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Comparison of Three Different Types of Fixed Partial Implant Prosthesis: A Long-Term Retrospective Study of Clinical Outcomes and Cost Effectiveness

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Abstract:

Objective: To study the performance of 2 to 3 posterior bone-level dental implants constructed with either 3 non-splinted crowns (NSC), 3 splinted crowns (SC), or a 3-unit fixed partial denture supported by 2 implants (FPD)

Material and methods: Patients treated with 3 metal-ceramic NSC, SC or a 3-unit FPD were included in the present retrospective study. Implant survival and success rate as well as all biological and technical complications were collected. The cost associated with each of the treatment options was evaluated in the comparative analysis.

Results: One hundred forty-five patients (40 NSC, 52 SC and 53 in the FPD) receiving 382 bone level implants (120 NSC, 106 FPD and 156 SC) were included (mean follow-up of 76.2 months). Lack of success was observed in 33.8% of the total patient sample, being lower in the FPD group. Implant survival rates were 92.5% in the NSC, 100% in the FDP and 88.5% in the SC, with significant difference noted between the FPD and SC ($p=0.01$). Overall, 9.9% of the total implants were found to have peri-implantitis (PI), with 16.7% in the SC, 7.5% in the NSC and 2.8% in the FDP. Patients presenting prosthodontic complications were significantly higher in NSC (32.5%) than FPD (13.2%) and SC (15.4%). The total cost of the FPD group was significantly lower when compared to the NSC and SC groups ($p<0.001$).

Conclusions: An implant-supported FPD seems to present the most ideal long-term therapeutic solution in rehabilitating a 3-unit edentulous area

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Introduction:

Dental implants have played an integral role in the management of partially edentulous patients in both maxilla and mandible (Jung, et al. 2012). Although long-term success has been widely established, the outcome is influenced by factors that guide clinicians to select the most appropriate surgical and prosthodontic approach (Flemmig & Beikler 2009, Grossmann, et al. 2005).

Among these, determining whether to use a prosthodontic component composed of splinted versus non-splinted crowns (Ravida, et al. 2018). The splinted crowns tend to distribute the occlusal forces placed on the implants, resulting in a less frequent occurrence of prosthodontic complications and decreased strain on the surrounding peri-implant bone (Clelland, et al. 2016, Yilmaz, et al. 2011). However, the literature supporting this treatment option is often conducted through finite and photoelastic analyses due to the ethical boundaries preventing the use of occlusal overload in humans (Guichet, et al. 2002, Huang, et al. 2005, Yoda, et al. 2016). In 2002, Guichet et al. demonstrated a reduced overall peak stress induction around the central implant of a 3-unit splinted crowns restoration, whereas the stresses were concentrated around all the loaded implants when not splinted (Guichet, Yoshinobu & Caputo 2002). Similar results were also reported by Nissan et al. (2010) where less load to the crown margin was observed with splinted versus non-splinted implant restorations (Nissan, et al. 2010). Although these arguments present advantages for splinted restorations, maintaining adequate oral hygiene within the interproximal spaces is an essential practice to avoid the incidence of peri-implantitis (Serino & Strom 2009). This would render 3 single crowns an advantageous option over splinted crowns as a prosthodontic approach, particularly in patients with a past history of periodontitis and/or limited dexterity in cleaning (Renvert & Persson 2009). An additional disadvantage of splinting implant-retained crowns, is the challenge of framework fit and providing an adequate emergence profile (Ravida, Saleh, Muriel, Maska & Wang 2018).

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Another determining factor is the number of implants required in order to rehabilitate a partially edentulous area. This presents a conflict between one implant per missing tooth and an implant-retained bridge (Eliasson, et al. 2006). The use of a single implant per lost tooth seems to pose a plausible clinical choice in the reduction of the specific risk factors such as overload (de Souza Batista, et al. 2017). However, several investigations have demonstrated successful full-arch rehabilitation via cross-arch splinted prosthetics supported by a fewer number of implants than lost teeth (Cannizzaro, et al. 2011, Malo, et al. 2013, Malo, et al. 2003). In the treatment planning of restoring a 3-unit edentulous area, the lack of space and poor bone quality may interfere with the use of three implants. Such limitation can be overcome by using two implants supported by a bridge (de Souza Batista, Verri, Almeida, Santiago Junior, Lemos & Pellizzer 2017). Furthermore, an often-overlooked influence factor is the cost (Ravida, et al. 2018). The use of two versus three implants could likely influence the clinical decision of therapy. However, it is essential to compare the total cumulative cost including all the potential complications that may be accompanied with each therapeutic option.

Literature comparing the rehabilitation of 3-unit edentulous areas in the posterior maxilla or mandible using two versus three implants remains scarce (Eliasson, Eriksson, Johansson & Wennerberg 2006, Yi, et al. 2013). In addition, no previous article has evaluated the cost effectiveness of each therapeutic approach yet. Therefore, the aim of this study was to compare the survival rates, success and prosthodontic complication rates, incidence of peri-implantitis, and cost effectiveness of the 3 clinical options considered in rehabilitating a 3-unit edentulous area in the posterior maxilla or mandible.

Materials and Methods:

This study was approved by the University of Michigan, School of Dentistry, Institutional Review Board for Human Studies (HUM00114380). This retrospective investigation included all patients treated with 2 to 3 bone level implants (loaded with either 3 non-splinted crowns, 3 splinted crowns, or 2 implants supported 3-unit FPD) restoring a posterior 3-unit edentulous

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area between January 1990 and September 2017 at the University of Michigan School of Dentistry, Ann Arbor, MI, USA.

The physical and digital records that fall under the predetermined eligibility criteria were screened and evaluated by 3 examiners (MT, AR, SA). Any disagreement that arose during the evaluation and data collection process were resolved through discussion with the supervising investigator (HLW).

Inclusion criteria

1) Partially edentulous patients treated with 2 to 3 implants restoring a posterior (molars and premolars) maxillary or mandibular 3-unit edentulous area with a documented follow-up of ≥ 1-year following implant loading.
2) Cases with all dental implants placed during the same surgical appointment.
3) Patients who received implants loaded with titanium prefabricated abutments and either 3 metal ceramic splinted crowns (SC), 3 non-splinted metal ceramic crowns (NSC) or 2 implants supported fixed partial denture (FPD)
4) Presence of opposing occlusion (teeth / Implants)

Exclusion criteria

1) Partially edentulous patients who have received any of the aforementioned choices of prosthodontic rehabilitation methods loaded on >3 implants.
2) Patients with restored 3-unit edentulous areas in the anterior zone
3) Patients with ambiguous or incomplete charts
4) Patients with a <1-year follow-up period
5) Medically compromised patients (any past records of uncontrolled diabetes, radiation and/or chemotherapy treatment, psychological problems) and severe bruxism cases (diagnosed and/or self-reported).
6) Patients treated or maintained in centers outside the University of Michigan School of Dentistry
7) Patients with inaccessible files due to bad debt, destroyed record, or decease

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Data collection and Classification

All patient records were initially screened and evaluated against the aforementioned eligibility criteria. Subsequently, the selected cases were separated into 3-study groups based upon the selected definitive prosthesis: non-splinted crowns group, splinted crowns group, and fixed partial denture group (Figure 1).

As part of the data collection process, all relevant patient information, including age (at the time of implant placement), gender, presence of a smoking habit (≥1 cigarette/day), diabetes (validated via the patient's medical records) and history of periodontal disease, was obtained. A positive history of periodontal disease was determined to be present if ≥4 sites presented with ≥3 mm clinical attachment loss and there was a past history of scaling and root planing (Armitage 2004, Pihlstrom, et al. 2005), based on each patient's documented periodontal charts. Additional data including the number of implants and their positions, implant description (brand, length and diameter), and the type of crown retention (cement or screw retention) were also collected.

