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Research Article

# Marginal Accuracy of Titanium Framework Using Different Manufacturing Techniques in Fixed Partial Prostheses

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## Abstract

**Purpose:** This study aimed to evaluate marginal accuracy of titanium framework using different manufacturing techniques in fixed partial prostheses (Conventional casting, subtractive and additive manufacturing).

**Material and Methods:** Thirty resin replicas of a metallic master die were scanned. The design of the titanium framework was done utilizing 3Shape software (CAD) that resembles three-unit bridges to obtain Standard Tessellation Language (STL) file of the final design. Thirty titanium frameworks were fabricated and divided in to three groups according to manufacturing technique. Group C (n = 10): Casting manufacturing technique. Group S (n = 10): Subtractive manufacturing technique. Group A (n = 10): Additive manufacturing technique. In group (C), the framework wax pattern was fabricated using 3D printed wax pattern then invested and casted. In groups (S)and(A), The STL file of the final design of titanium framework was send to a computer aided manufacturing (CAM) machine and metal rapid prototyping machine. Each framework was luted to epoxy die under 2 kg static load. The luted assembly was segmented longitudinal at its center. The gap between die and framework was measured before and after sectioning at cervical shoulder in terms of vertical gap (VG) and horizontal discrepancy (HD), then were statistically analyzed by ANOVA/Tukey test ($P < 0.05$).

**Results:** The VG and HD values of titanium framework fabricated by subtractive technology showed high marginal accuracy compared to the others at all measurement locations. However, there was no statistical difference ($P > 0.05$) among the subtractive and additive technology. Casting titanium showed the least marginal accuracy in both VG and HD values.

**Conclusion:** The measured marginal accuracies of titanium framework fabricated by the subtractive and additive techniques demonstrated clinically acceptable marginal discrepancies on the working dies.

**Keyword:** Titanium, Marginal accuracies, Subtractive manufacturing, Additive manufacturing

## Introduction

Titanium as a coping material for metal ceramic restorations has gotten consideration in dentistry, with the thought that it may well be utilized as a reasonable elective for costly valuable metal amalgams. In spite of the long term clinical victory of rebuilding efforts utilizing valuable metal alloys [1], the expanding cost of gold has ended up a noteworthy driving drive to look for choices. Other than its lower fetched, other characteristics of titanium, such as its great biocompatibility, tall erosion resistance, moo particular gravity, and fitting mechanical properties, are engaging to clinicians [2,3].

Commercially Pure Titanium (CP Ti) is regularly utilized for dental implants and for crowns, bridges. Be that as it may, immaculate titanium casting is risky since of its tall dissolving point and expanded affectability at tall temperatures to encompassing conditions than customary dental amalgams. Liquid titanium has tall liking for gas components such as oxygen and nitrogen, and tall reactivity with silica venture materials which caused a responsive layer (alpha-case) on the surface with resultant insufficient titanium castability [4,5].

Casting innovation is experiencing a radical move due to industrialization. Digitalized innovations are being utilized for the generation of metallic structures, basically in prosthetic dentistry. These innovations can be classified as based on subtractive fabricating, such as the processing of pre-manufactured materials helped by computer-aided design/computer-aided fabricating (CAD/CAM) systems [6-8] or on added substance fabricating, such as the as of late created laser sintering innovation [9-12].

Different studies have appeared that more prominent precision of multiunit fixed restorations can be accomplished with CAD/CAM than with conventional creation methods such as casting [13,14].

CAD/CAM innovation was consolidated to create the titanium adapting creation prepare less difficult and speedier. In this strategy, the die on the working cast was checked, utilizing either an optical or touch probe scanner, to send information to a computer. After digitizing the die, the adapting was essentially planned on the computer utilizing the procured information and system specific CAD program, and after that the electronic record was exchanged to extraordinary milling unit to manufacture the coping [2].

Modern CAD/CAM frameworks are able to manufacture not as it were the single crown coping, but too the metal framework for a fixed partial denture of up to 14 units, or customized implant abutments [15,16]. As for the exactness of the items, indeed in spite of the fact that CAD/CAM innovation is moderately modern and requires change, the speed with which it has been created to surrender comes about comparable to the routine lost-wax method is noteworthy [17].

Additive Manufacturing (AM) is characterized as the fabricating prepare to construct three dimensional objects by including layer-upon-layer of fabric. The method begins with a computer-aided-design (CAD) record that incorporates data around how the wrapped-up item is gathered to look [18]. The fabric can be plastic, metal or wax. AM is accomplished utilizing an added substance prepare, where progressive layers of material are laid down in numerous shapes. It is additionally considered diverse from conventional machining strategies that for the most part depend on the expulsion of fabric by subtractive forms like milling [19].

