorative Dent. 2018 Mar/Apr;38(2):173-179. doi:10.11607/prd.2846. PMID: 29447309.

83. Otero N, Scarton J, Pizzolante LL, Inglese S, Sclar AG, Wong F. The Effect of Implant Abutment Design on Long-Term Soft Tissue Stability: A Clinical Case Report. Int J Periodontics Restorative Dent. 2018 November/December;38(6):841–847. doi: 10.11607/prd.3068. Epub 2018 Feb 16. PMID: 29451930.

84. Rompen E, Raepsaet N, Domken O, Touati B, Van Dooren E. Soft tissue stability at the facial aspect of gingivally converging abutments in the esthetic zone: a pilot clinical study. J Prosthet Dent. 2007 Jun;97(6 Suppl):S119-25. doi: 10.1016/S0022-3913(07)60015-8. Erratum in: J Prosthet Dent. 2008 Mar;99(3):167. PMID: 17618926.

85. Schepke U, Meijer HJ, Kerdijk W, Raghoebar GM, Cune M. Stock Versus CAD/CAM Customized Zirconia Implant Abutments - Clinical and Patient-Based Outcomes in a Randomized Controlled Clinical Trial. Clin Implant Dent Relat Res. 2017 Feb;19(1):74-84. doi: 10.1111/cid.12440. Epub 2016 Jul 31. PMID: 27476829; PMCID: PMC5297995.

86. Long L, Alqarni H, Masri R. Influence of implant abutment fabrication method on clinical outcomes: a systematic review. Eur J Oral Implantol. 2017;10 Suppl 1:67-77. PMID: 28944369.

87. Iliev, G.; Filtchev, D.; Trifkovi´c, B.; Jevremovi´c, D.; Pavlova, Z.; Slavkov, S.; Stoeva, D. Mechanical Resistance of Different Implant Suprastructures: A Laboratory Study. Appl. Sci. 2023, 13, 6100. https:// doi.org/10.3390/ app13106100

88. Stoeva, D.; Filtchev, D.; Nikolova, N.; Pavlova, Z.; Slavkov, S.; Iliev, G. Clinical Evaluation of Implant Suprastructures Depending on the Biomechanical Characteristics of the Materials Used. Appl. Sci. 2022, 12, 8659. https://doi.org/10.3390/ app12178659