Peri-implantitis, Survival and Success rate:

The definition for peri-implantitis proposed by the 8th European Workshop on Periodontology in 2011 (Tonetti, et al. 2012), where peri-implantitis was defined as clinical inflammation in combination with radiographic marginal bone loss >2 mm, was used to classify cases into positive or negative for peri-implantitis. Using a commercially-available software (ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA), marginal bone levels as well as the horizontal and vertical distance between the implants of an individual case were measured at baseline (time of prosthodontic loading). Meanwhile, the degree of marginal bone loss associated with each included implant was recorded at the final follow-up appointment utilizing calibrated periapical radiographs via the same software (Schneider, et al. 2012). Two individual calibrated examiners (AR & SB) performed the calculations separately, but if significant differences arose, a third reviewer (MT) was included for reassessing the radiographs to arrive at a final resolution. Peri-implantitis was first evaluated per patient, then per implant

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individually. The prevalence of peri-implantitis was recorded using a binary score for each implant (0 for a healthy implant, 1 for a diseased implant) to calculate the percentage of diseased implants. To collect data on each implant position independently, each implant was assigned an identification alphabet based on location. This included labeling all mesial implants as “Implant A”, all central implants as “Implant B” and all distal implants as “Implant C”. Similar values were assigned to patients based on the presentation of peri-implantitis around any implants (0 for a patient with all healthy implants, 1 for a patient with radiographic signs of 1 diseased implant). Implant failure was defined as a removed, lost, mobile or fractured implant (Chrcanovic, et al. 2014), and calculated for each implant individually and then for each patient with the same standards used previously for peri-implantitis. Success rate was evaluated at the patient level, where a case (SC, NSC or FPD) was classified as successful when an absence of biological and prosthodontic complication throughout the follow-up period was demonstrated (0 for a patient with some prosthodontic or biologic complication, 1 for a patient without any prosthodontic or biologic complication).

Prosthodontic complications:

Prosthodontic complications included a 1) fractured/chipped/replaced prosthesis, 2) fractured prosthesis, 3) crown/prosthesis de-cementation and/or 4) loosened abutment screw, and along with the associated management were registered at the patient follow-up appointments.

Case Follow-Up Periods:

To ensure more meticulous data analysis, three independently defined follow-up periods were recorded during data acquisition. These were (1) follow-up based on implant survival, (2) follow-up based on implant loading (prosthodontic follow-up), and (3) follow-up based on the occurrence of peri-implantitis. The marked period for the follow-up based on implant survival was the duration between implant placement and final documented date during which the implant remained in the oral cavity. In the case of an implant having been lost or extracted, the date of disease presentation was decided as the final follow-up mark. The set period for the follow-up based on implant loading was the duration between implant loading and final

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documented clinical appointment date. At any point during the prosthodontic follow-up period where a prosthodontic complication arose, the timeframe (in months) was recorded for data analysis. Finally, the marked period for the follow-up based on the peri-implantitis was the duration between implant placement and the last radiograph in which the bone around the implants was visible.

Cost:

The cost analysis was patient-centered aimed at distinguishing all the costs of diagnostic, therapeutic and follow-up procedures. The primary objective of this analysis was to achieve a holistic comprehension of the cost–effectiveness related to each of the three treatment modalities studied in this investigation, as well as their entailing complications.

The average cost of individual clinical procedures across the 1 to the 22-year follow-up period (upper limit determined by the case with the longest follow-up) was predetermined, to ensure standardization among the sample, and utilized in the analysis. This was performed by calculating the mean of the individual costs of a procedure from every year since 1997, at the University of Michigan School of Dentistry. This precludes any interference, by the regular rate of inflation across the 1 to the 22-year timeline, with the reliability of the cost analysis, standardizing the cost for all patients. A pricelist was generated based on these means and all procedures associated with each patient file were recorded by 3 study investigators (MT, AR, SA). Wherever doubt arose, the supervising investigator (HLW) was referred to. With these records, the cost of treatment and management performed on each patient was noted and computed into the following categories of cost:

1. Initial Cost: Implant + Prosthesis Placement Fees
2. Cost of Complication Management: Prosthodontic Complication Management Fees
3. Total Cost: Initial Cost + Cost of Complication Management

The purpose of analysis was to simulate a clinical setting where a patient is not pardoned for payment as a means to have a fair and elaborate comparison between the

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treatment approaches. Therefore, whether or not the patient had actually paid for the provided treatments, actual cost was presumed within the particular patient's cost of treatment.

Within the initial cost, every treatment fee, such as preliminary consultation appointments, use of radiographic and/or laboratory diagnostic aids, laboratory fees and preparations, and the entire cost of surgery, were included. Complication management cost included any fee related to follow-up maintenance, as well as management of any complication pertaining to any component of the implant-prosthesis structure.

The average cost of each procedure was calculated as follows:

Cost1 + Cost2 + Cost3 + Cost4 .../n

where:

Costx = Procedure Cost at a Given Year

n = Total number of Costx events per procedure

Statistical analyses

The demographic profile, clinical characteristics and post-hoc power analysis of the included sample were compared using: 1) t-test analyses (t); 2) Chi^2 homogeneity tests (Chi^2); 3) ANOVA F-test (F); 4) Mann-Whitney test (MW) and 5) Kruskal-Wallis test (KW). The probability of peri-implantitis, implant failure and prosthodontic complications among the three groups were calculated using a multiple binary logistic regression: estimation of odds ratio (OR) adjusted by smoking, history of periodontitis, follow-up time, gender, age, diabetes, arch and bone augmentation. The McNemar test was performed to compare the incidence of peri-implantitis in 2 specific positions of the same patient. Peri-implantitis at the implant level was estimated using a generalized estimation equation (GEE) model to determine intra-subject correlations. The effect of the horizontal/vertical distance on the peri-implantitis probability was evaluated by incorporating this covariate to the previous model. The survival rates of the 3 groups were analyzed and compared using by Chi^2 and Fisher's exact test. At the implant level, to evaluate the survival rate, the Kaplan-Meier function was performed, and the Log Rank (Mantel-Cox) test with hazard ratio (HR) estimation was used for the overall comparison of the survival curves.

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Finally, the cost analyses were performed using non-parametric tests of Kruskal-Wallis and Mann-Whitney. The level of significance used in the analyses was set at 5% ($\alpha = 0.05$).

Results

Clinical characteristics and demographic profiles:

A total of 329 3-unit posterior edentulous sites restored with an implant-supported prosthesis were initially screened for possible inclusion. Following thorough examination, 145 cases (pertaining to 64 males and 81 females with a mean age of 60.7 ± 10.1 years old) were selected and subsequently divided into 3 study groups (40 in the NSC, 52 in the SC and 53 in the FPD) (Fig 2) for analysis. The remaining cases were excluded based on the following reasons: a) <1-year follow-up (52), b) anterior zone cases (32), c) ineligible number of implants or final prosthodontic designs (32), d) files with incomplete clinical information (16), e) files with no relevant cases (15), f) implant placement or loading (single crown group) occurred in different appointments (14), g) implant loading performed in centers outside the University of Michigan School of Dentistry clinics (14), h) inaccessible files (8), or i) patients with uncontrolled diabetes (1).

Overall, 382 implants (120 in the NSC, 106 in the FPD and 156 in the SC) were included in the present study. Table 1 provides the demographic and baseline clinical parameters. All prostheses were porcelain-fused-to-metal and either screw-retained (standard protocol for prosthetic screw tightening via a torque controller set at 30 Ncm) or cement-retained using premier implant cement kit (Premier Dental, Plymouth Meeting, PA, USA). Patient age, implant location (maxillary or mandibular) and bone augmentation were found to be significantly different among the three groups ($p<0.05$).

