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# Comparison of the Passivity between Cast Alloy and Laser-Welded Titanium Overdenture Bars

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## Abstract

**Purpose:** The purpose of this study was to investigate the fit of cast alloy overdenture and laser-welded titanium-alloy bars by measuring induced strain upon tightening of the bars on a master cast as well as a function of screw tightening sequence.
**Materials and Methods:** Four implant analogs were secured into Type IV dental stone to simulate a mandibular edentulous patient cast, and two groups of four overdenture bars were fabricated. Group I was four cast alloy bars and Group II was four laser-welded titanium bars. The cast alloy bars included Au–Ag–Pd, Pd–Ag–Au, Au–Ag–Cu–Pd, and Ag–Pd–Cu-Au, while the laser-welded bars were all Ti–Al–V alloy. Bars were made from the same master cast, were torqued into place, and the total strain in the bars was measured through five strain gauges bonded to the bar between the implants. Each bar was placed and torqued 27 times to 30 Ncm per screw using three tightening sequences. Data were processed through a strain amplifier and analyzed by computer using StrainSmart software. Data were analyzed by ANOVA and Tukey's post hoc test.
**Results:** Significant differences were found between alloy types. Laser-welded titanium bars tended to have lower strains than corresponding cast bars, although the Au–Ag–Pd bar was not significantly different. The magnitudes of total strain were the least when first tightening the ends of the bar.
**Conclusions:** The passivity of implant overdenture bars was evaluated using total strain of the bar when tightening. Selecting a high modulus of elasticity cast alloy or use of laser-welded bar design resulted in the lowest average strain magnitudes. While the effect of screw tightening sequence was minimal, tightening the distal ends first demonstrated the lowest strain, and hence the best passivity.

The problem of passivity between metal frameworks and bars on implants has received considerable attention. It is important for successful long-term osseointegration of any implant treatment to have passive fit between the implant framework and the underlying structures.[1] Jemt[2] defined passive fit as the level that does not cause any long-term clinical complications and suggested that misfits smaller than 150 $\mu$m were acceptable.

The precision of fit between the prosthetic framework and implants is regarded by some authors as an important factor for the long-term survival of implants and the preservation of bone.[3-14] The absence of a passive adaptation is proposed to induce a continuous stress between the bar and implant structures with uneven loading of the supporting implants.[3] Misfit of the metal framework may cause mechanical problems of the prosthesis and implants or biologic complications of the surrounding tissue.[15] Mechanical problems may include loosening of the screws or fracture of various components in the system.[16-19] Biologic problems may include tissue reaction complications, failure in implant osseointegration, soreness, tenderness, and marginal bone loss.[20-24]

Several attempts using different techniques have been made to improve the passivity between metal frameworks and implants. These techniques included casting the framework in sections and using master reference casts,[25] a low-fusing metal cast,[26] and different impression techniques.[27-29] Sectioning and soldering the metal framework have shown some improvement in the precision of fit but still do not create perfect passivity.[30] Some authors have suggested using a cement medium to compensate for any discrepancy, as intraoral luting of the framework may decrease the strain overall and in the bone around the implants; however, there are no studies that show long-term success for such treatments, and the passivity of the framework

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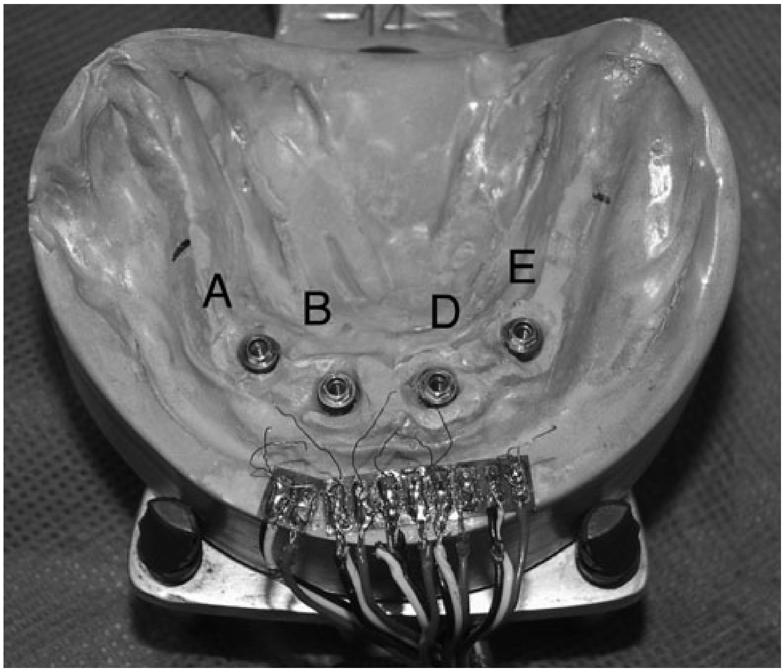