All AM innovations include arrangement of steps that move from the virtual three-dimensional geometric representations to the physical resultant portion. Due to assortment of the item requests and the level of complexity, AM includes in handle advancement completely different ways and distinctive degrees [20].

Additive technique by using solid free form, without supporting material has three different categories [21]

- Three-Dimensional Printing Stereo Lithography (3D) which prints wax, resin and ceramics utilizing Ultraviolet laser.
- Selective Laser Sintering (SLS) which employments high control laser to liquefy little particles of plastic, ceramics or glass to form a mass that has the specified three-dimensional shape
- Direct Laser Metal Sintering (DLMS) which use high control laser to meld metal powder to create the required shape.

The minimization of fixed prosthodontics restoration marginal gap is an imperative point within the field of prosthodontics. The quintessence of concern is the space existing between the tooth arrangement and the rebuilding edges where both meet the oral environment. Higher marginal precision (littler marginal gaps) leads to less gingival disturbance, less cement washout and consequently progressing the clinical result and life span of the restoration. Data on the negligible fit of titanium bridges is constrained, and the comes about of titanium crown considers are contradictory [4].

Holmes., *et al.* characterized the inner gap as the estimation between the axial wall of the arranged tooth and the inner surface of the casting, whereas the same measurement at the edge is called "marginal gap" (22). It is considered the finest elective estimation since it continuously be the largest error at the edge and reflects the whole crown misfit at that point, both vertically and evenly [23].

Numerous creators compare the minimal fit of CAD/CAM created restorations with routine made metal copings or crowns [17,24,25]. It has been expressed that the minimal fit of single titanium crowns is way better than titanium three-unit FPD [26,27]. It is critical to note that all past studies managed with marginal precision of CP Ti inlays or crowns to compare them to other combinations. In any case, small data is accessible on the minimal accuracy of titanium restorations fabricated with additive and CAD/CAM systems.

The null hypothesis was that differences would be found in marginal fit of titanium framework fabricated from different methods: Conventional casting, subtractive and additive manufacturing.

## Materials and Methods

### Fabrication of stainless steel model

A stainless-steel model with two abutments dies that resembles three-unit bridge were prepared with an occluso-gingival height of 7.5 mm, a taper of 6°- and 1-mm shoulder finish line all around using a standardized Computer Numerical Control machined (CNC) (POLY Gim machinery, Diamond, Swiss). The overall diameter of the die at the base will be 10 mm and the distance between them were10 mm (Figure 1).

**Figure 1:** Stainless-steel model.

### Fabrication of the specimens

Thirty titanium frameworks were fabricated and divided in to three groups according to manufacturing technique. Group C (n = 10): Casting manufacturing technique. Group S (n = 10): Subtractive manufacturing technique. Group A (n = 10): Additive manufacturing technique.

### Optical scanning of the stainless-steel dies

The stainless-steel dies were sprayed with scan spray (VITA powder scan spray, Germany) in order to decrease its glancing to make an accurate optical impression.

Then the model was placed in the optical scanner (Zirkon ZahnR optical scanner S600 ARTI, Gais, Italy). The scanner was used to scan the model from all surfaces reproducing the finest details.

### Fabrication of the resin dies:

After optical scanning of the stainless-steel model, the 3Shape software was used to make the design of the resin dies which were used for fabrication of 3D printed resin dies (Figure 2). After designing the resin dies, the software design was transferred to a 3D printer (Ultra 3SP, Envision Tech, Gladbeck, Germany). An accurate replica of the stainless-steel model was printed using light cure methacrylic resin to obtain 3D printed dies.


**Figure 2:** Design of resin dies.

### Fabrication of the Framework Design

Optical scanning of the 3D printed resin model using 3Shape scanner (3shape Dental Designer, 3shape E2, Copenhagen, Denmark) which used a laser-based optical scanning method. The CAD design module determined the margin location and titanium framework was designed 1 mm-thick including 30µm of cement film thickness with no space 1mm from the margin using CAD software following the manufacturer's instructions. The software determined the framework length and thickness then it gives the final shape of the desired framework (Figure 3).

