# Fit of Screw-Retained Fixed Implant Frameworks Fabricated by Different Methods: A Systematic Review

Jaafar Abduo, BDS, DClinDent[a]/Karl Lyons, BDS, MDS, FRACDS[b]/Vincent Bennani, DDS, PhD[b]/
Neil Waddell, MDipTech, HDE[c]/Michael Swain, BSc, PhD[d]

***Purpose:*** The aim of this study was to review the published literature investigating the accuracy of fit of fixed implant frameworks fabricated using different materials and methods. ***Materials and Methods:*** A comprehensive electronic search was performed through PubMed (MEDLINE) using Boolean operators to combine key words. The search was limited to articles written in English and published through May 2010. In addition, a manual search through articles and reference lists retrieved from the electronic search and peer-reviewed journals was also conducted. ***Results:*** A total of 248 articles were retrieved, and 26 met the specified inclusion criteria for the review. The selected articles assessed the fit of fixed implant frameworks fabricated by different techniques. The investigated fabrication approaches were one-piece casting, sectioning and reconnection, spark erosion with an electric discharge machine, computer-aided design/computer-assisted manufacturing (CAD/CAM), and framework bonding to prefabricated abutment cylinders. ***Conclusions:*** Cast noble metal frameworks have a predictable fit, and additional fit refinement treatment is not indicated in well-controlled conditions. Base metal castings do not provide a satisfactory level of fit unless additional refinement treatment is performed, such as sectioning and laser welding or spark erosion. Spark erosion, framework bonding to prefabricated abutment cylinders, and CAD/CAM have the potential to provide implant frameworks with an excellent fit; CAD/CAM is the most consistent and least technique-sensitive of these methods. *Int J Prosthodont 2011;24:207–220.*

Passive fit of an implant framework is one of the mechanical parameters expected to influence the longevity of an implant prosthesis.[1,2] Passive fit is defined as simultaneous and even contact of all the fitting surfaces and the absence of strains before load applications.[3–6] However, it is difficult to expect that all the fitting surfaces are perfectly mating since an inevitable degree of inaccuracy would always be present. Many authors have tried to provide criteria for passive fit or acceptable fit of implant frameworks. Brånemark defined a framework to be passively fitting if the gap between the framework and abutment was 10 μm or less.[1] Jemt suggested that framework misfit of less than 150 μm was acceptable.[7] A definition of passive fit from a biomechanical perspective, however, is lacking.[4,5] In addition, the relationship between the degree of fit and mechanical or biologic complications has yet to be established.[8] Based on this, many authors have argued against the significance of passive fit and concluded that well-controlled conventional crown and fixed partial denture techniques are adequate in providing long-term successful implant treatment.[4–6] Nevertheless, until clear guidelines are presented regarding the acceptable level of fit, together with a method to confirm it, it is crucial to aim for the best framework fit possible to minimize strain and gap formation.

It is generally accepted that clinical methods are deficient in detecting slight fit inaccuracies of implant frameworks, and it has been demonstrated that clinically acceptable frameworks can exhibit a degree of misfit when compared with in vitro studies.[5,9,10]

[a]*Associate Professor in Prosthodontics, Faculty of Dentistry, University of Western Australia, Crawley, WA, Australia; Formerly, Department of Oral Rehabilitation, University of Otago, Dunedin, New Zealand.*
[b]*Senior Lecturer and Prosthodontist, Department of Oral Rehabilitation, University of Otago, Dunedin, New Zealand.*
[c]*Senior Lecturer, Department of Oral Rehabilitation, University of Otago, Dunedin, New Zealand.*
[d]*Professor in Dental Materials, Department of Oral Rehabilitation, University of Otago, Dunedin, New Zealand.*

***Correspondence to:*** *Dr Jaafar Abduo, Faculty of Dentistry, University of Western Australia, 35 Stirling Highway, Crawley, WA, Australia. Fax: 0061 8 9346 7666. Email: jaafar_abduo@hotmail.com*

**Table 1** Inclusion Criteria

| |
|---|
| Peer-reviewed journal article |
| English language publication |
| Control group present |
| Assessing the fit of screw-retained frameworks |
| Complete or partial prosthesis framework |

To enhance the fit of implant frameworks, fabrication materials and methods of relative predictability should be used to minimize the reliance on clinical methods to detect slight inaccuracies.

Several approaches have been proposed to enhance the fit of implant frameworks. In general, they can be divided into two categories: addition of fit refinement steps or elimination of fabrication steps. The first category includes sectioning and soldering/laser welding, spark erosion with an electric discharge machine (EDM), and bonding the framework to prefabricated cylinders. The second category includes computer-aided design/computer-assisted manufacturing (CAD/CAM) and other rapid prototyping technologies. The potential for CAD/CAM to enhance the accuracy is based on omitting certain fabrication steps, such as waxing, investing, and casting. The purpose of this study was to systematically review all in vitro research on the fit of screw-retained implant frameworks fabricated by the available techniques and materials.

## Materials and Methods

A comprehensive electronic search was performed through PubMed (MEDLINE) using Boolean operators. The following keywords were combined: "oral," "dental," "implant," "framework," "fit," "accuracy," "gap," "fitting surface," "bridge," and "fixed prosthesis." No publication year limit was used. The purpose of the search was to obtain all the in vitro studies on the fit of implant fixed partial prosthesis frameworks. The search included articles published through May 2010 and was limited to peer-reviewed articles written in English that contained all or part of the key words in their headings. The electronic search was supplemented by manual searching through the following journals: *International Journal of Prosthodontics, International Journal of Periodontics & Restorative Dentistry, International Journal of Oral and Maxillofacial Implants, Clinical Oral Implants Research, Implant Dentistry and Related Research, Implant Dentistry, Journal of Oral Implantology, Journal of Oral Rehabilitation, Journal of Prosthetic Dentistry, Journal of Prosthodontics,* and *Quintessence International*. In addition, the references of the selected articles were reviewed for possible studies for inclusion. The titles and abstracts of all articles were reviewed, and after reading the abstract to assess for possible inclusion, the full text of the article was reviewed and cross-matched against the predefined inclusion criteria (Table 1).