**Figure 1** Four implant analogs were secured in stone to fabricate a master cast. Analogs were placed in positions A, B, D, E.

depends on many factors, including the attention to detail of the technician/clinician team.[31]

Some studies have suggested that passivity of the prostheses to the implants is of minor importance. A study in a baboon animal model with induced misfit of the prosthesis to the implants demonstrated no apparent correlation between passive fit and bone loss.[32] In a report of a 5-year clinical study of 14 patients, in whom none of the prostheses examined achieved passivity on the implants, the authors suggested that there is a biologic tolerance for misfit. They were not able to associate bone loss and lack of passivity.[33] Lack of passive fit of the prostheses on the implants may or may not cause bone loss or lack of osseointegration, but it is an important issue in mechanical complications such as screw fracture.[34]

Cast alloy bar overdenture frameworks have been used for years; however, achieving the required passivity may be both time consuming and technique sensitive, in that possible distortion may occur at any step of the fabrication process due to the inconsistency of volumetric and linear expansion of the materials used from the impression to the finishing procedures.[35-41] Laser-welded titanium alloy bar overdentures have been presented as an alternative to the cast gold-alloy bar. Titanium alloy has been used successfully in dentistry because of its excellent biocompatibility, good corrosion resistance, adequate physical properties, and affordable cost compared to precious metals.[42-48]

The purpose of this study was to investigate the passivity between cast alloy bars and laser-welded titanium alloy bars by measuring the strain induced on screw tightening. This strain, which can result from lack of precise fit between the implant and the bar could potentially be transmitted to the bone and surrounding tissues. The cumulative change of strain from the fully seated untightened state to the tightened state gives an estimate of the passivity of fit of the torqued implant-supported bar. Because the strain may be dependent on the order of screw tightening, three tightening sequences were investigated to determine any effects on the passivity of fit.

## Materials and methods

Four implant analogs (BioHorizons Implant Systems, Inc., Birmingham, AL) were secured into Type IV dental stone into positions A, B, D, and E as defined by Misch[49] to simulate a mandibular edentulous patient cast (Fig 1). Two groups of four bars each were fabricated. Group I consisted of cast alloy bars cast from identical patterns by four commercial dental laboratories each using a differing alloy (Table 1). The cast alloy bars were fabricated from the patterns using traditional lost-wax technique. Group II consisted of four laser-welded implant bars made from extra-low interstitial (ELI) grade titanium alloy. Each was fabricated with rectangular titanium bar stock and straight custom cylindrical implant abutment. These components were indexed and laser welded by DECA Fiberweld V3.0 (BTI Laser, Utica, NY) while on the master cast. The patterns for the cast bars (group 1) were made on the same master cast with the same rectangular dimensions as the laser-welded bars (group 2), 4 mm height and 2 mm width. Prior to evaluation, all bars were evaluated for consistent dimensions and were visually and tactilely inspected for fit on the master cast.

The surface strain on the bars was measured by five strain gauges (CEA-06-032UW-120, Vishay Measurement Group, Inc., Raleigh, NC) bonded with cyanoacrylate on the connectors between the implant abutments. These positions were identified as A-B, A-B Top, B-D, D-E, and D-E Top (Fig 2). The

**Table 1** Cast and laser-welded (LW) bars

| Bar type | Bar alloy | Composition | Modulus E (GPa)[a] | n | $\varepsilon_{(TOT)}$ |
|---|---|---|---|---|---|
| Cast (1) | Au-Ag-Pd | 54%—15.5%—26.5% | 118 | 27 | 608 ± 78 |
| Cast (2) | Pd-Ag-Au | 75%—6.5%—6% | 111 | 27 | 714 ± 77 |
| Cast (3) | Au-Ag-Cu-Pd | 60%—21%—14.5%—3.5% | 86 | 27 | 1740 ± 111 |
| Cast (4) | Ag-Pd-Cu-Au | 54.5%—27%—13.5%—2% | 89.6 | 27 | 1305 ± 41 |
| LW (1) | Ti-Al-4V (ELI) | 90%—6%—4% | 113 | 27 | 472 ± 63 |
| LW (2) | Ti-Al-4V (ELI) | 90%—6%—4% | 113 | 27 | 516 ± 86 |
| LW (3) | Ti-Al-4V (ELI) | 90%—6%—4% | 113 | 27 | 730 ± 88 |
| LW (4) | Ti-Al-4V (ELI) | 90%—6%—4% | 113 | 27 | 414 ± 79 |

