The Effect of Gold alloy, Titanium, and Zirconia Abutments on Biological Parameters of Anterior Implant Restoration during 3-9 Years Follow up: A Cross-sectional Study

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Abstract

Anterior single-tooth implant showed a high success rate in recent times. Multifactorial factors influence the favorable esthetic outcome. The biocompatibility of implant abutment materials was an important factor affecting the transmucosal zone of peri-implant soft tissue. Gold alloy, zirconia, and titanium have been used as an abutment for the anterior implant. Each material provides individual benefits and drawbacks. Previous studies showed different outcomes in terms of histological analysis, soft tissue parameters, and marginal bone loss. The objectives of this study were to evaluate and compare biological parameters among different abutment materials in a cross-sectional study. Twenty patients who were treated with a single central incisor implant at the Faculty of Dentistry, Chulalongkorn University, were recruited. Demographic data, biological parameters such as modified plaque index (mPI), modified sulcus bleeding index (mSBI) and probing depth (PD), and CBCT scan were collected. Labial bone thickness and height were measured at the platform level of the bone level implant. All data of each abutment material were compared by One-Way ANOVA or Kruskal-Wallis test, of which 0.05 was the significant level. All of 20 central incisor implants showed good osseointegration. Modified plaque index (mPI), modified sulcus bleeding index (mSBI), and probing depth (PD) were low and showed no statistically significant difference among abutment materials. Zirconia abutment showed the highest labial bone thickness (2.41±0.96 mm), which was significantly different from gold alloy abutment while labial bone height showed no significant difference among abutment materials. In conclusion, from the comparison of these three types of abutments, zirconia abutment showed the best results for maintaining bone thickness over time. Though, there was no significant difference in terms of labial bone height among the three abutments. However, these three types of abutments also showed a similar acceptable status for periodontal parameters during 3-9 years follow-up.

Keywords: *implant, abutment materials, periodontal status, labial bone*

1. Introduction

Recently, a dental implant has been widely used due to its high success rate. Single-tooth implant in anterior maxilla showed a 90-97% success rate in clinical studies (Creugers et al., 2000; Henry et al., 1996; Jung et al., 2008). For long-term success in implant restoration, there were multifactorial factors to promote successful esthetic outcomes. The type of abutment materials was one of the factors that influence the soft tissue stability around the implant. The Transmucosal zone of the peri-implant soft tissue was a critical area for the emergence profile of abutment contour. The biocompatibility of material was a significant factor in this particular transmucosal area (Abrahamsson & Cardaropoli, 2007). Various materials such as titanium, zirconia, and gold alloy have been used as implant abutment materials. Each material showed different advantages and disadvantages on peri-implant soft tissue response.

Titanium has been used as implant abutment for decades due to its strength and biocompatibility to soft tissue. It was considered a gold standard abutment because of its high success rate and properties (Osman & Swain, 2015; Turkoglu, Kose, & Sen, 2019). However, titanium abutment in the anterior region possibly showed the greyish color of the soft tissue around the implant and affected the esthetic outcome (Kim et al., 2016).

Zirconia has been introduced as an abutment recently with prefabricated and customized design. Due to its white color, zirconia abutment is a better choice for thin biotype patients. Zirconia abutment is recommended for the esthetic zone. Moreover, it was reported that zirconia showed good biocompatibility to soft tissue and lower plaque accumulation (Degidi et al., 2006). However, zirconia abutment was reported for abutment fracture (Ekfeldt, Fürst, & Carlsson, 2011), especially in the small diameter of dental implants.

Gold alloy abutment has been used as implant abutment by customized casting techniques for decades. The emergence profile of this abutment can be designed and fabricated to fit the gingival contour of each patient. The abutment contour was designed to maintain gingival architecture. Furthermore, because of its gold color, this abutment enhances warm soft tissue color (Vigolo et al., 2006). However, the biocompatibility of gold alloy is still controversial. Sampatanukul et al compared the number of inflammatory cell responses of human tissues around different implant materials over 8 weeks follow-up. They reported that the area of inflammation and amount of inflammation cells were found higher in the soft tissue around the gold alloy abutments than titanium and zirconia abutments. Gold alloy showed the worst epithelium attachment when compared to titanium and zirconia (Sampatanukul et al., 2018). However, one animal study showed a different result in histological analysis. There was no significant difference in epithelium attachment length between titanium and gold abutments in dogs over 6 months follow-up (Abrahamsson & Cardaropoli, 2007). Some studies in humans used periodontal parameters such as bleeding on probing, plaque index, pocket formation to evaluate the healthiness of the soft tissue. Titanium and zirconia abutments showed no clinical difference of plaque score, bleeding score, pocket depth, and gingival recession in a 1-year follow-up (Carrillo de Albornoz et al., 2014). Moreover, gold alloy and titanium abutments also exhibited similar results of gingival inflammation and pocket depth in a 4-year prospective study (Vigolo et al., 2006). Nevertheless, No clinical study provided the comparison of soft tissue parameters among gold alloy, titanium, and zirconia together in a long-term human study.