A general linear model type ANOVA, with the current sample of n = 145 patients, reached a power of 76.4% to detect an average effect size (f = 0.25) in the mean MBL difference between the three types of prostheses as significant, assuming a 95% confidence level. The same model at the implant level (n = 382) achieved a 90.9% power with the same conditions. This value was corrected by the dependence between observations (multiplicity of implants per patient), assuming a moderate correlation ($\rho = 0.5$).

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Survival rate:

At the patient level, 93.8% of the patients did not experience implant failure. When this percentage was equated among the studied groups, survival rates were 92.5% in the NSC, 100% in the FDP and 88.5% in the SC (fig 3a). An inter-group comparison showed a statistically significant difference between the FPD and SC (p=0.01), in addition to a trend towards less failure in FPD when compared with NSC (p=0.07). The difference between the NSC and SC was not statistically significant (p=0.58). At the implant level, 366 (95.8%) of the total 382 implants were still in function by the end of the total study follow-up period (97.5% in the NSC, 100% in the FDP and 91.7% in the SC). A statistically significant difference between the FPD and SC (p<0.01) was also demonstrated at this level. However, as opposed to the patient level, a statistical trend was observed between the NSC and SC (p=0.04) at the implant level, while FPD reported again less failure rate than SC (p=0.07). The Log Rank (Mantel-Cox) test confirmed the non-equality in survival distribution between the FDP and SC (p<0.01) (fig3b).

Success rate:

The total success rate in the entire patient sample was 66.2%. This percentage was distributed across the study groups as 81.1% in the FPD, 61.5% in the SC and 52.5% in the NSC (corresponding success rate percentages summarized in figure 4). Patients with an FPD compared to NSC demonstrated a decreased probability of implant-related complications of up to 74% (OR=0.26, p=0.004). This can also be viewed as NSC being at a 289% greater risk of implant-related complications than an FPD (OR=3.89, p=0.004). However, the risk between SC and NSC was comparable (p=0.385). Similarly, SC is at a 168% higher risk of developing implant-related complications than an FPD (OR=2.69, p=0.029).

Peri-implantitis:

A total of 16.6% of the patient sample developed peri-implantitis (in ≥1 of their implants). This percentage fluctuates from 5.7% in the FPD to 17.5% in the NSC and 26.9% in the SC. Table 2

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outlines the same information as the number of affected implants in the same individuals. Overall, 9.9% of the total implants were found to have peri-implantitis, with 16.7% in the SC, 7.5% in the NSC and 2.8% in the FDP (figure 5a). Hence, a patient with an FPD has a decreased probability of developing peri-implantitis by up to 72% (OR=0.28, p=0.082) when compared to NSC. Similarly, a patient with SC was shown to be at an increased risk of developing peri-implantitis by about 74%, when compared to NSC (OR=1.74, p=0.289). Finally, a patient with an FPD presents a significantly reduced risk (84%) of developing peri-implantitis as compared to SC (OR=0.16, p=0.007). At the implant level, an implant under an FPD has a decreased probability of developing peri-implantitis by up to 64% (OR=0.36, p=0.090) with respect to being under SC. In the same way, an implant splinted to a second implant demonstrated 2.5 times (or 147%) greater risk of acquiring peri-implantitis than that associated with single crown prostheses (OR=2.47, p=0.156). Finally, an implant associated with an FPD showed to be at a significantly reduced risk of developing peri-implantitis (95.4%) as opposed that having a splinted prosthesis (OR=0.146, p=0.003).

Results from the generalized estimation equation depicted that neither the horizontal distance between the implants (p=0.5) nor the vertical distance (p=0.4) were factors associated with the incidence of peri-implantitis.

Figure 5b summarizes the PI rate the implants according to location (A, B and C) among the three groups. No differences in PI incidence were detected between the mesial and distal implants (A and C, respectively) among the study groups, while the central implants (B) pertaining to the SC demonstrated a significantly higher probability of PI than those of the NSC (OR=5.70, p=0.029). The risk is quantified as a 470% greater risk between the two. Furthermore, when the comparison among implants A, B and C within the same prosthodontic design was performed, only implant B within a splinted prosthodontic design tends to present with a higher PI rate than implant C (p=0.070).

Prosthodontic complications

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Table 3 gives an overview of all occurred complications with respect to time and the number of prostheses that were being followed. During the entire study period, prosthodontic complications were found in 19.3% of the patients. NSC, FPD and SC had 32.5%, 13.2% and 15.4% prosthodontic complications, respectively (Figure 6a). A patient with an FPD demonstrated a reduced risk of complications by up to 68% (OR=0.32, p=0.029) when compared with NSC. This can also be expressed as a 216% higher risk for NSC compared to an FPD (OR=3.16, p=0.029). Furthermore, the SC group showed a reduced risk for prosthodontic complications (OR=0.38, p=0.057) when compared with NSC, where NSC had a risk 165% higher than SC (OR=2.65, p=0.057). Additionally, each added year reduced the risk of the overall complications by 6% (OR = 0.94, p = 0.031). The different types of prosthodontic complications per group are outlined in Figure 6b. Out of all the documented complications, 10.3% had crown chipping, 6.9% de-cementation, 4.1% crown fracture, and 0.7% prosthodontic screw loosening. When the different types of complications were compared, the FPD were associated with less de-cementation than the NSC (p=0.005) and SC (p=0.057). With respect to the occurrence of crown fractures, the SC portrayed a superior outcome to the NSC (p=0.033).

Cost:

As depicted in Table 4, the primary factor to be considered was the initial cost associated with each prosthodontic design, where FPD costs only $ 6,998 (-16% with respect to the other two prostheses). The higher source of variability was in the costs per complication and on average was higher for the NSC than the SC (p=0.081) and the FPD (p=0.001) Figure 7. Finally, the total cost of the FPD group was significantly lower than the NSC and SC (p<0.001). Although there were no differences between the FPD and SC at the complication level of analysis, the initial cost of the SC is higher than those of an FPD.

Discussion:

The choice of therapeutic approach pertaining to the final restoration of a posterior 3-unit edentulous site is at the discretion of the operator, and It is a common occurrence that

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different clinicians tend to lean towards certain approaches for the correction of the same case. The present study presents a clear perspective of the perceivably comparable treatment choice in the aforementioned clinical scenario, addressing all the clinical variables, including patient-related outcomes such as the associated finances, to provide clinicians with objective criteria when selecting the most appropriate therapy. The design of the present study is slightly different from that completed by Eliasson and coworkers (Eliasson, Eriksson, Johansson & Wennerberg 2006, Yi, Lee & Kim 2013), since we focused our attention on the posterior region and we included 3 distinct study groups (SC, FDP and NSC).

Our results suggest that the NSC and SC (3-implant supported prosthesis) had a greater incidence of peri-implantitis than the 2-implant supported FPD. This implies that the higher bending moment associated with 2 implants in-vitro (de Souza Batista, Verri, Almeida, Santiago Junior, Lemos & Pellizzer 2017) did not have a detrimental impact on marginal bone loss. This was further confirmed by the higher rate of peri-implantitis in SC as opposed to an FPD (Hasan, et al. 2015, Huang, Huang, Ko, Hsu, Chang & Chen 2005, Shigemitsu, et al. 2013, Yilmaz, Seidt, McGlumphy & Clelland 2011).

Clinically, the present study does not reflect the results of a 10-year randomized controlled trial comparing 3 splinted versus 3 non-splinted implants in 44 patients (132 implants), where not a single implant exhibited failure or biologic complications such as peri-implantitis or peri-implant mucositis (Vigolo, et al. 2015). This discrepancy between the two studies could be attributed to: different treatment environments of academic setting versus private practice; prospective versus retrospective study; and experienced surgeon versus beginner between their and ours, respectively.