[a]Manufacturer supplied data

strain gauge A-B was bonded on the facial surface of the bars between the implant abutments A and B. Strain gauge A-B Top was bonded on the superior surface of the bars between implant abutments A and B. Strain gauge B-D was placed on the facial surface of the bars between implant abutments B and D. Strain gauge D-E Top was bonded on the superior surface of the bars between implant abutments D and E. Strain gauge D-E was placed on the facial surface of the bars between implant analogs D and E. The gauge wires were precision soldered to the bondable terminals (CPF-75C, Vishay Measurements Group, Inc.) that were connected to the strain amplifier (System 5000, Vishay Measurements Group, Inc.).

Each bar was fully seated in position on the master cast, and a visual inspection of initial fit was assured. Each strain gauge was zeroed, and the screws were torqued individually to 30 Ncm using a calibrated torque wrench (BioHorizons Implant Systems, Inc.) collecting strain versus time data. Each implant bar was torqued 27 times, 9 times for each of the three sequences used (A-B-D-E, A-D-B-E, A-E-B-D) following a randomized design by bar and sequence. Data were processed through a strain amplifier and analyzed by computer using StrainSmart software (Vishay Measurements Group, Inc.). Absolute values of magnitude from each strain gauge were added to produce a total strain value for the bar for each test of each sequence. Each of the 27 seatings for each bar and tightening sequence were torqued, loosened, and re-torqued three times to reduce variability. Data were analyzed using ANOVA, where $\alpha = 0.05$ (SAS v 9.1, Cary, NC).

## Results

All bars were trial seated on the master cast, and none of the bars presented any gap or rocking by visual inspection when placed in position before screw tightening occurred. Continued evaluation of the implant analogs on the master cast did not demonstrate any visual signs of wear or degradation throughout the experiment.

Two-way ANOVA evaluating both the bar type and tightening sequence showed significant differences for each effect as well as the interaction between effects. Due to the stronger influence of the bar type and a weak interaction, the main effect was further investigated in a modified factorial one-way ANOVA ($\alpha = 0.05$) using Tukey's post hoc tests for considering results from each bar and tightening sequence combination

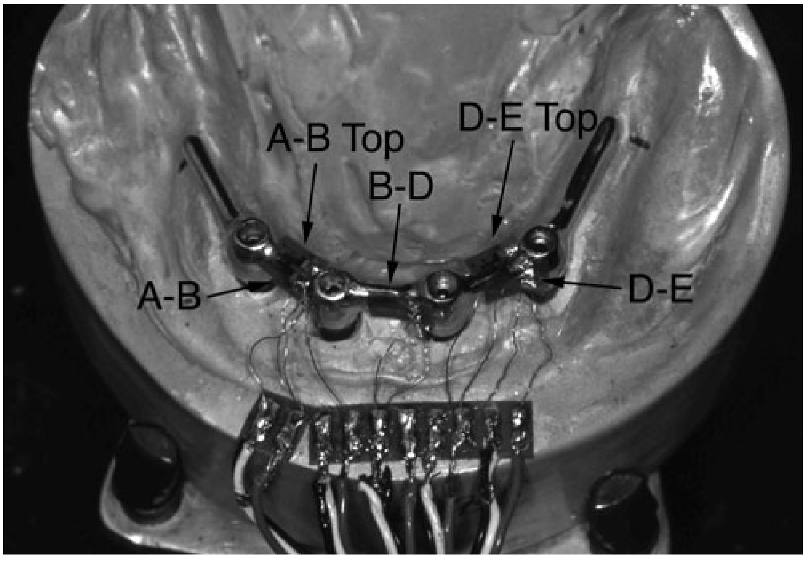


**Figure 2** Strain gauges bonded to an implant bar (A-B, A-B Top, B-D, D-E, D-E Top) and connected to terminals for analysis.

