# Description and Evaluation of a Simplified Method to Achieve Passive Fit Between Cast Titanium Frameworks and Implants

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Because osseointegrated implants have no resilience in bone, passive fit between dental implants and prosthetic superstructures has been identified, both from biologic and mechanical perspectives, as a potential discriminating prognostic factor. Distortion of the metal framework during the casting procedure has been cited as a main cause of misfit. The objectives of the present article were to describe a recently presented method (CrescoTi Precision method) intended to correct for distortion in cast titanium frameworks, and to elucidate and evaluate the method by photoelastic and strain gauge techniques. The method appears to be an efficient and accurate procedure for correcting for distortion in cast titanium frameworks.

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**Key words:** cast framework, dental implants, distortion, laser welding, misfit, passive fit, photoelastic analysis, precision of fit, strain gauge analysis, titanium

Because osseointegrated implants have no resilience in bone, the importance of passively fitting superstructures to prevent transformation of stress from the superstructure to the implant and surrounding bone has been emphasized.[1–3] Such stress factors may result in microfractures of the peri-implant bone, ischemia, and other adverse effects, which may compromise implant success and survival. The nonresilient interface between bone and implant may also force tightening of the superstructure, resulting in complications such as fracture of the metal framework and prosthetic retaining screw.[4,5]

Distortion of the framework during the casting procedure has been cited as the main cause of misfit both in implant frameworks and in conventional restorations.[3,6,7] Casting distortion is difficult to predict; factors such as linear casting shrinkage of the metal or alloy used, the thickness as well as the pattern of the frame, and the casting technique influence the distortion and should therefore be considered.[1,3,8,9] Several soldering techniques to correct framework distortion have been described. These techniques involve either casting in separate units or vertical sectioning of the cast into separate units, followed by indexing on the master cast or in the mouth.[10] Soldering techniques are usually used for gold frameworks, while laser-welding techniques are recommended for titanium frameworks. A prerequisite for laser welding is that the gap between the surfaces to be assembled must be narrow and as parallel as possible.[11]

A nonconventional approach (Procera) to avoid titanium casting distortion has been presented by Nobel Biocare (Göteborg, Sweden). Premachined, commercially pure titanium components are assembled to an implant framework by use of a stereo laser-welding technique.[12] This method is supposed to yield strong, distortion-free, and passively fitting frameworks, but the technique seems complicated. A less complicated method (CrescoTi Precision) to fabricate passively fitting titanium frameworks has been developed by CrescoTi Systems AB (Kristianstad, Sweden). This method uses a conventional approach to framework fabrication, ie, the lost wax casting

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technique. Correction of distortion involves horizontal sectioning of the cast framework followed by the use of a laser-welding technique, wherein the coronal part of the framework is reassembled to new premachined titanium cylinders mounted on the implant analogues in the master cast. Before the welding procedure can be accomplished, the cylinders must be cut in the same horizontal plane as the lower surface of the framework.

The objective of the present article was to describe the CrescoTi Precision method to correct for distortion in cast titanium frameworks, and to elucidate and evaluate the method by photoelastic and strain gauge techniques.