A peculiar trend emerging from the analysis is that the central implant (B) under SC has a nearly 6-fold higher probability of developing peri-implantitis than the central implant under NSC and higher peri-implantitis rate than the adjacent distal implant (C). Although the higher inter-group difference could be explained by the reduced cleanability of splinted prostheses, the finding

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that within the same group the distal implant (often considered more challenging to clean) is less affected presents an interesting novelty that deserves more attention in future studies.

In addition, residual cement may also be another contributing factor for the incidence of peri-implantitis (Wilson 2009). However, in the present study, only 12 patients of each group's had received a cemented prosthesis (Table 1), accounting to, at most, less than 30% of the patients in each set. Given that at baseline, the patient distribution in terms of prosthesis type heavily disfavors a substantial presence of cement around the implants, and we felt that it may be misleading stress the relevance of cement to the occurrence of peri-implant disease within the confines of this investigation.

The implant survival rate was calculated with and without the Kaplan Mayer test. When this test was not used, the rate was calculated without considering that there were censored cases throughout the observation period. The Kaplan Mayer methodology allowed for the estimation of the survival function accounting for the duration in which the implants were in the mouth. Hence, the longer the follow-up period, the lower the number of implants considered. Thus, the 77% survival rate of the SC at the end of the follow-up period is based on only a few cases that reached the final follow-up and should be interpreted with caution.

The high survival rate demonstrated by the FPD (100%) is not striking. Yi and coworkers previously reported no failure in an average follow-up of 4 years (Yi, Lee & Kim 2013), and similarly, Spies et al. confirmed these results across a 3-year follow-up period using all-ceramic bi-layered implant-supported 3-unit fixed dental prostheses (Spies, et al. 2016). Excellent results (96.8% survival rate) have also been reported at 5 years of follow-up (Eliasson, Eriksson, Johansson & Wennerberg 2006).

The FPD has also portrayed higher success rates than the other groups, with 81% of patients without any reporting of complications or concern throughout the entire follow-up. Contrarily, despite the higher peri-implantitis rate and implant failures, SC presented a slightly higher

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success rate (61.5%) than NSC (52.5%). The explanation for this is the higher resistance to prosthodontic complication that accompanies the splinted crowns, particularly due to their resistance to rotational movements enhancing their stability to eccentric forces (Faucher & Bryant 1983). In fact, NSC was the prosthodontic design that had presented with more complications such as crown de-cementation and prosthodontic screw loosening. This observation has been previously reported in a prospective split-mouth study where splinted and non-splinted implant crowns (placed in 15 patients) were observed along 3 years and all screw loosening reportedly only occurred on the non-splinted side (Clelland, Chaudhry, Rashid & McGlumphy 2016). Furthermore, a systematic review found that screw loosening was associated with 5.6% of the implants restored with splinted crowns and with 12.7% of those restored with single crowns along a 5-year follow-up period (Pjetursson, et al. 2007). Also, similarly to our results, they reported a higher incidence of ceramic chipping and fracture occurred with single crown (3%) than with their splinted counterparts (0.7%).

To compare the expenses associated with the three groups, one of the advantages was having a long observational period. To the best of our knowledge, no study has previously compared the cost of the three treatment approaches; therefore, a direct comparison of our findings to the literature was not possible in this regard. As demonstrated by the results of the current research, an FPD, due to the placement of one less implant, presented with a -16% less initial cost with respect to the other two groups. Additionally, the difference further increased over the study period due to the expenses associated with treatment of the complications being higher in the NSC groups.

The present study is not exempt from limitations such as different implant systems, diameters and length; the lack of information about the soft tissue thickness and the bucco-lingual position of the examined implants. Therefore, further studies considering these variables are necessary in the future, to confirm our results. Additionally, an inherit limitation of the retrospective nature of this study is the preclusion of identifying the occlusal profile of individual patients. In fact, the uncontrollable variability in occlusion and dynamic of opposing

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tooth positions poses an inability to generate a categorical set of data indicating an exact and persistent opposing structure, such as tooth only, crown only or both tooth and crown, across the observational period. For example, a case may have commenced with an opposing set of teeth at baseline but along the follow-up exhibited a loss of one or more of those teeth. This varying dynamic among cases creates a set of scenarios that cannot be confined to a fixed set of opposing occlusion categories to be tested.

The type of occlusal adjustment implemented is another clinical parameter essential to ensuring optimal treatment and a more standardized study population. Within this study's clinical setting, canine-guided occlusal correction is the primarily enforced approach to such cases. However, as with other routine, minute details of treatment, patient charts did not consistently contain whether canine-guided or group function occlusion was employed. For that reason, this may be considered a limitation of the overall study constituents.

In conclusion, an implant-supported FPD seems to present the most ideal long-term therapeutic solution in rehabilitating a 3-unit edentulous area by demonstrating: 1) comparable peri-implantitis rate to NSC and lower than SC; 2) comparable survival rate to NSC while higher than SC; 3) similar complication rate to SC while lower than NSC; 4) higher success rate than both NSC and SC; 5) lower total cost than NSC and SC.

Conflict of interest

The authors do not have any financial interests neither directly nor indirectly in the companies whose materials were utilized in this study. This paper was partially supported by the University of Michigan Periodontal Graduate Student Research Fund.

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REFERENCES

Armitage, G. C. (2004) Periodontal diagnoses and classification of periodontal diseases. *Periodontol 2000* **34**: 9-21.

Cannizzaro, G., Felice, P., Soardi, E., Ferri, V., Leone, M. & Esposito, M. (2011) Immediate loading of 2 (all-on-2) versus 4 (all-on-4) implants placed with a flapless technique supporting mandibular cross-arch fixed prostheses: Preliminary results from a pilot randomised controlled trial. *Eur J Oral Implantol* **4**: 205-217.

Chrcanovic, B. R., Albrektsson, T. & Wennerberg, A. (2014) Reasons for failures of oral implants. *J Oral Rehabil* **41**: 443-476.

Clelland, N., Chaudhry, J., Rashid, R. G. & McGlumphy, E. (2016) Split-mouth comparison of splinted and nonsplinted prostheses on short implants: 3-year results. *Int J Oral Maxillofac Implants* **31**: 1135-1141.

de Souza Batista, V. E., Verri, F. R., Almeida, D. A., Santiago Junior, J. F., Lemos, C. A. & Pellizzer, E. P. (2017) Finite element analysis of implant-supported prosthesis with pontic and cantilever in the posterior maxilla. *Comput Methods Biomech Biomed Engin* **20**: 663-670.

Eliasson, A., Eriksson, T., Johansson, A. & Wennerberg, A. (2006) Fixed partial prostheses supported by 2 or 3 implants: A retrospective study up to 18 years. *Int J Oral Maxillofac Implants* **21**: 567-574.

Faucher, R. R. & Bryant, R. A. (1983) Bilateral fixed splints. *Int J Periodontics Restorative Dent* **3**: 8-37.

Flemmig, T. F. & Beikler, T. (2009) Decision making in implant dentistry: An evidence-based and decision-analysis approach. *Periodontol 2000* **50**: 154-172.

Grossmann, Y., Finger, I. M. & Block, M. S. (2005) Indications for splinting implant restorations. *J Oral Maxillofac Surg* **63**: 1642-1652.

Guichet, D. L., Yoshinobu, D. & Caputo, A. A. (2002) Effect of splinting and interproximal contact tightness on load transfer by implant restorations. *J Prosthet Dent* **87**: 528-535.

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Hasan, I., Bourauel, C., Keilig, L., Stark, H. & Luckerath, W. (2015) The effect of implant splinting on the load distribution in bone bed around implant-supported fixed prosthesis with different framework materials: A finite element study. *Ann Anat* **199**: 43-51.