To stabilize soft tissue characteristics, bone support underneath is an important factor for sustainable esthetic outcomes. It was recommended that optimal labial bone thickness should be 2 mm to maintain soft tissue stability and prevent further bone resorption (Grunder, Gracis, & Capelli, 2005). To gain and maintain proper labial bone thickness, various bone augmentation techniques were suggested, such as bone block graft prior to implant placement and guided bone regeneration (GBR techniques) with implant placement. GBR technique was one of the most successful treatments for increasing labial bone thickness even though the patient already has labial bone intact (Benic & Hämmerle, 2014). Nonetheless, the abutment materials also affected the stability of alveolar bone in clinical studies. A previous study reported that the gold abutment showed higher marginal bone loss than titanium and zirconia abutments in a 3-year follow-up (Hosseini et al., 2013). Similarly, in vitro study also showed bone resorption and gingival recession in the gold alloy abutment group, compared with titanium (Abrahamsson et al., 1998). Though, some studies showed different results. Titanium and gold abutment exhibited no significant difference of marginal bone loss on periapical film in a one-year prospective study (Drago, 2003). None of these studies use the measurement from the 3D image over time.

To clarify the long-term effect of abutment materials, clinical examinations such as the amount of plaque accumulation, bleeding index, and probing depth were evaluated. Additional investigation by CBCT was done to describe the amount of labial bone support. Therefore, the objective of this study was to evaluate and compare biological parameters such as periodontal status and the amount of labial bone of a single central incisor implant using different abutment materials in a cross-sectional study.

2. Objectives

2.1) To evaluate and compare the periodontal status of a single central incisor implant using different abutment materials in a cross-sectional study.

2.2) To evaluate and compare labial bone thickness and height of a single central incisor implant using different abutment materials in a cross-sectional study.

3. Materials and methods

In this cross-sectional study, samples were patients who were treated with a single central incisor bone level implant in the maxillary region at the Faculty of Dentistry, Chulalongkorn University, between January 2011 and September 2017. Major restorations on adjacent teeth such as veneer or crown were excluded. The exclusion criteria were an active periodontal disease, heavy smoker (>10 cigarettes/day), uncontrolled systemic disease, and no posterior tooth support. The study protocol was approved by the Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (HREC-DCU-2019-029). All included participants signed an informed consent form. Patients were recalled for regular maintenance programs. The basic clinical information was explored, including sex, age, parafunctional habit, history of complications, treatment record, and frequency of periodic maintenance care.

3.1 Intraoral examination and periodontal evaluation

Clinical parameters were examined according to a previous study (Buser et al., 2008). Modified plaque index (mPI), modified sulcus bleeding index (mSBI), and probing depth (PD) were recorded at the mesial, distal, buccal, and palatal sides.

3.2 Measurement of labial bone height and thickness

Labial bone was assessed by dental CBCT. Labial bone was measured in 2 parameters; thickness and height. CBCT image was interpreted by the INFINITT program. The implant was adjusted to be centered in all views; sagittal, coronal, and transverse plane. In sagittal view, horizontal reference line (blue line) was located at the platform of implant, while vertical reference line (yellow line) was moved to the center of the fixture and bisected implant equally in anteroposterior dimension. The implant was rotated until the fixture was parallel with a vertical reference line or perpendicular with a horizontal plane on both sagittal and coronal plane. Labial bone thickness was the distance from the implant platform level to the outer cortex of the labial bone. This line must be parallel with the horizontal reference line and perpendicular to the vertical reference line. Labial bone height was determined by distance from the horizontal reference line at the implant platform to the highest point of the labial wall perpendicularly. Figure 1 shows the measurement of labial bone height and thickness on CBCT image. This parameter could be both positive value and negative value. If the peak of labial bone was higher than the implant platform, a positive value was given, while a negative score meant the peak of labial was below the implant platform.