For the purpose of uniformity in this review, the in vitro fit assessment techniques were classified into two groups: dimensional measurements and modeling techniques. Dimensional measurements are the methods used to measure the dimension, distortion, or the actual gap between the framework and infrastructure. Modeling techniques are the methods that can quantify the implications of any misfit. In relation to dimensional measurements, only two-dimensional distortion data were extracted to determine the vertical fit of the assessed frameworks.

## Results

The electronic search initially retrieved a total of 248 articles. Based on the analysis of titles and abstracts, 180 articles were excluded, leaving 68 articles eligible for inclusion. After applying the inclusion criteria, 24 articles were considered suitable for full-text analysis. Manual searching and review of references in selected articles identified a further 2 articles. Therefore, a total of 26 articles were considered for review. After article selection, the relevant information from each article was extracted.

### *Description of Studies*

The selected studies showed significant variation in experimental design and methodology of implant framework fit assessment. Heterogeneity was even more complicated by the different implant and abutment systems. The approaches used to assess framework fit included the following.

**Dimensional Measurements.** The following dimensional measurements were used to assess framework fit:

- Microscopic examination of the actual vertical gap in conjunction with the replica approach, where the thickness of a light-body impression material that filled the fitting interface was measured
- Photogrammetric technique, which analyzed the three-dimensional (3D) distortion of the implant framework by superimposing images of the framework and master cast

- Laser videography, which involved laser digitizing of the framework and master cast to determine 3D distortions
- Use of a coordinate measuring machine to measure framework distortion in three dimensions

The studies showed variation in dimensional measurement conditions. Some studies measured the vertical gap formed between the framework and infrastructure when all the screws were tightened.[11–16] For the purpose of uniformity, this parameter was called final fit value (FF). Other studies measured the vertical gap on nontightened implants following tightening of the retaining screw on the most distant implant, as described for the one-screw test.[17] Despite the test being employed originally as a qualitative clinical method to assess the passivity of an implant framework, it has been applied to in vitro studies to quantify the deviation from passive fit.[12,14–16,18–21] This parameter was referred to as the passive fit value (PF). Other studies assessed the vertical gap between the framework and infrastructure when none of the retaining screws were tightened.[22–27] This can occur when an image of the framework is superimposed on the master cast. This parameter was named the vertical distortion value (VD).

**Modeling Techniques.** The following modeling techniques were used to assess framework fit:

- Strain gauge analysis (SGA), which involved applying strain gauges on a cast or the framework to determine strain development as a result of tightening the retaining screws; greater strain magnitude was indicative of greater framework distortion
- Photoelastic stress analysis (PSA), based on the use of a transparent resin material that exhibited color changes with stress when viewed with a polarizing lens; greater stress development was indicative of greater framework distortion

**Implant Framework Fabrication Method.** A summary of all the studies considered is listed according to fabrication method (Tables 2 to 6). From the selected studies, five implant framework fabrication methods were identified: *(1)* conventional casting of noble metal and base metal alloys; *(2)* sectioning and reconnection through soldering (the sectioned framework is indexed and reconnected with fused solder), cast-to (the sectioned junction is waxed and cast directly to the primary casting), vertical laser welding (the framework is either sectioned or composed of several pieces that can be connected by laser welding), and horizontal laser welding (the framework body is milled or cast, followed by sectioning the fitting surface of the framework cylinders; prefabricated cylinders are laser welded to the framework body—commonly referred to as the Cresco Ti Precision method); *(3)* spark erosion with EDM, used to refine the fitting surface of the framework; *(4)* CAD/CAM, which involves fabricating the implant framework by means of computer numeric controlled (CNC) milling; and *(5)* framework bonding to a prefabricated abutment cylinder, where the framework body is constructed with space to accommodate a prefabricated cylinder and resin bonding is used to attach the framework body to the cylinders.

There is agreement between the in vitro studies that there is no implant framework fabrication approach or material that can provide absolute passivity of fitted frameworks. However, the studies also showed that different techniques or materials provide significantly different results. The potential of any fabrication technique to minimize the misfit of an implant framework is presented in Fig 1. Because of such variability, it was not possible to formulate an appropriate meta-analysis.

Eight articles assessed the fit of one-piece cast implant frameworks of different metals.[12–15,19,20,28,29] The assessed materials were gold (Au) alloy, silver-palladium (Ag-Pd) alloy, titanium (Ti), cobalt-chromium (Co-Cr) alloy, and nickel-chromium (Ni-Cr) alloy. Two studies compared the fit of Au casting with Ti casting and showed the superiority of Au casting.[12,19] One assessed the fit of Ag-Pd with Ni-Cr frameworks and found that Ni-Cr casting had the tendency to provide more accurate outcomes.[28] One compared the fit of frameworks fabricated by Ag-Pd and Ti and found the Ag-Pd casting to be more accurate.[20] Two studies compared the fit of Ti, Co-Cr, and Ni-Cr frameworks. One found Ti frameworks had a superior fit, followed by Ni-Cr and Co-Cr frameworks,[14] while the other found that Ti and Co-Cr casting suffered from more variation than Ni-Cr casting.[15] Two studies primarily compared the fit of Ti and Co-Cr frameworks and found a general tendency for the Ti casting to provide more accurate results.[13,29]