Huang, H. L., Huang, J. S., Ko, C. C., Hsu, J. T., Chang, C. H. & Chen, M. Y. (2005) Effects of splinted prosthesis supported a wide implant or two implants: A three-dimensional finite element analysis. *Clin Oral Implants Res* **16**: 466-472.

Jung, R. E., Zembic, A., Pjetursson, B. E., Zwahlen, M. & Thoma, D. S. (2012) Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. *Clin Oral Implants Res* **23 Suppl 6**: 2-21.

Malo, P., Nobre, M. & Lopes, A. (2013) Immediate loading of 'all-on-4' maxillary prostheses using trans-sinus tilted implants without sinus bone grafting: A retrospective study reporting the 3-year outcome. *Eur J Oral Implantol* **6**: 273-283.

Malo, P., Rangert, B. & Nobre, M. (2003) "All-on-four" immediate-function concept with branemark system implants for completely edentulous mandibles: A retrospective clinical study. *Clin Implant Dent Relat Res* **5 Suppl 1**: 2-9.

Nissan, J., Ghelfan, O., Gross, M. & Chaushu, G. (2010) Analysis of load transfer and stress distribution by splinted and unsplinted implant-supported fixed cemented restorations. *J Oral Rehabil* **37**: 658-662.

Pihlstrom, B. L., Michalowicz, B. S. & Johnson, N. W. (2005) Periodontal diseases. *Lancet* **366**: 1809-1820.

Pjetursson, B. E., Bragger, U., Lang, N. P. & Zwahlen, M. (2007) Comparison of survival and complication rates of tooth-supported fixed dental prostheses (fdps) and implant-supported fdps and single crowns (scs). *Clin Oral Implants Res* **18 Suppl 3**: 97-113.

Ravida, A., Barootchi, S., Tattan, M. A., Saleh, M. H. A., Gargallo-Albiol, J. & Wang, H. L. (2018) Clinical outcomes and cost effectiveness of computer-guided versus conventional implant-retained hybrid prostheses: A long-term retrospective analysis of treatment protocols. *J Periodontol*.

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Author Manuscript

Ravida, A., Saleh, M. H. A., Muriel, M. C., Maska, B. & Wang, H. L. (2018) Biological and technical complications of splinted or nonsplinted dental implants: A decision tree for selection. *Implant Dent* **27**: 89-94.

Renvert, S. & Persson, G. R. (2009) Periodontitis as a potential risk factor for peri-implantitis. *J Clin Periodontol* **36 Suppl 10**: 9-14.

Schneider, C. A., Rasband, W. S. & Eliceiri, K. W. (2012) Nih image to imagej: 25 years of image analysis. *Nat Methods* **9**: 671-675.

Serino, G. & Strom, C. (2009) Peri-implantitis in partially edentulous patients: Association with inadequate plaque control. *Clin Oral Implants Res* **20**: 169-174.

Shigemitsu, R., Ogawa, T., Matsumoto, T., Yoda, N., Gunji, Y., Yamakawa, Y., Ikeda, K. & Sasaki, K. (2013) Stress distribution in the peri-implant bone with splinted and non-splinted implants by in vivo loading data-based finite element analysis. *Odontology* **101**: 222-226.

Spies, B. C., Witkowski, S., Butz, F., Vach, K. & Kohal, R. J. (2016) Bi-layered zirconia/fluor-apatite bridges supported by ceramic dental implants: A prospective case series after thirty months of observation. *Clin Oral Implants Res* **27**: 1265-1273.

Tonetti, M., Palmer, R. & Working Group 2 of the, V. E. W. o. P. (2012) Clinical research in implant dentistry: Study design, reporting and outcome measurements: Consensus report of working group 2 of the viii european workshop on periodontology. *J Clin Periodontol* **39 Suppl 12**: 73-80.

Vigolo, P., Mutinelli, S., Zaccaria, M. & Stellini, E. (2015) Clinical evaluation of marginal bone level change around multiple adjacent implants restored with splinted and nonsplinted restorations: A 10-year randomized controlled trial. *Int J Oral Maxillofac Implants* **30**: 411-418.

Wilson, T. G., Jr. (2009) The positive relationship between excess cement and peri-implant disease: A prospective clinical endoscopic study. *J Periodontol* **80**: 1388-1392.

Yi, Y. J., Lee, J. Y. & Kim, Y. K. (2013) Comparative clinical study of three-unit fixed partial prostheses supported by two or three implants. *Int J Oral Maxillofac Implants* **28**: 1110-1115.

Yilmaz, B., Seidt, J. D., McGlumphy, E. A. & Clelland, N. L. (2011) Comparison of strains for splinted and nonsplinted screw-retained prostheses on short implants. *Int J Oral Maxillofac Implants* **26**: 1176-1182.

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Yoda, N., Liao, Z., Chen, J., Sasaki, K., Swain, M. & Li, Q. (2016) Role of implant configurations supporting three-unit fixed partial denture on mandibular bone response: Biological-data-based finite element study. *J Oral Rehabil* **43**: 692-701.

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Legends:

Tables

Table 1: Clinical characteristics and patient demographics of the three studied groups.

Table 2: Number of implants with peri-implantitis by group.

Table 3: Incidence of prosthodontic complications per year for the three studied groups

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Figure 1: Clinical depiction of the 3 different treatment approaches represented in the study groups; (1) 3 posteriors implants loaded with 3 non-splinted crowns; (2) 3-unit fixed partial denture supported by 2 implants (FPD); (3) 3 posteriors implants loaded with 3 splinted crowns

Figure 2: Percentage distribution of treatment modalities within the study sample.

Figure 3: (a) Rates of implant failure at the implant and patient level across the study groups, (b) cumulative survival rates of each study group sample.

Figure 4: Success rates represented at the implant level of each study group samples.

Figure 5: Peri-implantitis incidence rates, (a) at the patient and implant levels and (b) according to implant position, across the study sample.

Figure 6: Prosthodontic complication rates, (a) at the patient level and (b) according to type of complications, across the study sample.

Figure 7: Projected comparison of costs pertaining to each treatment approach study group.

Table 1: Profile of the treatment groups according to variables at the patient and implant level

		Groups			
		Single c.	**FPD**	**Splinted**	**p-value**
Patient level	**N (patients)**	40	53	52	
	Age (years)	58.0 ± 8.3 (56.5)	63.4 ± 10.8 (64.0)	60.2 ± 10.0 (60.5)	**0.032* (F)**
	Women	22 (55.0)	33 (62.3)	26 (50.0)	0.445 (Chi^2)
	Smokers	10 (25.0)	13 (24.5)	16 (30.8)	0.733 (Chi^2)