## Materials and Methods

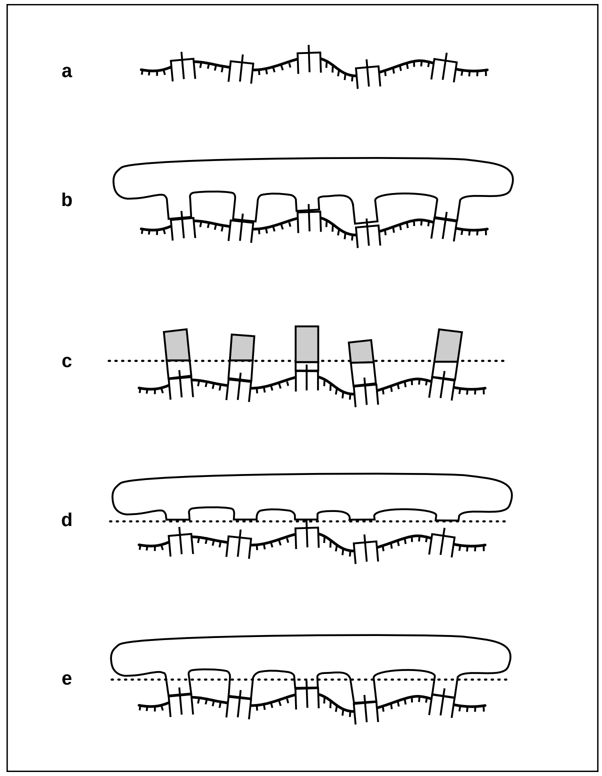
**The CrescoTi Precision Method.** This method (outlined in Figs 1a to 1e) may be described as follows. The cast titanium framework is mounted temporarily on the implant analogues in the master cast using two or three retaining screws, which, however, are not tightened. Any horizontal and vertical misfit can now be observed. Sticky wax is used to secure the master cast to the framework (Figs 1a and 1b). The retaining screws are then removed. The master cast and the attached titanium framework is now mounted with plaster onto an articulator-like "jig" consisting of one upper and one lower stand; each stand is supported by four legs, those on the upper stand being longer than those on the lower. The stands, connected by plaster, framework, master cast, and sticky wax, are positioned on the same table. This procedure preserves the vertical and horizontal relation between framework and master cast.

The sticky wax connection between the "units" is broken, and the lower unit with the master cast is moved horizontally from the upper unit with the framework. New prefabricated titanium cylinders, with exact copings to the type of implants or abutments used, are screw-tightened onto their analogues in the master cast. A horizontal plane is defined, and each titanium cylinder is cut along this plane (Fig 1c).

The "legs" of the framework are cut along the same horizontal plane (Fig 1d).

The framework is released from the plaster, placed passively on the cut surfaces of the mounted cylinders in the master cast, and initially assembled by point laser welding followed by careful laser welding around the entire periphery of the joints. The original vertical height of the framework is preserved (Fig 1e).

**Photoelastic Experiment.** Three 13-mm-long (3.7-mm-diameter) titanium screw implants (CrescoTi Systems AB) were placed along a straight line in a 15 × 30 × 55 mm resin block, cast in Araldit




**Figs 1a to 1e** Schematic illustration of CrescoTi Precision method. (a) Master cast with implant replicas. (b) The cast framework is positioned and fixed on the master cast using sticky wax. Observe the vertical and horizontal misfit. The master cast, together with the attached framework, is then mounted with plaster onto an articulator-like jig to secure the horizontal and vertical relation between the two units. (c) The master cast and the framework are separated. Prefabricated impression tubes (copings) are mounted on the implant replicas. A "horizontal plane" is defined, and the tubes are cut in this plane. (d) The framework "legs" are cut in the same horizontal plane as the tubes. (e) The parallel planes between the tubes and the framework make it possible to place the framework passively on the tubes with maximum contact. Using a stereo laser technique, the surfaces are welded together.

F with setting agent 956 (Ciba Geigy, Basel, Switzerland). The distances between the implants were 10 and 20 mm, respectively, and the upper portion of the implants did not exceed 2 mm above the upper surface of the model (Fig 2). The implants were placed almost parallel to each other.

Plastic tube copings were mounted directly onto the implants, and four frameworks were waxed and then embedded in Rematitan Plus casting mass (Dentaurum, Pforzheim, Germany), burned out, and finally cast in commercially pure titanium grade 2 by use of a Castmatic casting machine (Castmatic-S, Iwatani International, Osaka, Japan). Each waxup was as similar to the next as could be achieved. Prefabricated wax rolls (4.5 mm in diameter) were used