Thirteen studies were identified assessing the effect of sectioning and reconnection.[3,11,13,15,16,18,20–23,27,29,30] For the reconnection procedure, nine studies assessed the laser welding procedure, while four assessed the soldering procedure. Three studies on the laser welding procedure assessed horizontal sectioning and welding: One of them compared Ti horizontal welding with Au casting and did not report significant improvement in fit,[22] one assessed the effect of horizontal laser welding for Ti and Co-Cr alloy and found them to be similar,[27] while another found that horizontal laser welding has the tendency to provide a more superior outcome than spark erosion.[21] Seven articles studied vertical welding. Five of these studies found an improvement after the procedure,[15,20,22,23,29]

**Table 2** Summary of Studies Assessing the Effect of Different Casting Metals

| Study | Casting metals | Sample size | No. of implants | Implant system (fit level) |
|---|---|---|---|---|
| Costa et al[28] | Pd-Ag alloy<br>Ni-Cr alloy | 8<br>8 | 4 | Conexão (implant) |
| Eisenmann et al[19] | Gold alloy<br>Titanium | 6<br>6 | 5 | Brånemark (abutment) |
| Koke et al[29] | Co-Cr alloy<br>Titanium | 10<br>10 | 2 | Frialit (abutment) |
| Sartori et al[12] | Gold alloy<br>Titanium | 5<br>5 | 2 | Conexão (abutment) |
| Castilio et al[13] | Titanium alloy<br>Co-Cr alloy | 5<br>5 | 3 | Conexão (abutment) |
| de Torres et al[14] | Titanium<br>Co-Cr alloy<br>Ni-Cr alloy | 5<br>5<br>5 | 5 | Titamax (abutment) |
| de Sousa et al[20] | Ag-Pd alloy<br>Cast titanium | 5<br>5 | 5 | Conexão (implant) |
| Tiossi et al[15] | Ni-Cr alloy<br>Co-Cr alloy<br>Titanium | 6<br>6<br>6 | 2 | Conexão (abutment) |

FF = final fit; PF = passive fit; VD = vertical distortion; PSA = photoelastic stress analysis; SGA = strain gauge analysis; NA = not available.

while one did not find a difference.[13] One study assessed the effect of vertical laser welding on Ti and Ag-Pd alloy and found that only Ti showed an improvement after laser welding.[20] One study assessed the effect of the sectioning pattern prior to laser welding and found that diagonal sectioning resulted in the least vertical gap.[16] One study compared the effect of vertical and horizontal laser welding and reported that vertical welding provided a more consistent outcome; however, the fit was not found to be significantly different to the horizontal welding technique.[22]

One study reported an improvement in fit with the soldering procedure,[30] while another study did not report a significant improvement.[11] One study assessed two-piece casting followed by soldering and found improvements when compared with one-piece casting followed by sectioning and soldering.[3] The cast-to procedure was generally found to produce frameworks that had greater accuracy of fit than conventional soldering.[18] After comparing spark erosion with soldering, spark erosion was found to provide superior fit.[18]

A total of four articles assessed the effect of spark erosion.[12,18,19,21] Two studies applied spark erosion to Au and Ti cast frameworks[12,19] and found greater improvement for Ti frameworks than for those manufactured from Au. The other two studies applied spark erosion for Au alloy. One showed spark erosion provided a more superior outcome compared to sectioning and soldering, but for the cast-to procedure.[18] The other study reported an insignificant improvement in fit for Au alloy frameworks after spark erosion.[21]

Five studies assessed the fit of CAD/CAM implant frameworks.[24–27,31] All of these studies used frameworks milled from Ti. Three studies compared the fit of milled Ti frameworks with conventional cast Au frameworks.[24,25,31] Two of these reported the superiority of milled Ti frameworks,[25,31] while one did not find a significant difference.[24] One of the studies compared the fit of milled Ti frameworks with Ag-Pd cast frameworks and confirmed the superiority of frameworks produced with CAD/CAM milling.[26] One study compared the fit of milled Ti frameworks with horizontal welding of the Ti and Co-Cr alloy frameworks. All frameworks showed a good level of accuracy, but the CAD/CAM frameworks had less vertical distortion.[27]

Six studies assessed framework bonding to prefabricated abutment cylinders.[3,5,6,32–34] All studies reported the superior accuracy obtained compared to the one-piece[5,6,32–34] and two-piece[3] casting techniques. Two studies applied the procedure after ceramic layering and confirmed the ability of the technique to avoid distortion produced from ceramic application.[6,34]

| Assessment method | Fit condition (μm) FF | PF | VD | Main findings |
|---|---|---|---|---|
| Microscopic examination | NA<br>NA | NA<br>NA | NA<br>NA | Slightly significantly better fit with Ni-Cr than Pd-Ag |
| Measuring microscope (×200) and PSA | NA<br>NA | 12.7<br>31.6 | NA<br>NA | Significantly better fit for cast gold framework than cast titanium framework |
| Microscopic examination (×160) and SGA | 72.0<br>40.0 | NA<br>NA | NA<br>NA | Insignificant difference between cast titanium and Co-Cr frameworks |
| Microscopic examination | 12.6<br>30.1 | 69.2<br>94.2 | NA<br>NA | Significantly better fit for cast gold framework than cast titanium framework |
| Microscopic examination (×60) | 25.3<br>24.1 | NA<br>NA | NA<br>NA | Insignificant difference |
| Microscopic examination (×15) | 22.0<br>66.0<br>32.0 | 88.0<br>229.0<br>200.0 | NA<br>NA<br>NA | Significantly better passive fit for titanium; insignificant difference in passive fit for Ni-Cr and Co-Cr; insignificant difference in final fit for titanium and Ni-Cr; significantly better final fit for titanium and Ni-Cr than Co-Cr |
| Microscopic examination (×600) | NA<br>NA | 60.3<br>119.8 | NA<br>NA | Significantly better fit for Ag-Pd than titanium |
| Microscopic examination (×15) | 25.0<br>54.2<br>48.4 | 70.7<br>118.6<br>118.6 | NA<br>NA<br>NA | More variable outcome for Co-Cr and titanium than Ni-Cr |