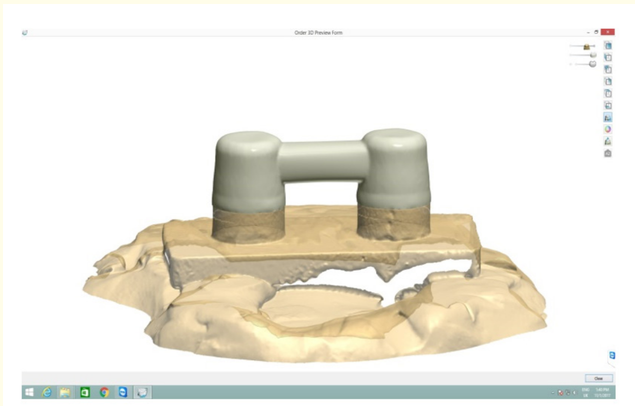

**Figure 3:** CAD design of the final shape of framework.

### Casting manufacturing technique

The design of the framework was done using 3Shape software. To standardize the wax pattern contour and dimension to be exactly as same as the other two groups. The wax patterns were 3D printed using 3D printing wax (FTD snow white, Alkmaar, Netherlands).

Each wax pattern was sprued, then invested in a mold ring using a silica-free and phosphate free, alumina and magnesia-based investment (Titavest CB, J. Morita, Japan) for titanium casting at a 20mL/100g (water/powder) mixing ratio. Wax elimination was achieved by heating the mold to 850°C at 6°C/minute according to the manufacturer'<?>*. The mold temperatures before casting were 200 C for magnesia investment. Casting with Commercially Pure Titanium (CP Ti) ASTM grade 2 (Titan Ti; J. Morita, Japan) was performed using a titanium casting machine (Ticast Super R, Selec, Osaka, Japan). After casting, the copings were airborne-particle abraded with120 mm aluminum oxide (Silfradent, Modulars, Italy) at 3-bar pressure to remove the investment. The casting sprues were removed using a handpiece with a 0.6 mm separating disc (Bego, Germany) close to the contour of the framework to obtain the final shape.

### Subtractive CAM manufacturing technique

The STL file of the final design of titanium framework was send to a computer aided manufacturing (CAM) machine. The milling was done using a 5-axis milling machine. Titanium milled from ready-made titanium blank (Titan, Zirkonzahn T4, Gais, Italy). The final restoration is then cut from a prefabricated blank using finishing law speed burs (Figure 4 and 5).

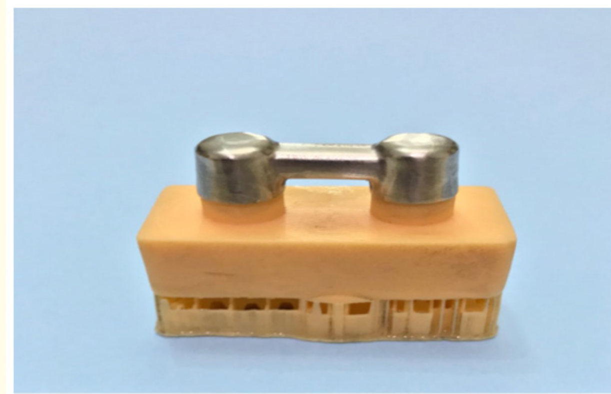

**Figure 4:** The final shape of framework.

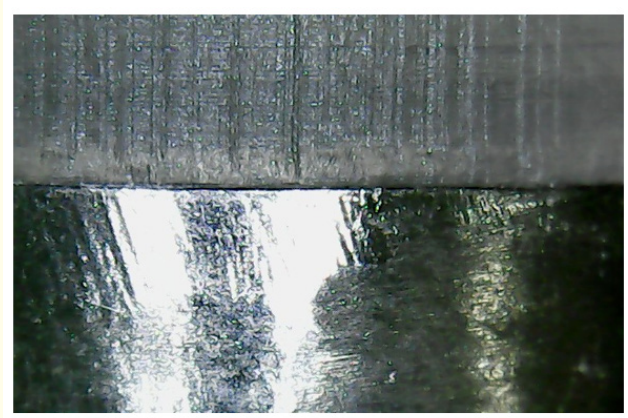

**Figure 5:** Shot of the margin.

### Additive manufacturing technique

The STL file of the final design of titanium framework was send to a metal rapid prototyping (3D printing) machine (M3linear, concept laser, Germany). Then, the additive manufacturing part where 3D printing is made using selective laser sintering to build titanium framework. Finishing and polishing of the fitting surface of the framework were done using finishing rubber titanium kit to allow ensure complete setting.