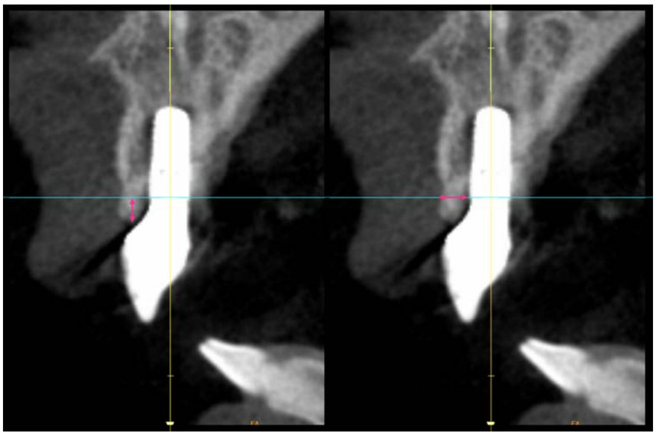

Figure 1 Measurement of labial bone height and labial bone thickness from CBCT image (pink arrow)

One examiner was assigned to measure all intraoral examinations and CBCT interpretations. A post graduated dental student in the Esthetic restorative and implant dentistry program was selected as an examiner. The examiner must not be involved in any part of the treatment. Intra-examiner reliability had done by re-evaluating the scores 3 times every week.

3.3. Statistical analysis

All data were analyzed by statistical software (SPSS 21.0, SPSS, Chicago, IL, USA). The Shapiro-Wilk test was used to test normality. Observation time, Mean differences of probing depth (PD), labial bone thickness, and height among different abutment materials showed a normal distribution and were compared by One-Way ANOVA. While modified sulcus bleeding index (mSBI) showed a non-normal distribution and was compared by the Kruskal-Wallis test. A P-value of less than 0.05 would be considered statistically significant.

4. Results and Discussion

4.1 Results

According to the inclusion criteria, 20 patients were recruited for the experiment. The youngest patient in this study was 27 while the oldest was 61 years old, with an average age of 45.05±10.43. The mean observation period was 75.8±24.25 months after the prosthesis was completely done, of which 40 months was the minimum and 113 months was the maximum time of implant use. Titanium abutment showed the longest observation time, while zirconia abutment showed the shortest follow-up period. However, there was no significant difference among the three abutment groups. The treatment information associated with a single implant was shown in Table 1. All of the implants were in the upper central incisor position. Regarding implant systems, 11 of the implants were Straumann® system (Institute Straumann, Basel, Straumann, Switzerland), while 9 of them were Astratech™ system (Dentsply Implant, Mölndal, Sweden). All implants were bone-level implants with a platform switching design. Abutment materials in this study were gold alloy (UCLA), zirconia, and titanium as 50, 30, and 20% respectively. The majority of the implants were placed at the healed site as delayed placement. Six implants were immediate implant placement and only one was early implant placement. Delayed loading protocol was applied in every case. Guided bone regeneration was done simultaneously in most samples. Both deproteinized bovine bone mineral (Bio-Oss Collagen, Geistlich Pharma AG) and biphasic calcium phosphate ceramic bone (Straumann Bone Ceramic, Institut Straumann AG) were used as bone substitutes in 13 and 6 cases, respectively, by the GBR technique. An autogenous bone graft harvested from mandibular ramus was done in one case, while alveolar ridge expansion was performed in 3 cases. Connective tissue graft was done after implant placement and fully osteointegrated in 8 cases.

All of 20 maxillary central incisor implants showed good osseointegration, no mobility, and suppuration. 11 cases showed no functional problems after loading. However, there were some problems in 9 cases. Prosthodontic problems were found in most cases, for example, dislodgement of crown restoration in cemented type crown and resin composite dislodgement at the screw hole. Clinical parameters such as modified plaque index (mPI), modified sulcus bleeding index (mSBI), and probing depth (PD) were listed in Table 2. In summary, patients presented good oral hygiene and healthy gingiva. The modified sulcus bleeding index was low. There was no statistically significant difference of modified sulcus bleeding index and probing depth among abutment materials (see Table 3).