## Discussion

### *Conventional Casting*

It has been stated that the fit of a cast implant framework is influenced by the casting steps, including wax pattern fabrication, investing, and casting.[35] The identified studies, in general, showed a tendency for noble metal alloys to produce implant frameworks with a superior fit compared to base metals, such as Ti, Co-Cr alloy, and Ni-Cr alloy. Au alloy casting was also shown to exhibit the best casting accuracy for complete[19] and partial frameworks.[12] Therefore, it can be speculated that Au alloy is the ideal material for one-piece casting. This is further supported by the fact that additional treatment through spark erosion did not statistically enhance the fit of Au alloy frameworks.[19] An economic alternative to Au alloy is Ag-Pd alloy, which was shown to exhibit superior fit to Ti casting.[20] The superior castability of noble metal alloys is related to the materials' high density, which allows the molten metal to fill the lost wax space predictably. In addition, the low solidus temperature of these alloys means they are susceptible to less shrinkage as they cool to room temperature.[36] An additional advantage of casting noble metal alloys for implant frameworks is the availability of the cast-on abutment, which has a machined Au alloy fitting surface. The cast-on abutment with the prefabricated machined surface is less prone to inaccuracies while casting compared to the burnout plastic sleeve used for base metal casting.[37,38] This might explain the outcome of Costa et al,[28] who cast Ni-Cr and Ag-Pd using burnout plastic sleeves and found that cast Ni-Cr frameworks exhibited a better fit than cast Ag-Pd frameworks.

Base metal alloys, such as Co-Cr and Ni-Cr, have the advantage of low cost and superior physical properties, especially for thin sections. However, there are concerns regarding the corrosive release of ions and their potential allergenic properties.[36] In relation to implant framework fit, studies showed inferior fit for base metal alloys. It was apparent that Co-Cr exhibited a worse fit in comparison to Ni-Cr.[14,15] The inferior accuracy of base metal alloy casting may be a result of the high solidus temperatures compared to noble metal alloys, which increase their contraction on cooling. In addition, the thermal conductivity and density of these alloys are lower than Au, which makes casting procedures more difficult.[36] Increased hardness would also complicate their finishing and polishing.[39] Unfortunately, to date, there are no defined casting standards in relation to choice of investment-alloy combination and casting temperature, which may have a profound effect on the final framework dimension.

**Table 3** Summary of Studies Assessing the Effect of Different Sectioning and Reconnection Procedures

| Study | Casting metals | Sample size | No. of implants | Implant system (fit level) |
|---|---|---|---|---|
| **Soldering** | | | | |
| Clelland et al[30] | High palladium alloy (sectioning and soldering) | 3 | 5 | Brånemark (abutment) |
| Zervas et al[11] | High palladium alloy<br>Sectioning and soldering with low fusing<br>Sectioning and soldering with high fusing | 10<br>5<br>5 | 2 | Biomet 3i (abutment) |
| Romero et al[18] | Gold alloy<br>Sectioning and cast-to<br>Sectioning and soldering | 30<br>10<br>10 | 2 | Stereos (abutment) |
| Watanabe et al[3] | Gold alloy<br>Sectioning and soldering<br>Two-piece casting and soldering | 4<br>4<br>4 | 3 | IMZ (abutment) |
| **Laser welding** | | | | |
| Jemt[22] | Gold alloy<br>Titanium horizontal welding<br>Titanium vertical welding | 10<br>10<br>10 | 5 | Brånemark (abutment) |
| Riedy et al[23] | Gold alloy<br>Titanium vertical welding | 5<br>5 | 5 | Brånemark (abutment) |
| Koke et al[29] | Co-Cr alloy<br>Two-piece cast Co-Cr alloy then laser welding | 10<br>10 | 2 | Frialit (abutment) |
| Castilio et al[13] | Titanium alloy (vertical sectioning and laser welding)<br>Co-Cr alloy (vertical sectioning and laser welding) | 5<br>5 | 3 | Conexão (abutment) |
| de Sousa et al[20] | Ag-Pd alloy (vertical sectioning and laser welding)<br>Titanium (vertical sectioning and laser welding) | 5<br>5 | 5 | Conexão (implant) |
| Tiossi et al[15] | Ni-Cr alloy (vertical sectioning and laser welding)<br>Co-Cr alloy (vertical sectioning and laser welding)<br>Titanium (vertical sectioning and laser welding) | 6<br>6<br>6 | 2 | Conexão (abutment) |
| de Aguiar et al[16] | Ni-Cr alloy<br>Vertical sectioning and laser welding transversely<br>Vertical sectioning and laser welding diagonally | 6<br>6<br>6 | 2 | Neodent (abutment) |
| Fischer et al[21] | Gold alloy<br>Horizontal sectioning and laser welding | 6<br>6 | 3 | Straumann (abutment) |
| Hjalmarsson et al[27] | Titanium (horizontal sectioning and laser welding)<br>Co-Cr (horizontal sectioning and laser welding) | 10<br>10 | 5 | Brånemark (implant) |

FF = final fit; PF = passive fit; VD = vertical distortion; SGA = strain gauge analysis; NA = not available.