**Table 2** Total strain ($\varepsilon$) for each bar

| Bar alloy | n | ABDE | ADBE | AEBD |
|---|---|---|---|---|
| Au-Ag-Pd | 9 | 571 ± 124 | 609 ± 29 | 644 ± 21 |
| Pd-Ag-Au | 9 | 771 ± 69 | 714 ± 77 | 655 ± 30 |
| Au-Ag-Cu-Pd | 9 | 1,699 ± 80 | 1,850 ± 99 | 1,673 ± 55 |
| Ag-Pd-Cu-Au | 9 | 1,339 ± 43 | 1,293 ± 29 | 1,284 ± 27 |
| Ti-Al-4V (1) | 9 | 484 ± 73 | 492 ± 62 | 439 ± 45 |
| Ti-Al-4V (2) | 9 | 545 ± 48 | 505 ± 82 | 498 ± 117 |
| Ti-Al-4V (3) | 9 | 791 ± 66 | 772 ± 45 | 628 ± 34 |
| Ti-Al-4V (4) | 9 | 455 ± 83 | 443 ± 65 | 343 ± 28 |

as group.[50] Although the effect of the interaction between the tightening sequence and material type of bar is deemed to be minor, some combination of effect is anticipated as screw tightening is a mechanical function, and strains would be affected by the material's elastic modulus. Additionally, the sample size for each cast alloy was limited to one bar due to cost considerations. Thus, without greater statistical power, these data should not be extrapolated to support conclusions of general strain behavior for each alloy. Nonetheless, trends for each group provide the following observations regarding cast alloy bars and laser-welded bars used in this study.

The total microstrain for the cast alloy bars was generally greater than that for laser-welded titanium; however, the alloy type had a significant influence on the total strain. The means and standard deviations of the total microstrain of each bar type are summarized in Table 1. In general, low modulus alloys demonstrated greater total strain, reflecting greater deformation on loading. The laser-welded titanium bar demonstrated less total strain than the specimens from the cast alloy groups. The Au-Ag-Pd and Pd-Ag-Au bars were statistically similar to the laser-welded bars. The laser-welded bars demonstrated similar total strain, although titanium bar #3 demonstrated significantly greater strain from every other titanium bar, suggesting a slight difference of component positioning when laser welding, a difference in the quality of the connector between components, or possible variation of the strain gage readings.

Each bar was tightened multiple times in each of the three sequences. Table 2 summarizes the total strain from each tightening sequence. Table 3 shows the overall results and statistically significant differences for each bar. Because of statistical power considerations, the trends of tightening for each bar are shown in Figure 3. The bars demonstrated the least total strain magnitude when the screws on the ends were tightened prior to tightening the middle screws (AEBD), although for most of the bars this difference was not significant. The magnitude of the differences for each tightening sequence in each bar was small. Hence, a specific sequence of screw tightening had minimal impact on the strains developed and the potential passivity on the fit.

**Table 3** Comparison of tightening sequence by bar

| Bar | Sequence | | | | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Au-Ag-Cu-Pd | ADBE | A | | | | | | | | | | 1850 |
| Au-Ag-Cu-Pd | ABDE | | B | | | | | | | | | 1699 |
| Au-Ag-Cu-Pd | AEBD | | B | | | | | | | | | 1673 |
| Ag-Pd-Cu-Au | ABDE | | | C | | | | | | | | 1339 |
| Ag-Pd-Cu-Au | ADBE | | | C | | | | | | | | 1293 |
| Ag-Pd-Cu-Au | AEBD | | | C | | | | | | | | 1284 |
| LW (3) | ABDE | | | | D | | | | | | | 791 |
| LW (3) | ADBE | | | | D | | | | | | | 772 |
| Pd-Ag-Au | ABDE | | | | D | | | | | | | 771 |
| Pd-Ag-Au | ADBE | | | | D | E | | | | | | 714 |
| Pd-Ag-Au | AEBD | | | | | E | F | | | | | 655 |
| Au-Ag-Pd | AEBD | | | | | E | F | | | | | 644 |
| LW (3) | AEBD | | | | | E | F | | | | | 628 |
| Au-Ag-Pd | ADBE | | | | | E | F | G | | | | 609 |
| Au-Ag-Pd | ABDE | | | | | | F | G | H | | | 571 |
| LW (2) | ABDE | | | | | | F | G | H | I | | 545 |
| LW (2) | ADBE | | | | | | | G | H | I | | 505 |
| LW (2) | AEBD | | | | | | | G | H | I | | 498 |
| LW (1) | ADBE | | | | | | | | H | I | | 492 |
| LW (1) | ABDE | | | | | | | | H | I | | 484 |
| LW (4) | ABDE | | | | | | | | | I | J | 455 |
| LW (4) | ADBE | | | | | | | | | I | J | 443 |
| LW (1) | AEBD | | | | | | | | | I | J | 439 |
| LW (4) | AEBD | | | | | | | | | | J | 343 |