## Cementation process

All titanium frameworks were cemented with a cement (Ketac Cem Easymix, 3M ESPE, USA) to the resin master dies under a 2 kg static load.

## Marginal gap evaluation

### Vertical marginal gap

Each specimen was photographed using USB Digital microscope with a built-in camera (Scope Capture Digital Microscope, Guangdong, China) connected with an IBM compatible personal computer using a fixed magnification of 80X.

The vertical component of the marginal discrepancy measured by measuring the void from the base of the titanium framework to the surface of the die along the long axis of the tooth Then morphometric measurements were done for each shot, 12 equidistant landmarks along the cervical circumference for each abutment. Then the data obtained were collected, tabulated and then subjected to statistical analysis.

### Horizontal marginal gap

All luted assemblies were embedded in acrylic resin (Acrostone cold-cure acrylic resin, Egypt) and sectioned mesio-distal at the center of the framework (Figure 6 and 7) to allow evaluation of horizontal marginal gap using a precision saw (Iso Met 4000, Buehler) with coolant system.

Each specimen was photographed as the previous technique. Shots of the margins were taken for each specimen. The horizontal component of the marginal discrepancy was measured from the base of the vertical component to the edge of the die. Then morphometric measurements were done for each shot, measurement of horizontal marginal gap for each abutment was repeated five times (Figure 8).

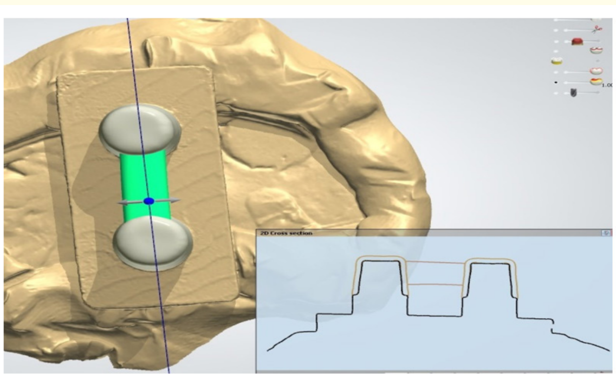

**Figure 6:** Software design of specimen sectioning.

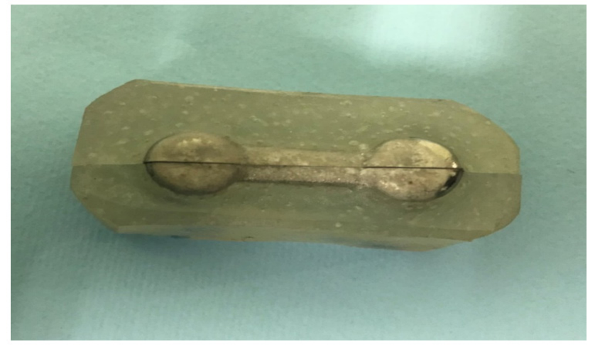

**Figure 7:** Mesio-distal sectioning of the specimen.

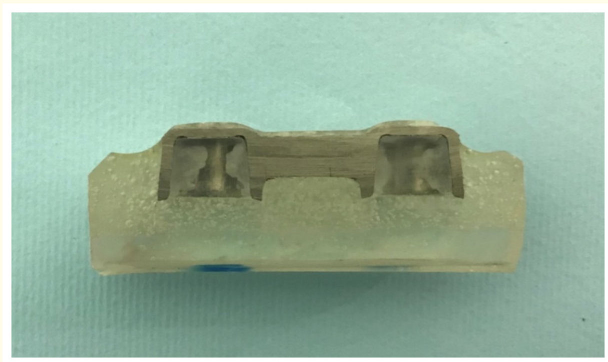

**Figure 8:** After sectioning of the specimen.

The results (n ¼ 10 bridges 20 shoulders) were analyzed by ANOVA/Tukey HSD posthoc test with a significant set up at $p < 0.05$. The results were analyzed using ANOVA/Tukey Post hoc test with a significant set up at $p < 0.05$.

## Results

Lists of vertical and horizontal marginal gap mean values in different groups were compared together using a one-way ANOVA test and there was significant difference between the different groups where P-value recorded < 0.05 was considered significant difference and P-value recorded < 0.001 was considered highly significant difference.