Cast Ti overcomes several of the inherent limitations of base metal alloys in terms of biocompatibility and handling. Ti has excellent biocompatibility, corrosion resistance, acceptable physical properties, and low density.[40] In relation to its application as an implant prosthesis framework, the similarity of the material would avoid the potential for galvanic corrosion.[41–43] The limitation of Ti is the requirement for advanced technology, special investments, and casting machines in the laboratory because of its high melting point and reactivity. Ti castings also suffer from poor surface reproduction.[44,45] In relation to the fit on implant components, the current review shows that cast Ti frameworks exhibit an inferior fit compared to noble

| | Fit condition (µm) | | | |
|---|---|---|---|---|
| Assessment method | FF | PF | VD | Main findings |
| | | | | |
| SGA | NA | NA | NA | Significant fit improvement after sectioning and soldering |
| Microscopic examination (×200) | 14.0<br>4.0<br>14.0 | NA<br>NA<br>NA | NA<br>NA<br>NA | Insignificant improvement with soldering with low-fusing solder |
| Microscopic examination | NA<br>NA<br>NA | 190.0<br>15.0<br>72.0 | NA<br>NA<br>NA | Significant improvement after cast-to procedure |
| SGA | NA<br>NA<br>NA | NA<br>NA<br>NA | NA<br>NA<br>NA | Two-piece casting and soldering provided better fit than one-piece casting, sectioning, and soldering |
| | | | | |
| Photogrammetric | NA<br>NA<br>NA | NA<br>NA<br>NA | 10.0<br>16.0<br>11.0 | Vertical welding provided the least distortion in all dimensions; insignificant difference between all groups |
| Laser videography | NA<br>NA | NA<br>NA | 26.2<br>19.2 | Significantly better fit with vertical laser welding |
| Microscopic examination (×160) and SGA | 72.0<br>17.0 | NA<br>NA | NA<br>NA | Significant improvement after laser welding of Co-Cr |
| Microscopic examination (×60) | 25.3<br>17.0<br>24.1<br>22.7 | NA<br>NA<br>NA<br>NA | NA<br>NA<br>NA<br>NA | Insignificant difference after sectioning and laser welding |
| Microscopic examination (×600) | NA<br>NA<br>NA<br>NA | 60.3<br>106.6<br>119.8<br>31.4 | NA<br>NA<br>NA<br>NA | Significant improvement after laser welding for titanium than Ag-Pd |
| Microscopic examination (×15) | 25.0<br>13.1<br>54.2<br>21.5<br>48.4<br>17.7 | 70.7<br>21.3<br>118.6<br>39.9<br>118.6<br>27.9 | NA<br>NA<br>NA<br>NA<br>NA<br>NA | Significant improvement in passive fit after laser welding for titanium and Co-Cr; significant improvement in vertical fit after laser welding for Co-Cr |
| Microscopic examination (×15) | 11.2<br>19.2<br><br>10.1 | 57.0<br>31.4<br><br>18.9 | NA<br>NA<br><br>NA | Significantly better fit after diagonal laser welding than single cast; insignificant difference in fit between single cast and transverse welding |
| Microscopic examination of replica | NA<br>NA | 23.7<br>13.7 | NA<br>NA | More improvement after horizontal laser welding |
| Coordinate measuring machine | NA<br><br>NA | NA<br><br>NA | 9.0<br><br>6.0 | Insignificant difference between horizontal welding of titanium and Co-Cr |

alloys.[12,19] Such results confirm the difficulty and sensitivity of casting Ti frameworks. Nevertheless, Ti has the tendency to have a superior fit than other base metals, such as Co-Cr[13,28] or Ni-Cr.[14] One study showed that Ni-Cr provides a more consistent result than Ti, but such a difference was not significant.[15] Therefore, base metals can be ranked as follows in terms of casting accuracy from best to worst: Ti, Ni-Cr alloy, Co-Cr alloy. Because of the inferior fit obtained compared to noble metal alloys, Ti and other base metal alloys have been deemed unacceptable for implant frameworks by two studies that suggested further treatment before their placement.[13,14]

**Table 4** Summary of Studies Assessing the Effect of Spark Erosion

| Study | Fabrication materials and methods | Sample size | No. of implants | Implant system (fit level) |
|---|---|---|---|---|
| Romero et al[18] | Cast gold alloy<br>EDM | 30<br>10 | 2 | Stereos (abutment) |
| Eisenmann et al[19] | Cast gold alloy<br>(EDM)<br>Cast titanium<br>(EDM) | 6<br><br>6 | 5 | Brånemark (abutment) |
| Sartori et al[12] | Cast gold alloy<br>(EDM)<br>Cast titanium<br>(EDM) | 5<br><br>5 | 2 | Conexão (abutment) |
| Fischer et al[21] | Cast gold alloy<br>EDM | 6<br>6 | 3 | Straumann (abutment) |

FF = final fit; PF = passive fit; VD = vertical distortion; EDM = electric discharge machining; PSA = photoelastic strain analysis; NA = not available.

**Table 5** Summary of Studies Assessing the Effect of CAD/CAM

| Study | Fabrication materials and methods | Sample size | No. of implants | Implant system (fit level) |
|---|---|---|---|---|
| Jemt et al[24] | CNC-milled titanium<br>Cast gold alloy | 10<br>10 | 5 | Brånemark (abutment) |
| Ortorp et al[31] | CNC-milled titanium<br>Cast gold alloy | 20<br>5 | 5 | Brånemark (abutment) |
| Takahashi and Gunne[25] | CNC-milled titanium<br>Cast gold alloy | 14<br>5 | 2-6<br>3-7 | NA (abutment) |
| Al-Fadda et al[26] | CNC-milled titanium<br>Cast Ag-Pd alloy | 9<br>9 | 5 | Brånemark (abutment) |
| Hjalmarsson et al[27] | CNC-milled titanium<br>Titanium (horizontal sectioning and laser welding) | 5<br>10 | 5 | Brånemark (implant) |

FF = final fit; PF = passive fit; VD = vertical distortion; CNC = computer numeric controlled; NA = not available.