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	Diabetes	3 (7.5)	3 (5.7)	4 (7.7)	0.905 (Chi^2)
	History of periodontitis	14 (36.8)	9 (18.0)	19 (38.0)	0.057 (Chi^2)
	Maxilla	22 (55.0)	26 (49.1)	16 (30.8)	**0.045* (Chi^2)**
	Mandible	18 (45.0)	27 (50.9)	36 (69.2)	
	Cement retained prosthesis	12 (30.0)	12 (22.7)	12 (23.1)	0.761 (Chi^2)
	Screw retained prosthesis	28 (70.0)	41 (77.3)	40 (76.9)	
	Bone augmentation	8 (20.0)	13 (24.5)	26 (50.0)	**0.003** (Chi^2)**
	Guided implants	13 (32.5)	16 (30.2)	10 (19.2)	0.289 (Chi^2)
	Implant failure	3 (7.5)	0 (0.0)	6 (11.5)	**0.046* (Chi^2)**
	Follow-up (months) survival rate	85.2 ± 40.4 (78.5)	80.1 ± 51.8 (63.0)	92.1 ± 51.2 (85.0)	0.272 (KW)
	Follow-up (months) Prosthodontic complications	72.6 ± 34.8 (70.0)	69.8 ± 51.7 (49.0)	85.4 ± 53.5 (79.5)	0.254 (KW)
	Follow-up (months) PI	61.8 ± 37.4 (58.0)	64.9 ± 50.2 (43.0)	78.7 ± 46.2 (60.0)	0.605 (KW)
	Prosthodontic complications	13 (32.5)	7 (13.2)	8 (15.4)	0.051 (Chi^2) 0.292 (Chi^2)^{aj}
	Decementation	6 (15.0)	0 (0.0)	4 (7.7)	**0.018* (Chi^2)**
	Chipping	6 (15.0)	5 (9.4)	4 (7.7)	0.505 (Chi^2)
	Fracture	4 (10.0)	2 (3.8)	0 (0.0)	0.058 (Chi^2)
	Screw loosening	1 (2.5)	0 (0.0)	0 (0.0)	0.269 (Chi^2)
	Peri-implantitis	7 (17.5)	3 (5.7)	14 (26.9)	**0.025* (Chi^2)** 0.056 (Chi^2) ^{aj}
	Success rate	21 (52.5)	43 (81.1)	32 (61.5)	**0.013* (Chi^2)** **0.034*(Chi^2)^{aj}**
Implant level	**n (implants)**	120	106	156	
	Implant Failure	3 (2.5)	0 (0.0)	13 (8.3)	**<0.001***(Chi^2)**
	PI	9 (7.5)	3 (2.8)	26 (16.7)	**0.009** (Chi^2)** **0.033* (Chi^2)^{aj}**
	PI implants A	2 (5.0)	2 (3.8)	8 (15.4)	0.091 (Chi^2) 0.275 (Chi^2)^{aj}
	PI implants B	2 (5.0)	---	12 (23.1)	**0.029* (Chi^2)** **0.042* (Chi^2)^{aj}**
	PI implants C	5 (12.5)	1 (1.9)	6 (11.5)	0.180 (Chi^2) 0.266 (Chi^2)^{aj}
	Horizontal Distance A-B	3.14 ± 1.37 (2.84)		3.25 ± 1.04 (3.02)	0.733 (t)
	Horizontal Distance A-C		9.04 ± 2.37 (8.52)		---
	Horizontal Distance B-C	3.34 ± 1.04 (3.14)		3.91 ± 1.20	0.062 (t)

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			(3.87)	
Vertical Distance A-B	0.95 ± 0.78 (0.76)		1.02 ± 0.83 (0.78)	0.738 (t)
Vertical Distance A-C		1.13 ± 0.90 (0.93)		---
Vertical Distance B-C	0.97 ± 0.71 (0.88)		1.08 ± 1.06 (0.62)	0.676 (t)

Numbers are expressed as: Number of cases (%) or mean ± standard deviation (median).

Chi^2 test results, F test of the ANOVA model, 2-sample t test, non-parametric Kruskal-Wallis test, Chi2 Wald model GEE test, logarithm-Kaplan-Meier (LR) test. (PI) Peri-Implantitis

*p< 0,05; **p< 0,01;***, p< 0,001; ^{aj},p-value of the adjusted model

Table 2: Number of implants with PI by group

Group

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	Total		Single crowns		FPD		Splinted	
	N	%	N	%	N	%	N	%
Total	145	100	40	100	53	100	52	100
0	121	83.4	33	82.5	50	94.3	38	73.1
1	15	10.3	6	15	3	5.7	6	11.5
2	4	2.8	0	0.0	0	0.0	4	7.7
3	5	3.4	1	2.5	0	0.0	4	7.7

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Table 3: Incidence of prosthodontic complications per year for the three studied groups

Type of Prosthesis	Prosthodontic Complication	Incidence of Events (in months)							Total
		0 - 12	12 - 24	24 - 36	36 - 48	48 - 60	60 - 120	120+	
FPD	De-cementation								0
	Fracture/Chipping		4	2	1			1	8
	Prosthodontic Screw Loosening								0
	No. of cases	53	53	48	33	27	26	7	
SC	De-cementation	4						3	7
	Fracture/Chipping	1	1			1	3		6
	Prosthodontic Screw Loosening								0
	No. of cases	52	52	46	42	36	31	13	
NSC	De-cementation	1	1	3	1		3		9
	Fracture/Chipping	2	6	3	2	1	4		18
	Prosthodontic Screw Loosening						1		1

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No. of cases	40	40	36	36	30	26	5

NSC, 3 non-splinted crowns; SC, 3 splinted crowns; FPD, 3-unit fixed partial denture supported by 2 implants

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Table 4: Cost expenditure through the overall follow-up time

	Groups			
	Single crowns	**FPD**	**Splinted**	***p*-value**
Initial Cost	8.301	6.998	8.301	---

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Cost for complications	356.4 ± 925.8 (0.0)	95.5 ± 602.7 (0.0)	182.0 ± 692.4 (0.0)	**0.005****
Total cost	8.657.4 ± 925.8 (8.301)	7.093.5 ± 602.7 (6.998)	8.483.0 ± 692.4 (8.301)	**<0.001*****

* p< 0,05; ** p< 0,01; *** p< 0,001

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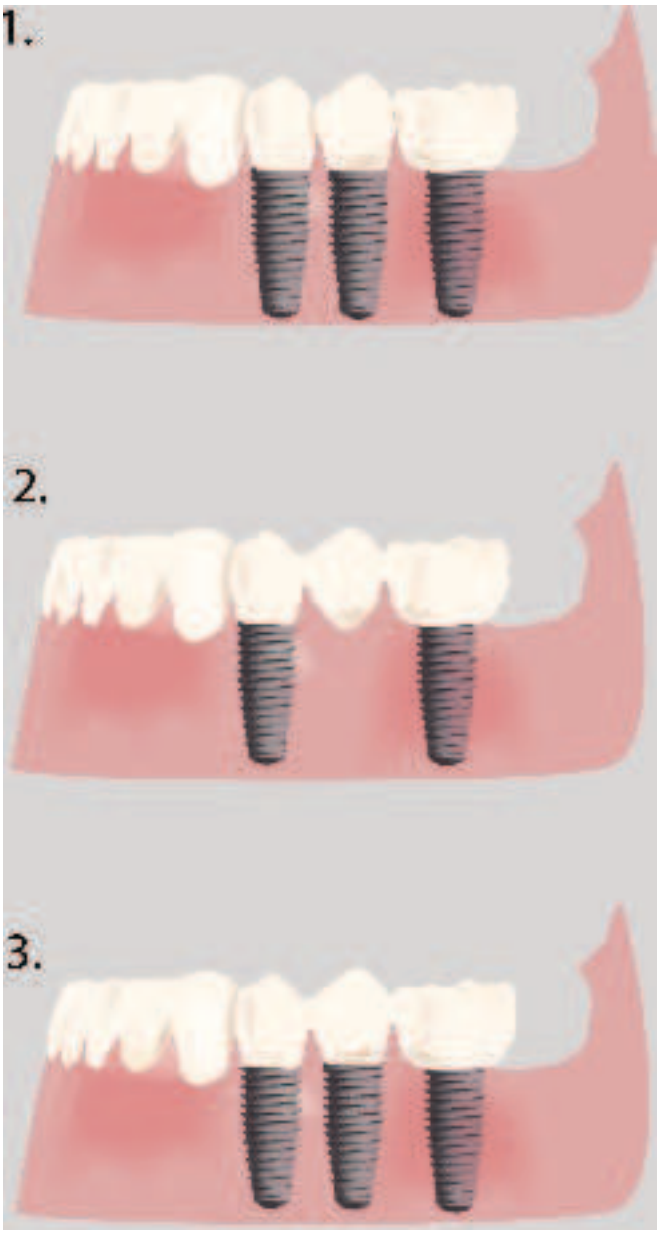