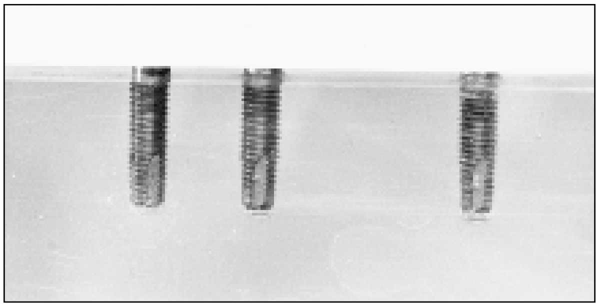


**Fig 2** The photoelastic resin model with three vertically positioned Cresco titanium screw implants.

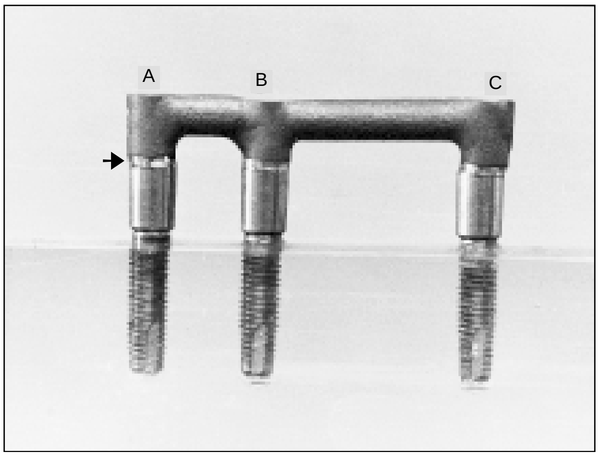



**Fig 3** A "precision" titanium framework attached to the implants in the photoelastic resin model. Note the weldings *(arrow)*.

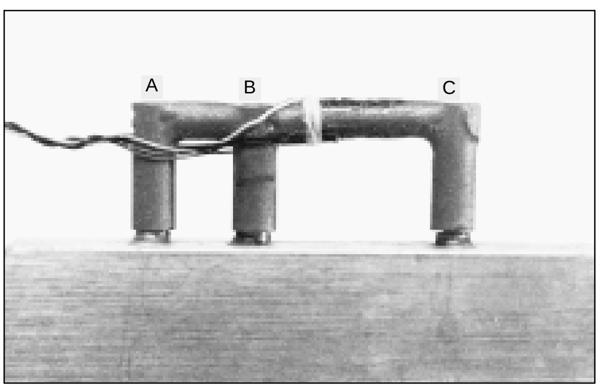



**Fig 4** As-cast titanium framework with strain gauges attached. The implants are placed in a brass block, and the framework has been screw-tightened to implants A and B. Observe the misfit at implant C.

for the horizontal connecting bar. The "bridge legs" were approximately 6 mm in height, and the connecting bar was 35 mm in length. Two of the four frameworks were subjected to the CrescoTi Precision procedure, while the other two were not.

The distances (gaps) between the "nonprecision" titanium frameworks and the implants at implant C (Fig 3) with the retaining screws tightened at implants A and B, as measured in a microscope, were 70 and 40 µm, respectively. Corresponding gaps for the precisioned frameworks were not measurable (< 5 µm).

One at a time, the titanium frameworks were then mounted on the photoelastic resin model using three titanium retaining screws tightened to 40 Ncm (Fig 3). (The tightening of the screws was done alternately.) The model was then placed in a polariscope with a monochrome Na-light and quarter wave plates to obtain a black-and-white image of the stress fringes in the photoelastic resin. The results were documented photographically, and the fringe order was counted.

**Strain Gauge Experiment.** In this experiment, three 13-mm-long Cresco screw implants were placed into a homogenous brass block (15 × 30 × 60 mm). The implants were positioned in the same manner as in the photoelastic experiment, ie, in a straight line with spacing of 10 and 20 mm, respectively. The holes in the test body had been prepared by drills and screw taps before the implants were placed. Four titanium frameworks were fabricated in the same manner as described earlier, ie, according to the lost wax casting technique. The dimension of the horizontal "bar" was identical for all four frameworks (3.5 × 35 mm), ie, the frameworks were standardized in design and dimensions.