Same letter denotes no significant difference

## Discussion

Passive fit of the bar or superstructure has been proposed to play an important role in the long-term success of implant treatment. When there is a lack of passivity and a screw is tightened into position, the framework and/or screw may distort. The gap between the implant and superstructure or bar may not be detected with an explorer and many exceed 500 $\mu$m (0.5 mm), even after screw tightening, without detection.[47] Studies have shown that complete contact of the bar to the implant platform allows compression, tensile, and shear forces to be applied on the components of the implant system and bone upon screw tightening. When this occurs, the bone may remodel to eliminate these forces;[47,48,51] however, resorption of the bone can occur when the forces are beyond physiologic or ultimate strength limits. Although the forces induced by tightening screws of a bar without passivity may not exceed physiological adaptation, when added to forces from the prosthesis or occlusion, the additive forces may become traumatic. Other complications, such as fracture of the components due to creep or fatigue of the materials, may occur.[52]

Several methods have been proposed for evaluating passive fit. Henry[53] suggested alternating finger pressure and perception of rocking motions. This consists of applying finger pressure on the end of the framework and then on the other end after placing the framework in position. Adell et al[4] suggested that this technique can be improved if saliva is present. It is considered misfit if rocking or saliva movement occurs. This method may be difficult if subgingival margins or several implants are involved in the restoration. Direct vision and tactile sensation techniques have been proposed.[24,54] These techniques can be improved by use of magnification and good lighting. These methods are used to check passivity and are frequently used as a complement to other techniques.

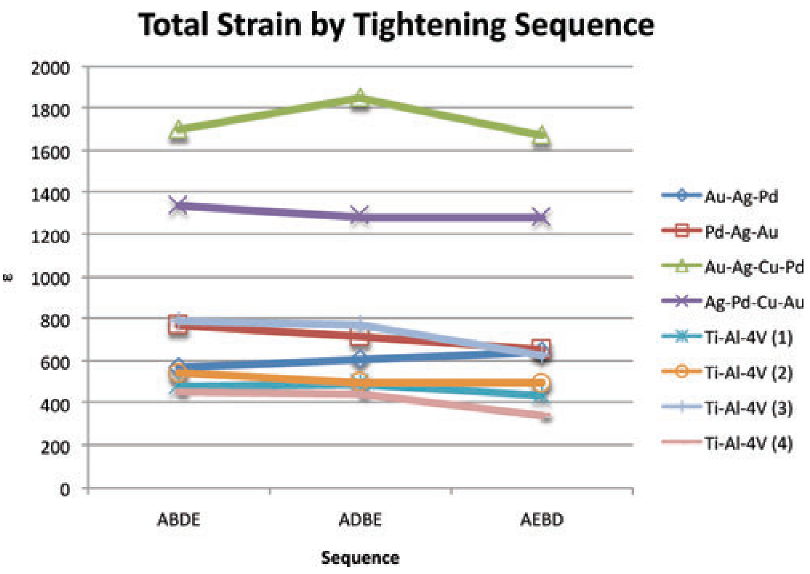


**Figure 3** Variations of total strain by tightening sequence.

Radiographs have been proposed for evaluation of the framework misfit.[24,55,56] Often indicated with subgingival bar-to-implant connection, radiographs should be attempted in perfect perpendicular alignment with the implant–abutment junction; otherwise, visualization of the joint is not possible. The "one-screw test" was suggested by Jemt.[2] It consists of tightening one screw in one end of the framework and then evaluating the other end for discrepancies. It is used mainly for long-span frameworks. It can be used in combination with radiographs for subgingival margins or with direct vision and tactile sensation when the margin is supragingival. A review of these methods of evaluating passive fit by Kan et al[31] concluded that there is no evidence-based research on the methods of evaluation of framework misfit and that their effectiveness has not been fully determined.