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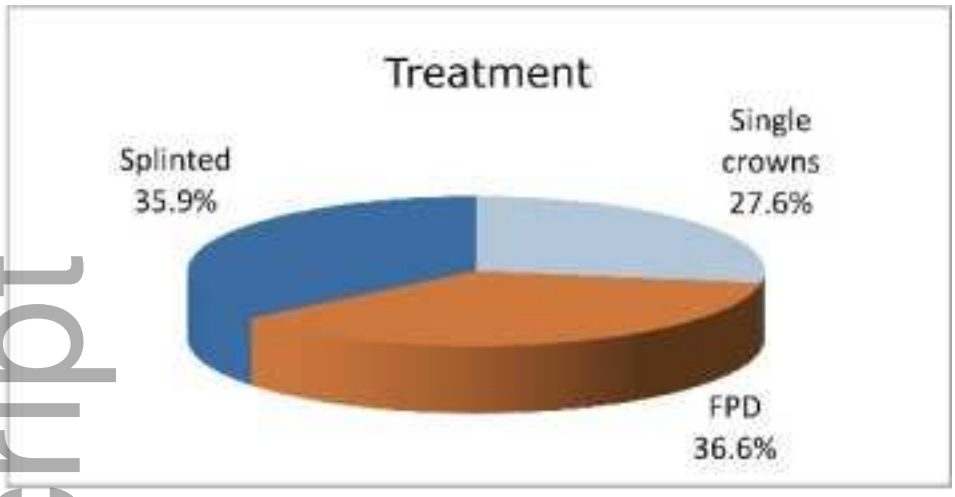

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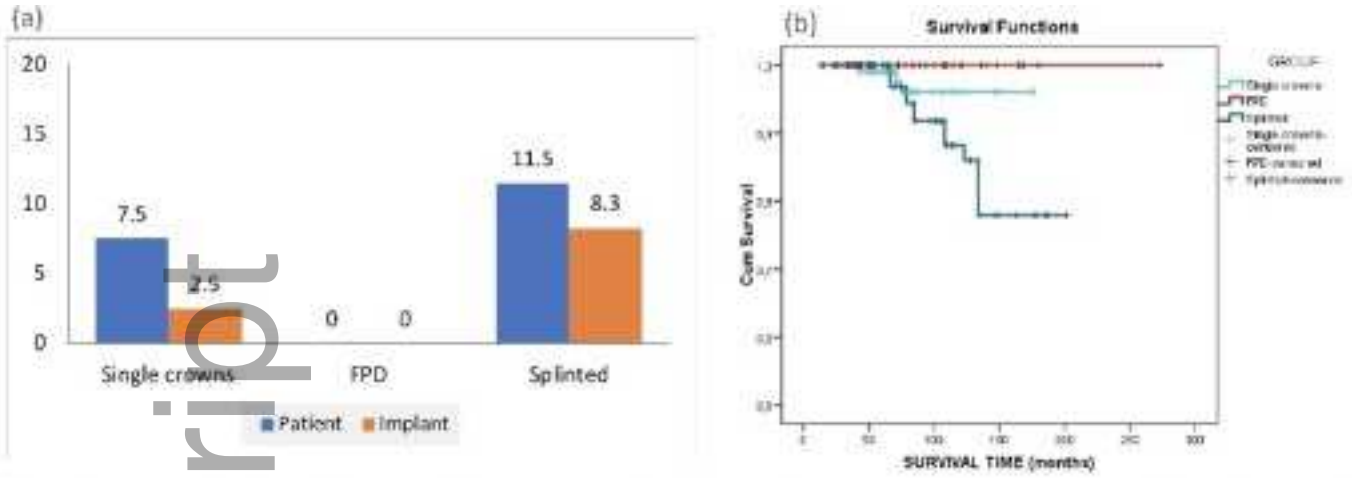

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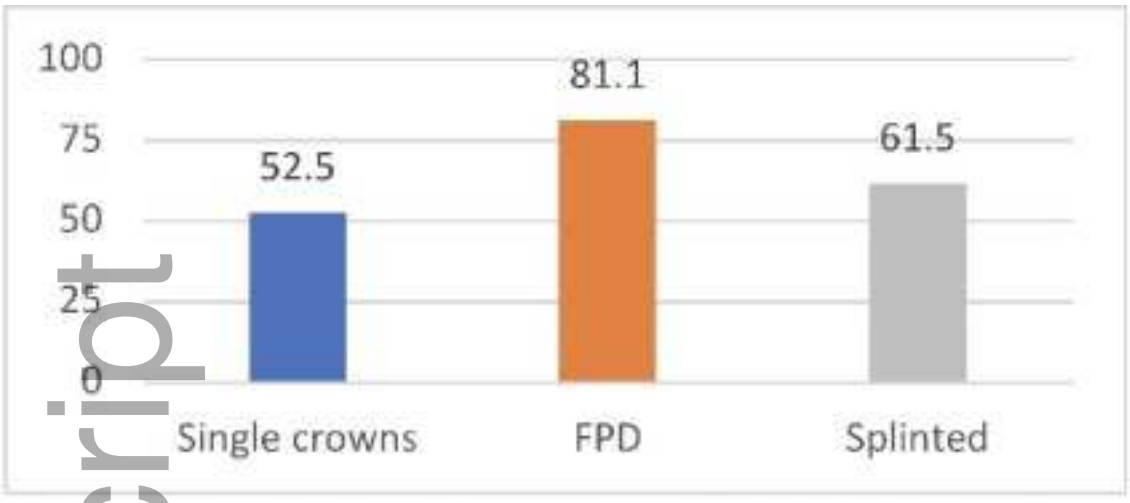

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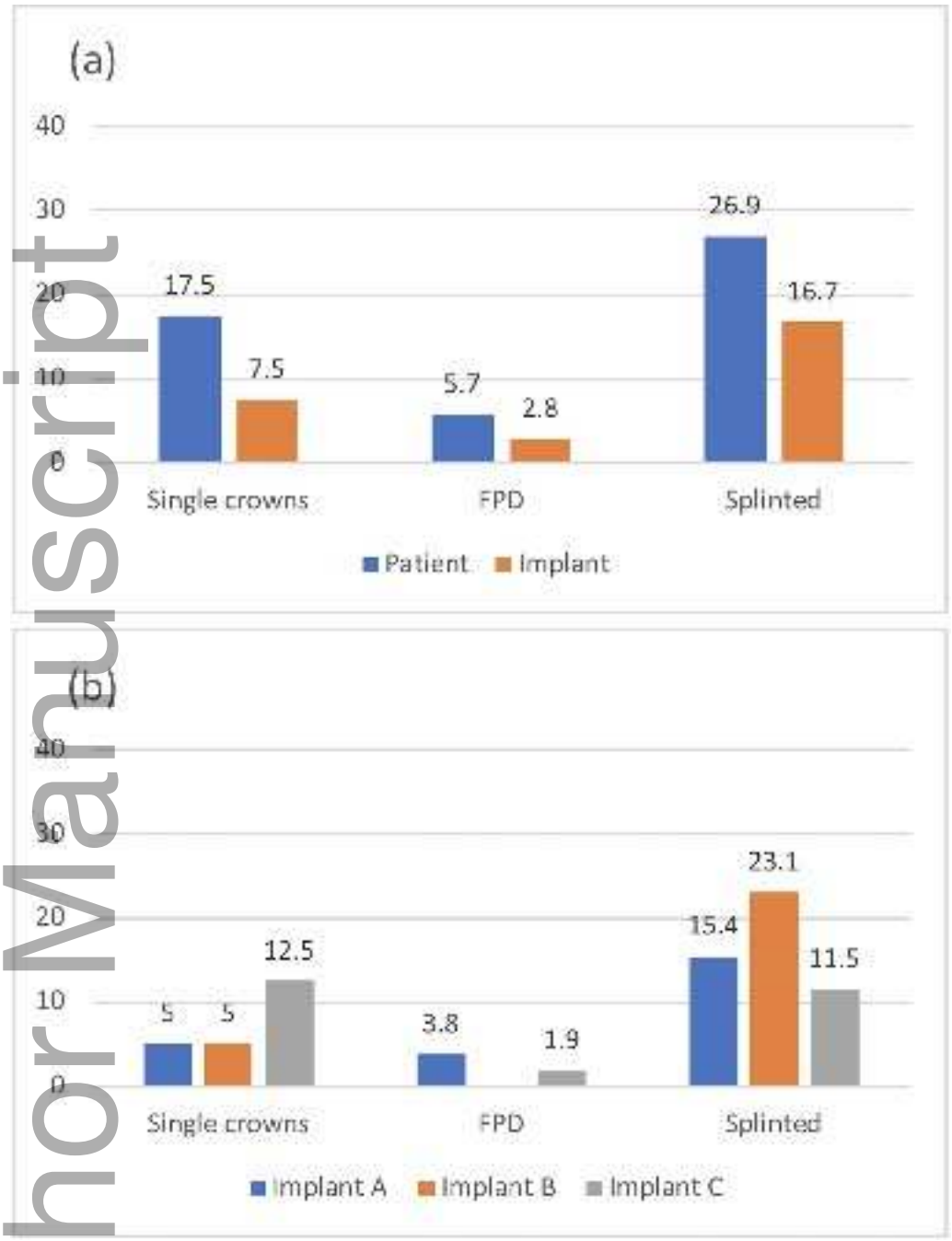