Table 1 Demographic data, Implant system and detail of treatment.

Variables	Subjects (n=20)
Age (years)	45.05±10.43
Gender	
- Male	13 (65%)
- Female	7 (35%)
Implant system	
- Straumann® Bone level implants, Regular CrossFit® 4.1 mm	11 (55%)
- Astratech™	9 (45%)
- Astratech™, Bone level implants, size 3.5 mm	1
- Astratech™, Bone level implants, size 4 mm	1
- Astratech™, Bone level implants, size 4.2 mm	1
- Astratech™, Bone level implants, size 4.5 mm	6
Abutment	
- Gold alloy abutment (Au 60%, Pd 20%, Pt 19%, Ir 1%)	10 (50%)
- Zirconia abutment	6 (30%)
- Titanium abutment	4 (20%)
Observation period (months)	75.8±24.3
- Gold alloy abutment	74.2±22.7*
- Zirconia abutment	69.2±30.6*
- Titanium abutment	89.8±16.3*
Implant placement	
- Immediate placement	6 (30%)
- Early placement (6-8 weeks)	1 (5%)
- Delay placement	13 (65%)
Soft tissue graft	8 (40%)
Bone augmentation technique	
- Bone block graft prior to implant placement with simultaneously guided bone regeneration	1 (5%)
- Guided bone regeneration only	16 (80%)
- Ridge expansion	1 (5%)
- Ridge expansion and guided bone regeneration	2 (10%)

*No significant difference among abutment groups (*p*-value>0.05), using One-Way ANOVA, followed by Tukey post hoc analysis.

Table 2 Modified plaque index (mPI), modified sulcus bleeding index (mSBI) and probing depth

	mPI	mSBI	PD (mm)
Maximum	0	2	4
Minimum	0	0	1
Mean ± SD	0	0.23±0.34	1.67±0.59

Table 3 Mean and median of modified sulcus bleeding index (mSBI) and probing depth (PD) among abutments

	Gold alloy	Zirconia	Titanium	P-value
mSBI	0.00±0.06	0.25±0.50	0.31±0.24	0.054
PD	1.63±0.34	1.63±0.34	1.84±1.280	0.821

The CBCT image illustrated the average labial bone thickness and labial bone height among the abutment materials. All data showed a normal distribution. The labial bone thicknesses were 1.36±0.42 mm, 2.41±0.96 mm, 1.31±1.10 mm in the gold alloy, zirconia, and titanium abutments, respectively. The zirconia abutment group showed the highest labial bone thickness with a significant difference, compared with the gold alloy abutment group. Moreover, the titanium abutment showed no significant difference in labial bone thickness as compared with the zirconia and gold alloy groups. While labial bone heights were 0.49±0.68 mm, 0.90±1.24 mm, 0.94±1.14 mm in the gold alloy, zirconia, and titanium abutments, respectively, no significant difference was found in the labial bone height among the three abutment materials (see Table 4).

Regarding the intraclass correlation coefficient, the results of this study were interpreted as excellent reliability, having a score of 0.978.

Table 4 Mean of labial bone thickness and height of each material (mm)

	Gold alloy (n=10)	**Zirconia abutment (n=6)**	**Titanium abutment (n=4)**	***P*-value****
Labial bone thickness	1.36±0.42[a]	2.41±0.96[b]	1.31±1.10[a,b]	0.035
Labial bone height	0.49±0.68	0.90±1.24	0.94±1.14	0.615

[*]Same superscript letter means no significant difference in the same row (*p*-value>0.05)

[**]Differences among abutment materials, analyzed using One-Way ANOVA, followed by Tukey post hoc analysis.

4.2 Discussion

This cross-sectional study aimed to evaluate and compare periodontal status and amount of labial bone among different abutment materials of single central incisor implants in the maxillary region during a 3-to-9-year follow-up. A total of 20 central incisor implant cases was recruited in this study with an average of 75.8±24.25 months of function. All implants showed good osseointegration. Only prosthodontic problems were found in maintenance visits, such as crown dislodgement for cemented retained restoration. No biological complications were recorded after loading. Among these 3 types of abutments in this study, 50% of the samples were gold alloy abutments while two implant systems were used. Straumann bone level implants create a biologically horizontal microgap to crestal bone to prevent bone resorption. Moreover, SLAactive surface modification can promote osseointegration. Astratech bone level fixtures show MicroThread neck and Conical Seal design, with Osseospeed technology to maintain marginal bone. Although, these two implant systems have different designs. Only bone-level implants with a platform switching design were used in this study.