In this study, passivity of fit was evaluated by a change of measured surface strain on the implant bars. This model is uniquely different from models whereby strain gauges are placed on the analog or in the dental cast substrate where the strain transferred to the supporting materials representing bone. By measuring the strain on the bar, the model is intended to be more representative of under in vivo conditions. Additionally, this study was designed to yield the effect of screw tightening sequences, which was a more severe test of passivity as each screw was tightened to maximum torsion. In clinical delivery of implant-supported bars, the effect of misfit is often masked by incremental tightening of the screws to gradually seat the bar onto the multiple implant platforms.

The bars were designed to compare induced strain for cast and laser-welded bars for this in vitro study. Therefore, a simplified bar design was selected and does not necessarily reflect features found on bars for clinical use such as attachments. This simplified design allowed for reliable replication of cast bars maintaining similar dimension to the laser-welded bars. As part of developing this model for clinical applications, the patterns were fabricated and cast of different alloys commonly used for implant bar fabrication using differing commercial laboratories. In general, due to very specific instruction and quality control, all the bars were deemed comparable for evaluation. Variations of cross-sectional area and bar morphology are known to adversely affect these type comparisons. Therefore, use of a master pattern for all cast bars based on the laser-welded bar shape and design was set up to minimize variability. An index was used to assure duplicity of orientation of the components for the laser-welding procedures. Although all four titanium bars were of identical stock, bar #3 revealed greater total strain upon torquing for all sequences tested. This suggests a possibility of a slight misfit of the components, despite having the appearance of complete seating by visual and tactile inspection.

A limitation of this model involves potential damage to the master cast from repeated seating and screw tightening. All abutments for both cast and laser-welded bars did not engage the hex. The bar contacted the flat surface of the implant platform, which was verified initially and subsequently at all seatings of each bar on the implant analogs of the master cast. To minimize the effect of repeated seating, a randomized study design was used. In this study, no effect of repeated seating was noted associated with any bar and tightening sequence. An additional consideration involves the repeated torquing of screws within the analogs. Repeated tightening did not appear to adversely affect the strain measures with this model; however, creep and fatigue deformation is likely within the screw threads, but this did not appear to have a significant effect when comparing successive measures.

The strain in the cast alloy bars was generally greater than that in the laser-welded titanium bars, thereby indicating less distortion during screw tightening. This suggests that less passivity may exist in the cast bars, which may be inherent in the bar fabrication technique, regardless of the alloy used. In the fabrication of cast alloy bars, the laboratories used a conventional lost-wax casting technique; due to the intrinsic properties of the materials used and to several technical steps required with this technique, some degree of distortion in inevitable.[31,57] As a result, it is difficult to always achieve a passive fit on the implants. The laser-welded titanium bars have the advantage of being fabricated in segments. In this procedure, the machined titanium rod is cut to fit intimately but passively between the titanium abutments on the master cast. The bar is secured in position with an index, and the laser welding is done using titanium filler wire added to achieve the proper contour. When the welding is completed, the bar is finished and polished.

Sequences of screw tightening had minimal impact on the magnitudes of total strain in this study. In all bars, the sequence of tightening the ends and then the middle (AEBD) resulted in the lowest total strain. This difference was significant in three of the eight bars evaluated. The mechanism for this lower strain magnitude is unclear. All bars have some degree of misfit, and the microseating of the bar should vary depending on the order of screw tightening. When ABDE and ADBE sequences were employed, the microseating of the bar on the first three implants allowed the bar over implant E to be effectively cantilevered before the final screw was torqued. This may have led to increased strain; however, for the AEBD sequence, the bar is stabilized in tightening over the implants on each end, then the bar is limited on further seating. In any case, the differences in the total microstrain for each sequence for each bar were minimal. To evaluate the differences between alloys, additional specimens, which are cost prohibitive due to the high cost for bar fabrication, are necessary. The microstrain results agreed with those of a study by Nissan et al[58] in which a master metal model was used to fabricate 30 stone casts using the splinted impression technique. Four strain gauges were attached to the superior surface of the master framework to measure the strain with different tightening sequences, tightening forces, and operators. They found no statistically significant differences among these variables.

## Conclusions

In this in vitro study, passivity of fit was evaluated as a function of total strain measured on implant support bars. Both cast alloy bars and laser-welded titanium bars showed some degree of misfit upon screw tightening. In general, cast alloy bars demonstrated less passivity than laser-welded bars, which may have been more dependent on alloy selection than variables associated with casting technique; however, further studies, with larger sample sizes, should give insight into the specific strain behavior for individual alloys. Screw tightening sequence was also found to be slightly important.

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