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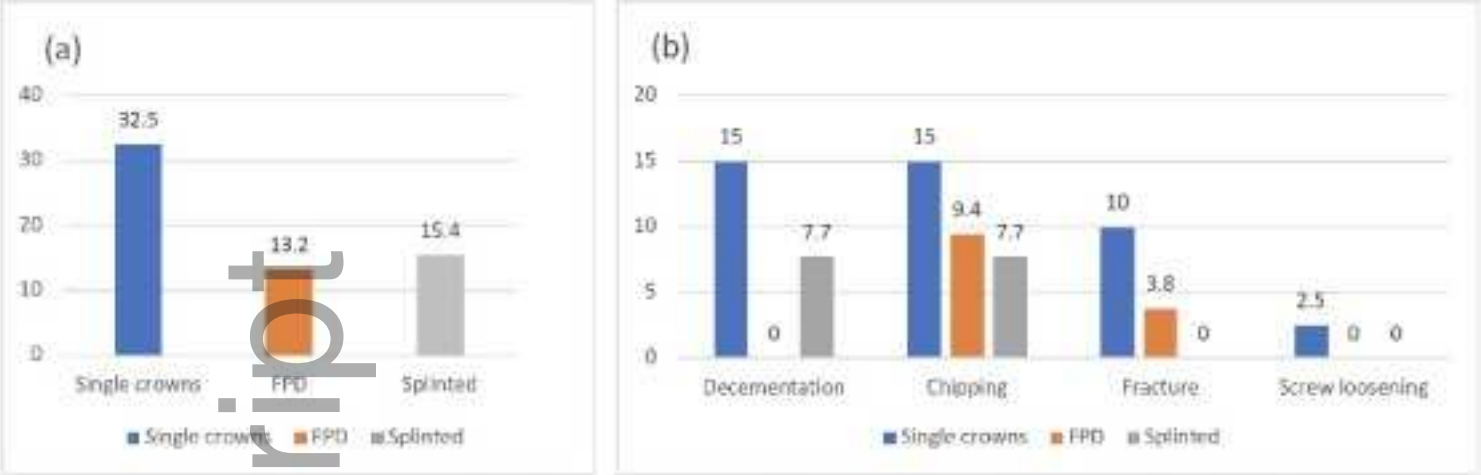

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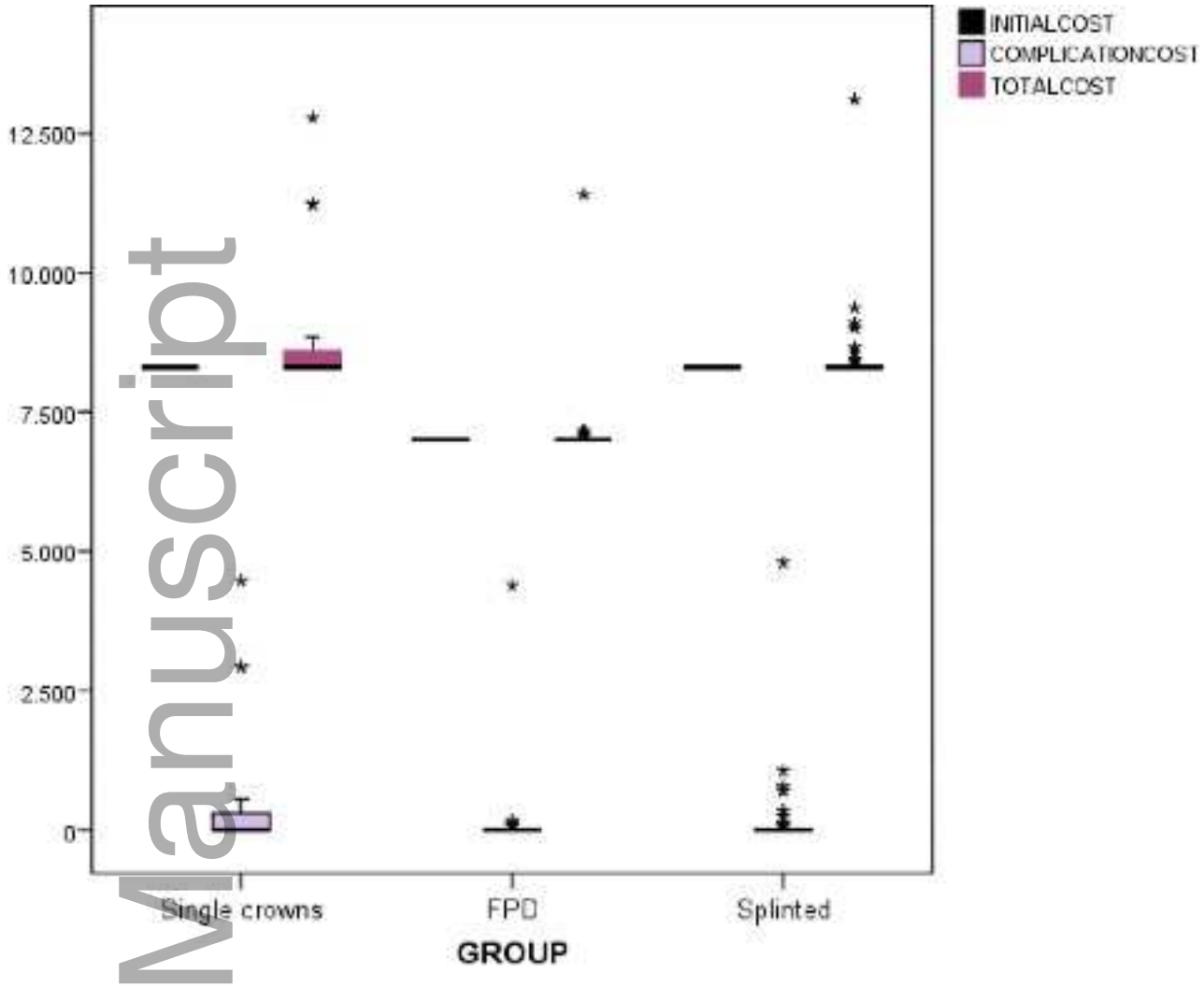

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