Clinical examinations of peri-implant soft tissue for all abutments were healthy. All patients showed good oral hygiene. No obvious dental plaque was recognized. Mild gingival inflammation was found in an uncompliant patient group. The modified sulcus bleeding index of each abutment material was low. The average periodontal pocket was 1.67±0.59 mm. The result of this study showed that the mean periodontal pocket depth was less than those in previous studies. In healthy peri-implant soft tissue, pocket depth showed 2.78 mm after one-year observation (Buser, Weber, & Lang, 1990). Correspondingly, pocket depth presented deeper with 3.8 mm in inflammation gingiva in a 7-year follow-up (Lekholm et al., 1986). Moreover, our study showed no statistical difference of all periodontal parameters among abutment groups. Likewise, a previous study compared tissue reaction between titanium and zirconia abutment using histological analysis after 3 months with a split-mouth design. Inflammatory response and number of blood vessel were similar between two types of materials (Van Brakel et al, 2012). On the other hand, gold was the controversial outcome. In a recent study, histological biopsy illustrated a higher amount of inflammation cells and a larger area of inflammation in the peri-implant soft tissue of gold alloy when compared with titanium and zirconia abutments (Sampatanukul et al., 2018). However, this study was done in 2 months in vivo study. The results for periodontal parameters such as gingival inflammation and bleeding on probing were similar to the in vitro study by Vigolo and colleagues. The randomized controlled clinical trial in 4 years follow found no significant difference of plaque presence, gingival inflammation, and bleeding on probing between titanium and gold alloy abutments in human split-month design (Vigolo et al., 2006).

According to the CBCT image, the labial bone characteristic was determined by its thickness and height at the implant-platform level. The zirconia abutment showed the highest labial bone thickness and achieved the optimal thickness of labial bone. Moreover, the labial bone height showed no significant difference among the abutment materials. Although zirconia showed the shortest follow-up time with 69 months of function, statistical analysis showed no difference in observation time among the abutment materials. Despite this, it was recommended that optimal buccal bone thickness should be 2 mm to maintain soft tissue stability and prevent further bone resorption (Grunder, Gracis, & Capelli, 2005). In this study, the remaining labial bone thickness from the gold alloy and titanium abutments showed a mean of 1.3 mm, which was according to the proper minimum thickness of the labial bone discussed by Miyamoto and Obama. Adequate buccal bone width should be at least 1.2 mm or more to provide a sufficient amount of underlying cancellous bone promoting adequate blood supply (Miyamoto & Obama, 2011). Moreover, the remaining labial bone thickness of the gold alloy abutment exhibited less than the zirconia abutment group. Similarly, a study by Hosseini et al compared alveolar bone resorption between gold, zirconia, and titanium abutments using periapical films in a 3-year prospective study. Marginal bone was more reduced in the gold alloy group than others (Hosseini et al., 2013). However, the gold alloy abutment was usually used in the improper angulated implant to correct its path. So, marginal bone loss might be a consequence of other factors such as inappropriate fixture position or angle of the abutment. This condition also happened in our study. Normally, the casting of gold alloy abutment was selected to use in complex cases, for example, buccoversion of the implant fixture. This situation probably compromises labial bone support. On the other hand, gold alloy abutment also showed good outcomes in other long-term human studies. They found that the marginal bone resorption between titanium and gold alloy abutments did not disparate in 4 years randomized controlled clinical trial (Vigolo et al., 2006).

To gain labial bone thickness, 19 cases in this study were augmented using guided bone regeneration simultaneously with implant placement. Chappuis and colleagues observed facial bone wall alterations after 10 years of function. Guided bone regeneration was done with a 2-layer composite technique graft. Autogenous bone chips, followed by deproteinized bovine bone mineral and covered with a collagen membrane, were simultaneously augmented on the same day of early implant placement. They found that labial bone thickness was stable in 10 years of follow-up (Chappuis et al., 2018). However, they did not mention the abutment material used. Moreover, different bone substitute materials such as Bio-Oss and Straumann bone Ceramic also showed similar successful outcomes in split-mouth dehiscence defects (Van Assche et al., 2013). In this study, only one zirconia abutment did not augment with the GBR technique. The GBR procedures were done in both gold alloy and titanium abutment groups (Table 5). However, they still showed minimum labial bone thicknesses.