Statistical analysis compared the vertical marginal gap of the three groups revealed that, the highest mean marginal gap value (56.31 ± 7.72) was found in casting group, followed by additive group (25.25 ± 8.43) while the lowest value (20.96 ± 8.94) was found in subtractive group. Post Hoc Test revealed no significant difference between subtractive and additive groups (P1 > 0.280). It revealed a highly significant difference between additive and casting groups (P2 < 0.001) and there was a highly significant difference between subtractive and casting groups (P3 < 0.001).

Statistical analysis compared the horizontal marginal gap of the three groups revealed that, the highest mean marginal gap value (79.36 ± 12.10) was found in casting group, followed by additive group (41.42 ± 8.13) while the lowest value (35.78 ± 2.33) was found in subtractive group. Post Hoc Test revealed no significant difference between additive and subtractive groups (P1 > 0.230). It revealed a highly significant difference between additive and casting groups (P2 < 0.001) and there was a highly significant difference between subtractive and casting groups (P3 < 0.001).

The comparison between vertical and horizontal marginal gaps of the three groups are graphically drawn in (Figure 9).

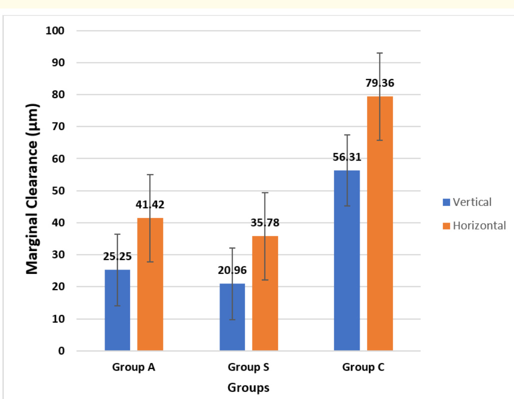


**Figure 9:** Bar chart Comparing between the three studied groups according to vertical and horizontal marginal gap.

## Discussion

This study inspected the alternatives of giving precise marginal fit of a titanium system depending on the manufacture strategies. It was found that the casting group had altogether higher negligible gap compared to both the subtractive and additive groups. It is critical to note that the lost wax technique has been utilized in dentistry for a noteworthy period of time. It appeared the slightest marginal fit among the tested groups.

Within the current study, a recognized common feature was a significantly greater vertical minimal gap within the casting group. Moreover, the cast group had essentially more prominent horizontal marginal errors. The more noteworthy minimal gap can clarify by gas retention and tall chemical reactivity of casting. Titanium is troublesome to be handled through the customary strategy of lost-wax. In tall temperatures, it responds with vaporous components such as nitrogen, oxygen and hydrogen and shapes a thick layer of oxides "alpha case" which may diminish the resistance and ductility of the structure obtained [28].

The minimal gap moreover can be clarified by commercially accessible silica investments can effortlessly be responded with Ti to deliver a really thick response layer for a Ti casting. In this manner, alumina ($Al_2O_3$), magnesia (MgO), calcia (CaO), zirconia ($ZrO_2$), and yttria ($Y_2O_3$) have recently and regularly been utilized as an oxide inhibitor in Ti casting. One application of these compounds could be a magnesium oxide (MgO)-based venture, which can essentially decrease the interfacial reactivity and is simple to control. In any case, the impediment of MgO-based investments is the low warm expansion rate that might not compare to the thermal properties of Ti ingots, making it troublesome to get a high-precision Ti casting lead to the marginal discrepancy [29]. Hence, magnesia investment did not give sufficient form extension to compensate for metal shrinkage. The tall relationship between investment thermal expansion and titanium bridge precision within the display study is in understanding with other studies utilized.

The present study showed that the subtractive group elicited the lowest marginal discrepancy compared to both the additive and casting groups. There was no statistical difference detected between the subtractive and additive groups. The value was smaller than values reported by previous studies [30-32]. The highest marginal accuracy of titanium bridges revealed by the present study, agrees with these study that used titanium-composite crowns scored values of 24.924 ± 4.451 µm on plaster die and of 20.331 ± 6.654 µm on natural tooth [33]. It is important to note that the measurements obtained were specific to the milling hardware/software combination in the study. One may contend that the innovation proceeds to move forward which the lower marginal discrepancy gotten can be the result of framework modification.

Another contends that computer-aided procedures for dental restorations are making strides quickly, and it is anticipated that the modifications to the framework will result in framework accuracy. The 5-axis processing motor is interesting within the dental industry and speaks to state-of-the-art accuracy processing. There have been numerous program corrections to the current frameworks since the time of experimentation to best utilize the processing innovation. Encourage experimentation with these enhancements is required to decide the greatness of the improvements [17].