**Table 6** Summary of Studies Assessing the Effect of Framework Bonding to Prefabricated Cylinders

| Study | Fabrication materials and methods | Sample size | No. of implants | Implant system (fit level) |
|---|---|---|---|---|
| Clelland and van Putten[32] | Cast gold alloy<br>Bonding to prefabricated cylinders | 3<br>3 | 5 | Brånemark (abutment) |
| Watanabe et al[3] | Cast gold alloy<br>Bonding to prefabricated cylinders | 4<br>4 | 3 | IMZ (abutment) |
| Heckmann et al[33] | Cast gold alloy<br>Bonding to prefabricated cylinders | 10<br>10 | 2 | Straumann (abutment) |
| Karl et al[5] | Cast gold alloy<br>Bonding to prefabricated cylinders | 10<br>10 | 3 | Straumann (abutment) |
| Karl et al[6] | Cast gold alloy<br>Bonding to prefabricated cylinders | 10<br>10 | 2 | Straumann (abutment) |
| Karl et al[34] | Cast gold alloy<br>Bonding to prefabricated cylinders | 10<br>10 | 3 | Straumann (abutment) |

FF = final fit; PF = passive fit; VD = vertical distortion; SGA = strain gauge analysis; NA = not available.

| Assessment method | Fit condition (µm) FF | PF | VD | Main findings |
|---|---|---|---|---|
| Microscopic examination | NA<br>NA | 190.0<br>7.5 | NA<br>NA | Significant improvement after EDM |
| Measuring microscope (×200) and PSA | NA<br>NA<br>NA<br>NA | 12.7<br>6.2<br>31.6<br>7.6 | NA<br>NA<br>NA<br>NA | Minimal improvement for gold frameworks after EDM; significant improvement for titanium after EDM; insignificant difference between cast gold and titanium frameworks after EDM |
| Microscopic examination | 12.6<br>5.4<br>30.1<br>16.1 | 69.2<br>12.8<br>94.2<br>29.6 | NA<br>NA<br>NA<br>NA | Significant improvement after EDM; insignificant difference between cast gold and titanium frameworks after EDM |
| Microscopic examination of replica | NA<br>NA | 23.7<br>20.1 | NA<br>NA | Minimal improvement after EDM |

| Assessment method | Fit condition (µm) FF | PF | VD | Main findings |
|---|---|---|---|---|
| Photogrammetric | NA<br>NA | NA<br>NA | 11.0<br>10.0 | Insignificant difference between the two systems |
| Coordinate measuring machine | NA<br>NA | NA<br>NA | 1.0<br>8.0 | Significantly better fit with CNC-milled frameworks |
| Microscopic examination of replica (×30) | NA<br>NA | NA<br>NA | 26.9<br>46.8 | Significantly better fit with CNC-milled frameworks |
| Coordinate measuring machine | NA<br>NA | NA<br>NA | 13.3<br>59.2 | Significantly better fit with CNC-milled frameworks |
| Coordinate measuring machine | NA<br>NA | NA<br>NA | 3.0<br>9.0 | Significantly better fit for CNC-milled frameworks than horizontal welding of titanium |

| Assessment method | Fit condition (µm) FF | PF | VD | Main findings |
|---|---|---|---|---|
| SGA | NA<br>NA | NA<br>NA | NA<br>NA | Significantly better fit with framework bonding |
| SGA | NA<br>NA | NA<br>NA | NA<br>NA | Best fit with bonded frameworks |
| SGA | NA<br>NA | NA<br>NA | NA<br>NA | Significantly lower strain with bonded frameworks |
| SGA | NA<br>NA | NA<br>NA | NA<br>NA | Significantly lower strain with bonded frameworks |
| SGA | NA<br>NA | NA<br>NA | NA<br>NA | Significantly lower strain with bonded frameworks |
| SGA | NA<br>NA | NA<br>NA | NA<br>NA | Significantly lower strain with bonded frameworks |

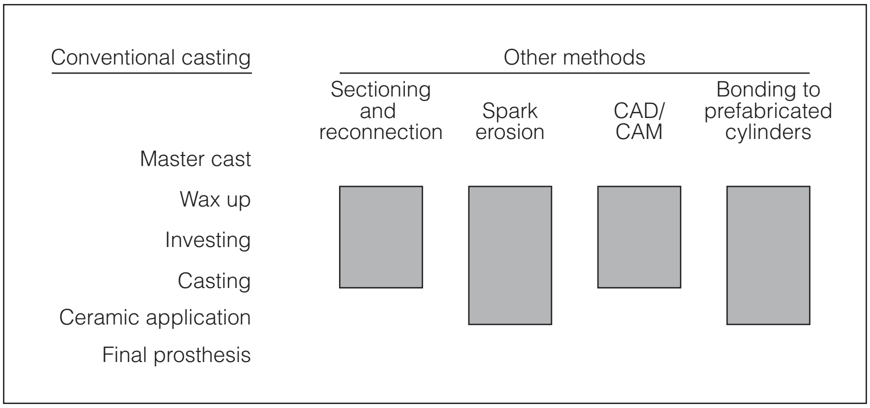


**Fig 1** **(left)** The error-introducing steps involved with conventional casting and **(right)** the potential of the other fabrication methods to improve fit. The shaded areas indicate the steps that can be compensated for or eliminated to improve final fit.

Therefore, it can be speculated that for cast frameworks, high noble metal alloys provide the most superior results in terms of accuracy of fit for partially and completely edentulous patients. Part of their superior outcome is the use of cast-on abutments. More refinement is required for implant frameworks cast from Ti, Co-Cr alloy, and Ni-Cr alloy. From the available evidence, it is not yet clear whether Ag-Pd alloy is capable of providing good fitting single cast frameworks. The variable outcomes obtained by the included studies indicate a plea for further research to formulate clear casting guidelines to enhance the predictability of implant framework fit.