Table 5 Bone augmentation technique of each abutment material.

	Gold alloy	Zirconia abutment	Titanium abutment
Bone block graft and guided bone regeneration	1	-	-
Guided bone regeneration only	8	5	3
Ridge expansion only	-	1	-
Ridge expansion and guided bone regeneration	1	-	1

Besides the abutment materials, there were several possible explanations for labial bone alteration. The bone remodeling process spontaneously induced labial bone reduction after the GBR technique (Ferrus et al., 2010). Moreover, the immediate implant placement showed both more vertical and horizontal bone resorptions than the delayed implant placement (Botticelli, Berglundh, & Lindhe, 2004).

In this study, the limitation was first the small number of samples of each abutment, which did not equal in each abutment group. It was difficult to control confounding factors such as implant system, connection design, bone augmentation technique, loading protocol in the cross-sectional study. Secondly, there were no CBCT images to compare the number of labial bone changes from the beginning after loading. It might be better to illustrate the exact quantity of labial bone resorption. A long-term prospective study with histological evaluation and CBCT image of labial bone should be done with a larger sample size in further study.

5. Conclusion

Within the limitations of this study, from the comparison of these three types of abutments, the zirconia abutment showed the best results for maintaining bone thickness over time. Gold alloy and titanium abutments showed the same acceptable results of labial bone thickness. Moreover, there was no significant difference in terms of labial bone height among the three abutments. However, these three types of abutments showed a similar acceptable status for periodontal parameters such as sulcus bleeding index, and probing depth during 3-9 years of the follow-up period.

6. References

Abrahamsson, I., Berglundh, T., Glantz, P. O., & Lindhe, J. (1998). The mucosal attachment at different abutments: An experimental study in dogs. *Journal of clinical periodontology*, *25*(9), 721-727.

Abrahamsson, I., & Cardaropoli, G. (2007). Peri-implant hard and soft tissue integration to dental implants made of titanium and gold. *Clinical Oral Implants Research*, *18*(3), 269-274.

Benic, G. I., & Hämmerle, C. H. (2014). Horizontal bone augmentation by means of guided bone regeneration. *Periodontology 2000*, *66*(1), 13-40.

Botticelli, D., Berglundh, T., & Lindhe, J. (2004). Hard-tissue alterations following immediate implant placement in extraction sites. *Journal of Clinical Periodontology*, *31*(10), 820-828.

Buser, D., Bornstein, M. M., Weber, H. P., Grütter, L., Schmid, B., & Belser, U. C. (2008). Early implant placement with simultaneous guided bone regeneration following single-tooth extraction in the esthetic zone: A cross-sectional, retrospective study in 45 subjects with a 2-to 4-year follow-up. *Journal of periodontology*,*79*(9), 1773-1781.

Buser, D., Weber, H. P., & Lang, N. P. (1990). Tissue integration of non-submerged implants. l-year results of a prospective study with 100 ITI hollow-cylinder and hollow-screw implants. *Clinical oral implants research*, *1*(1), 33-40.

Carrillo de Albornoz, A., Vignoletti, F., Ferrantino, L., Cárdenas, E., De Sanctis, M., & Sanz, M. (2014). A randomized trial on the aesthetic outcomes of implant-supported restorations with zirconia or titanium abutments. *Journal of clinical periodontology*, *41*(12), 1161-1169.

Chappuis, V., Rahman, L., Buser, R., Janner, S. F. M., Belser, U. C., & Buser, D. (2018). Effectiveness of contour augmentation with guided bone regeneration: 10-year results. *Journal of dental research*, *97*(3), 266-274.

Creugers, N. H. J., Kreulen, C. M., Snoek, P. A., & De Kanter, R. J. A. M. (2000). A systematic review of single-tooth restorations supported by implants. *Journal of dentistry*, *28*(4), 209-217.

Degidi, M., Artese, L., Scarano, A., Perrotti, V., Gehrke, P., & Piattelli, A. J. J. o. p. (2006). Inflammatory infiltrate, microvessel density, nitric oxide synthase expression, vascular endothelial growth factor expression, and proliferative activity in peri-implant soft tissues around titanium and zirconium oxide healing caps. *Journal of periodontology*, *77*(1), 73-80.