Milling accuracy is dictated by materials properties. High material hardness means low machinability and more involved forces [34]. Titanium and densely sintered zirconia are difficult to machine, rendering the bur more susceptible to tool failure and wear [35-37]. Consequently, the internal surface might be under-milled, hindering the fit of the restoration [38]. In addition, the hardness of these materials means that they are more prone to surface chipping and chattering especially under high feed rates, high cutting speed, and deficient cooling [39]. These cutting conditions also cause excessive vibrations and exert thermal and mechanical stresses on the workpiece, which contributes to dimensional distortions, especially in thin edges. To overcome these limitations, regular maintenance and bur replacement have been advised.

On the contrary, the mean values of marginal gaps recorded in the present study were different than that found by Han., *et al.* who compared the marginal accuracy of milled titanium and cast titanium crowns [40]. There was a tendency for a smaller marginal opening for cast titanium (52-76 m) than CAD/CAM titanium (60-80 m). This difference was significant enough to be associated with more microleakage. Fit problems might not be purely from milling. Two factors could explain the limited accuracy of the CAD/CAM protocols. The first factor is related to the familiarity and the associated learning curve in relation to restoration fabrication following the CAD/CAM protocols compared with the well-established conventional protocol. The second factor is although multiple steps are omitted, the CAD/CAM protocol introduces additional steps in the fabrication process which may result in the introduction of inaccuracies. Steps such as scanning, locating the margin digitally, software modelling, and milling will inevitably introduce source of inaccuracy [41].

The production of the fine details by milling is largely dependent on the diameter of the smallest milling bur which is normally about 1 mm [42]; however, smaller diameter milling burs do not appear to produce fine detail for accuracy [43].

This study showed that the additive group had an intermediate mean value compared to both the subtractive and casting groups. The additive manufacturing has been evaluated primarily by assessing the fit of the dental prosthesis. Quante., *et al.* found that the marginal fit of crown copings produced by selective laser melting of noble metal alloy and base metal was in the range of 67 to 99 µm which is within the acceptable clinical range (9). Ucar., *et al.* found that the fit of laser-melted base metal alloy copings is comparable to the fit of cast base metal alloy copings [44], and Örtorp., *et al.* showed that selective laser melting produced fixed dental prosthesis frameworks with almost comparable in fit discrepancies of those produced by milling [38]. In the current study high vertical marginal accuracy in additive group was coincided with Castillo-Oyague., *et al*. who found that copings produced by selective laser melting exhibited half the vertical gap (25 m) of cast copings [45].

The overall dimensional accuracy of selective laser melting has been attributed to the lack of force application and vibration of the machine during production of the work piece. This feature is of significant importance as it allows the production of delicate and thin structures without causing deformation or recoil of the components. For example, fixed partial prosthesis framework components can only be produced by selective laser melting [46,47]. Williams., *et al.* also reported that the fit of frameworks produced using the additive manufacturing procedure is comparable to frameworks produced using conventional methods [46]. The accuracy of additive technique is dependent on layer thickness and the width of curing beam. The thinner the layers and the narrower the curing beam, the more accurate the final product; however, increasing the number of layers and reducing the diameter of the beam will exponentially increase the fabrication time [48,49].

In addition, the production cost of the AM manufacturing has been estimated. High material and machine prices and low built rates produce expensive products compared with the conventional manufacturing costs. The raw titanium 3D printed parts have a matte and slightly rough surface.

Additive manufacturing (or 3D printing) is clearly receiving increased attention and being adopted as alternative to machining and casting. This is as a result of the associated key advantages which include the design flexibility, reduced processing costs, reduced waste, energy efficiency and improved functionality. The field of advanced manufacturing is evolving rapidly, with new technologies and discoveries appearing almost continuously and contributing to a very dynamic field. Furthermore, it has been shown that additive manufacturing can produce frameworks with customized rough surfaces but a smooth surface is required and additive manufacturing is currently not capable of producing parts with very smooth surface finishes. The final titanium product may have to be post-processed or finished to achieve the adequately smooth surfaces. To reduce Surface roughness, finer particles of powder and finer layer thicknesses can be printed [50].

## Conclusion

Within the limitations of this *in vitro* study, the following conclusions can be drawn.

- Titanium framework fabricated by CAD/CAM demonstrated significantly lower marginal discrepancy compared to all groups
- The measured marginal accuracies of titanium framework fabricated by the subtractive and additive techniques demonstrated clinically acceptable marginal discrepancies on the working dies.

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