### *Sectioning and Soldering/Laser Welding*

The rationale of sectioning and soldering is to overcome the inaccuracies produced from wax pattern fabrication, investing, and casting. The effect of sectioning and soldering is inconclusive from the available studies.[11,30] Despite the potential advantages of the soldering procedure, it is subjected to several variables, including resin index shrinkage, investment accuracy, and solder manipulation. Temperature concentration from the torch flame in the solder area will cause uneven thermal expansion. In addition, since the solder is composed of a different, lower-melting-point alloy, a corrosive potential and possible reduction of the soldered joint strength exists.[46,47]

If soldering is considered, there is a preference to use low-fusing solder[11] and casting the framework in separate pieces.[3] Because of the high ductility and relative softness of the low-fusing solder, the effect on the final strength of the framework has to be well-evaluated.[48] A modification of the soldering approach is the cast-to method, which was shown to provide a superior fit to the normal soldering procedure.[18] The advantage of cast-to soldering is greater control of the volume, position, and flow of the metal, which means less distortion of the position of the framework parts. In addition, a similar framework alloy can be used for the cast-on procedure.

Vertical laser welding was proven to be an efficient method in improving the fit for Ti and Co-Cr frameworks on two,[15,29] three,[13] and five implants.[23] This procedure can be performed after sectioning a one-piece framework[13] or for joining a two-piece framework.[29] Tiossi et al[15] found a maximum improvement for Co-Cr frameworks after laser welding when compared to Ti or Ni-Cr frameworks. In addition, laser welding of Ti frameworks provided a more prominent effect compared to Ag-Pd frameworks.[20] Such results may be a result of the poor initial fit of base metal frameworks.

The advantage of laser welding is the possibility of joining the framework without the need for additional material, thus retaining the characteristics of the original alloy without lowering the corrosion resistance or reducing the strength of the welded union.[47] However, the mechanical advantage of laser welding was not supported by a 15-year retrospective study that reported a greater incidence of fracture with laser-welded frameworks compared to conventional gold frameworks.[49] In all instances, framework fracture was associated with the laser-welded joint.

The efficiency of vertical laser welding was shown to improve with diagonal sectioning compared to transverse sectioning.[16] The improvement in the welding procedure with a diagonal pattern of sectioning could be because of the greater proximity of the diagonally sectioned parts, which facilitates the welding process and reduces the volume of fused metal needed between the sectioned parts. It is also possible that the direction of contraction during the welding process will lessen the longitudinal contraction of the framework.[16]

After comparing vertical and horizontal laser welding, Jemt[22] found that vertical sectioning provided more consistent results than horizontal sectioning. In comparison with spark erosion, horizontal laser welding showed a tendency for better fit.[21] The major advantage of horizontal laser welding is the ability to rectify the fitting surface of the frameworks by welding prefabricated components on the fabricated frameworks. However, several steps are still needed to achieve a good result, and laser welding is a critical step in the fabrication process. In addition, an operator learning process is expected.[21,27] Because of the sensitivity of this technique, the effectiveness of the approach in clinical practice has to be reviewed.

It appears that noble alloy frameworks do not require sectioning and reconnection because of their predictability in casting. However, for base metal frameworks, there is a clear advantage to sectioning and reconnection. A direct result of its simplicity and reliability, vertical laser welding is the procedure of choice, and diagonal, as opposed to transverse sectioning, is recommended. If the fitting surface is affected by the casting, then horizontal sectioning and laser welding of prefabricated components might be considered more appropriate.

### *Spark Erosion with EDM*

Spark erosion has been shown to improve the fit of base metal frameworks rather than noble alloys. Spark erosion provided significantly superior outcomes than sectioning and soldering Au frameworks.[18] On the contrary, Fischer et al[21] found no improvement from spark erosion compared to one-piece casting of Au alloy. After applying spark erosion for Au alloy and Ti frameworks, Sartori et al[12] found a significant reduction in misfit on two implants. The spark erosion effect was more pronounced for Ti, and the final fit of the two metals was not significantly different.[12] Another study provided confirming results on five implants. Eisenmann et al[19] found that the effect of spark erosion on the fit of Ti frameworks was more significant than that for Au frameworks. The results of the previous studies indicate that the effect of spark erosion was more pronounced for base metals, which can result in a poor initial fit after casting. The benefit of applying spark erosion for cast Au frameworks must be questioned.

Several factors contribute to the accuracy of frameworks machined by spark erosion. The procedure is performed without exerting any pressure on the framework, and the cutting electrodes never touch the prosthesis, which eliminates the risk of mechanical loading–induced distortion. This is critical for adjusting the fragile edges of the framework. Moreover, there is no heat produced with spark erosion, which further eliminates the possibility of thermal distortion.[19] A significant practical advantage of spark erosion is bypassing all the fabrication steps and allowing for adjustment after ceramic application.[12]

One of the limitations of spark erosion is wear of the electrode. With each electrical discharge, the metal is not only removed from the framework, but material is also removed from the electrode, which can lead to significant inaccuracies if the electrode is not replaced after prolonged use.[12] To date, the expense associated with spark erosion has hindered its universal use in commercial laboratories.

Therefore, there is clear merit to applying spark erosion to improve the fit of implant frameworks fabricated from base metals. However, it is questionable whether its application is useful for frameworks fabricated from noble alloys.