Drago, C. J. (2003). A clinical study of the efficacy of gold-tite square abutment screws in cement-retained implant restorations. *International Journal of Oral & Maxillofacial Implants*, *18*(2).

Ekfeldt, A., Fürst, B., & Carlsson, G. E. (2011). Zirconia abutments for single-tooth implant restorations: a retrospective and clinical follow-up study. *Clinical oral implants research*, *22*(11), 1308-1314.

Ferrus, J., Cecchinato, D., Pjetursson, E. B., Lang, N. P., Sanz, M., & Lindhe, J. (2010). Factors influencing ridge alterations following immediate implant placement into extraction sockets. *Clinical Oral Implants Research*, *21*(1), 22-29.

Grunder, U., Gracis, S., & Capelli, M. (2005). Influence of the 3-D bone-to-implant relationship on esthetics. *International Journal of Periodontics & Restorative Dentistry*, *25*(2), 113-119.

Henry, P. J., Laney, W. R., Jemt, T., Harris, D., Krogh, P. H., Polizzi, G., Giovanni; Z., George A., & Herrmann, I. (1996). Osseointegrated implants for single-tooth replacement: a prospective 5-year multicenter study. *International Journal of Oral & Maxillofacial Implants*, *11*(4), 450-455.

Hosseini, M., Worsaae, N., Schiødt, M., & Gotfredsen, K. (2013). A 3-year prospective study of implant-supported, single-tooth restorations of all-ceramic and metal-ceramic materials in patients with tooth agenesis. *Clinical Oral Implants Research*, *24*(10), 1078-1087.

Jung, R. E., Pjetursson, B. E., Glauser, R., Zembic, A., Zwahlen, M., & Lang, N. P. (2008). A systematic review of the 5-year survival and complication rates of implant-supported single crowns. *Clinical oral implants research*, *19*(2), 119-130.

Kim, A., Campbell, S. D., Viana, M. A., & Knoernschild, K. L. (2016). Abutment material effect on peri-implant soft tissue color and perceived esthetics. *Journal of Prosthodontics, 25*(8), 634-640.

Lekholm, U., Adell, R., Lindhe, J., Brånemark, P. I., Eriksson, B., Rockler, B., Lindvall, A. M., & Yoneyama, T. (1986). Marginal tissue reactions at osseointegrated titanium fixtures:(II) A cross-sectional retrospective study. *International journal of oral and maxillofacial surgery, 15*(1), 53-61.

Miyamoto, Y., & Obama, T. (2011). Dental cone beam computed tomography analyses of postoperative labial bone thickness in maxillary anterior implants: comparing immediate and delayed implant placement. *International Journal of Periodontics and Restorative Dentistry*, *31*(3), 215.

Osman, R. B., & Swain, M. V. (2015). A critical review of dental implant materials with an emphasis on titanium versus zirconia. *Materials*, *8*(3), 932-958.

Sampatanukul, T., Serichetaphongse, P., & Pimkhaokham, A. (2018). Histological evaluations and inflammatory responses of different dental implant abutment materials: A human histology pilot study. *Clinical implant dentistry and related research*, *20*(2), 160-169.

Turkoglu, P., Kose, A., & Sen, D. (2019). *Abutment Selection for Anterior Implant-Supported Restorations: An Update of Dental Implantology and Biomaterial*. London: IntechOpen. doi: 10.5772/intechopen.80965

Van Assche, N., Michels, S., Naert, I., & Quirynen, M. (2013). Randomized controlled trial to compare two bone substitutes in the treatment of bony dehiscences. *Clinical implant dentistryrelated research*, *15*(4), 558-568.

Vigolo, P., Givani, A., Majzoub, Z., & Cordioli, G. (2006). A 4-year prospective study to assess peri-implant hard and soft tissues adjacent to titanium versus gold-alloy abutments in cemented single implant crowns. *Journal of Prosthodontics*, *15*(4), 250-256. doi:10.1111/j.1532-849X.2006.00114.x

Van Brakel, R., Meijer, G. J., Verhoeven, J. W., Jansen, J., de Putter, C., & Cune, M. S. (2012). Soft tissue response to zirconia and titanium implant abutments: an in vivo within-subject comparison. *Journal of Clinical Periodontology*, *39*(10), 995-1001.