### *CAD/CAM*

All the studies that assessed the fit of CAD/CAM frameworks showed high levels of framework fit.[24–27,31] There is a clear tendency for CNC-milled frameworks to exhibit a superior and more consistent fit compared with conventional frameworks cast in a noble metal alloy.[25,26,31] The only exception was the study by Jemt et al,[24] which found an insignificant difference between CNC-milled frameworks and cast Au frameworks. However, the vertical gap of the frameworks in this study for both types was minimal, which might indicate meticulous laboratory techniques in casting frameworks. Hjalmarsson et al[27] found that CNC-milled frameworks exhibited significantly less vertical gap than horizontal sectioning and laser welding. Despite the unknown clinical significance of the difference in fit between the two systems, they reported the consistency and favorable technique sensitivity of CNC milling.[27]

The advantage of CAD/CAM resides in omitting several fabrication steps, including waxing, investment casting, and polishing. Such materials and procedures introduce inaccuracies that become more exacerbated with larger frameworks. These limitations are avoided in CAD/CAM. An additional advantage is the avoidance of creating welding joints, which are considered weak links and potential failure zones. Because of the predictability of CAD/CAM, Ortorp et al[31] mentioned the possibility of omitting the framework try-in step, given that the master cast is accurate, which reduces the overall chair time. The shortcoming with CAD/CAM is system generalization. This is even clearer with the exponential increase in the number of implant companies. Not all implant systems and components are compatible with CAD/CAM. This will likely be resolved with time, but until then, there are some restrictions.

To date, CNC milling of implant frameworks seems to be highly accurate and the most consistent framework fabrication approach. Other advantages include the reliance on industrialized machines for scanning and milling and minimizing man-made inconsistencies, as well as being the least technique-sensitive among all fabrication methods.

### *Bonding the Framework to Prefabricated Implant Cylinders*

Several studies have described the possibility of improving framework fit by bonding the fabricated frameworks on prefabricated Ti cylinders.[5,6,32–34] When the fit of the frameworks produced by this technique was assessed, it was found that they showed favorable outcomes compared to conventional casting. The rationale behind this approach is to compensate for the inevitable inaccuracies that can be incorporated within the framework during fabrication. It is also possible to perform the bonding procedure post-veneering.[6,34] Furthermore, it allows the predictable application of less expensive framework metals such as Co-Cr or Ni-Cr alloys, which also have excellent mechanical properties.

Despite the valid concept behind this approach, there are some serious limitations. Post-ceramic bonding to prefabricated cylinders may compromise the ability to preserve the occlusal relationship with the opposing arch. Furthermore, there are concerns regarding the longevity of the resin bond and its reparability without grossly affecting the fit of the prosthesis. In addition, there is a possible weakening effect of the relief space on the durability of the framework.

### *Further Considerations*

For single implant crowns, the microgap between the implant and single abutment was estimated to be in the range of 2 to 10 μm. Therefore, it may be logical to accept Brånemark's recommendation regarding passive fit (10-μm vertical gap or less).[1] Accepting this criterion, it appears that noble metal casting, sectioning and soldering/laser welding, spark erosion, and CAD/CAM have the potential to provide acceptable implant framework fit. However, the listed fabrication methods suffered from outcome variability, as observed from the available studies, with CAD/CAM providing the most consistent outcome.

One of the common limitations of the experimental setup of the included in vitro studies is the fit assessment of the framework on the master cast, which omits the effect of the impression procedure. This means that there is still a considerable possibility of underestimating the real fit values that can be produced in normal clinical practice.

Despite the overview provided by the included studies regarding the fit of implant frameworks when assessed by in vitro experiments, further research is required to clarify some practical matters, such as the long-term benefit obtained from using different methods, the anticipated maintenance level, and the cost efficiency of any system.

## Conclusions

Within the limitations of this systematic review, the following may be concluded:

- No material and method is ideal for fabrication of screw-retained fixed implant frameworks in all aspects.
- Casting of noble metal alloys is predictable in terms of implant framework fit, and no additional treatment is needed to improve the framework fit. Casting of base metals, such as Ti, Co-Cr alloy, and Ni-Cr alloy, generally does not provide an acceptable implant framework fit unless additional treatment is performed, such as laser welding or spark erosion. The benefit of soldering is unclear and perhaps superseded by laser welding.
- Spark erosion, CAD/CAM, and framework bonding to prefabricated cylinders have great potential to overcome significant inaccuracies produced by the fabrication procedure and provide implant frameworks with excellent fit. To date, CAD/CAM provides the most consistent outcome.

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*Literature Abstract*

**Comparison of the accuracy of invasive and noninvasive registration methods for image-guided oral implant surgery**

The registration procedure plays an important part in navigation surgery, and its accuracy ensures precise linking of the virtual plan to the surgical site. The current gold standard uses invasive bone markers that require surgical placement of the markers before imaging. Registration templates and external registration frames are noninvasive alternatives, but repositioning them might result in errors. The purpose of this study was to determine if noninvasive registration methods were as accurate as invasive bone markers. The fiducial registration error and target registration error of two noninvasive methods was compared to invasive bone marker registration. Computed tomography scans of a maxillary and mandibular stone cast with radiopaque markers on the occlusal, buccal, and palatal/lingual surfaces were obtained. An optical-based navigation system registered these embedded markers as well as the external markers, which had been mounted on a registration template and an external registration frame. Errors in point-based rigid body transformation were calculated. The use of 5 or 7 registration markers was also compared. Twenty-four registrations and 696 error measurements were performed. The external registration frame yielded significantly worse fiducial registration error compared with invasive and template-based registration. There was no difference in target registration error between invasive and noninvasive methods. The use of 5 or 7 markers did not show any significant difference. The predicted error of the navigation system significantly underestimated target registration error. Based on this study, noninvasive methods of registration using a registration template or external registration frame yielded the same accuracy as the invasive method. The use of 5 markers is sufficient. Clinically, the predicted error from the navigation system should not be mistaken as “navigation error.”

**Widmann G, Stoffner R, Schullian P, et al.** *Int J Oral Maxillofac Implants* 2010;25:491–498. **References:** 45. **Reprints:** Dr Gerlig Widmann, SIP, Department for Microinvasive Therapy, Department of Radiology, Innsbruck Medical University, Anichstrasse 35, A-6020 Innsbruck, Austria. Email: gerlig.widmann@i-med.ac.at—*Clarisse Ng, Singapore*