Two of the frameworks were subjected to the CrescoTi Precision procedure, while the remaining two frameworks were not. Strain gauges (EA 05 Measurements Group, Hants, England) were glued to the upper and lower surfaces of the horizontal bars (Fig 4).

The frameworks were then mounted on the implants in the brass model one at a time. The titanium retaining screws to implants A and B were tightened (40 Ncm) (Fig 4). Before the third retaining screw (implant C) was tightened, the gap between implant and framework was measured in a measuring microscope and with blades of known thickness. After measurements, the third retaining screw (implant C) was tightened, and the strains were recorded. The retaining screw at implant C was then removed, and the framework was loaded at implant C in a standard testing machine (Alvetron, Stockholm, Sweden) until the corresponding strain, as recorded earlier, was reached. The load required to generate the strain was recorded.

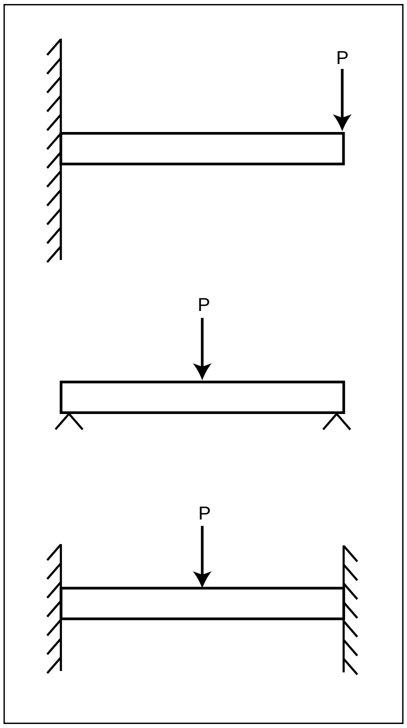



**Fig 5** Elementary beam loads used in the equations. P = load.

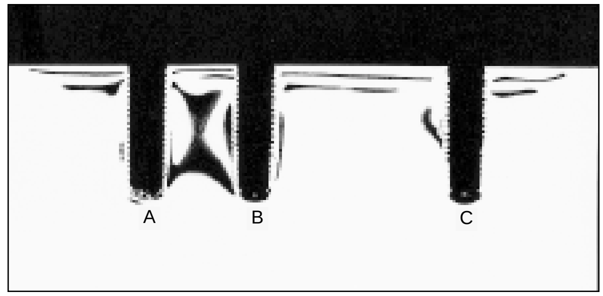



**Fig 6a** Photoelastic picture of the implants in the resin model with a "nonprecision" framework screw-tightened to the implants.

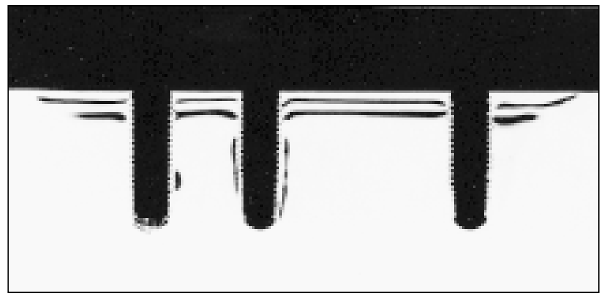


**Fig 6b** Photoelastic picture of a "precision" framework screw-tightened to the implants. Note the fringe order reduction as compared to Fig 6a.

To calculate strains if the misfit was located at implant B, the following test was undertaken: 50-µm-thick plates were placed between the implants at implants A and C (Fig 4) and the "precision" frameworks, which resulted in a gap at implant B. According to the laws of beams with fixed end points, high load is required to create deflection of the framework. The strains were recorded after the frameworks had been tightened to the implants (40 Ncm), and the load was recorded as described above.

**Beam Analysis.** The standardized and simplified design of the tested frameworks was chosen to facilitate the fabrication series and to adapt principal aspects of the results, but also to make it possible to use formulas for calculating stresses and strains. When the gap was placed at B or C (Fig 4), the tightening of the screw closely follows elementary beam loadings. The deflection and loads follow the equations[13]

$$\delta = \frac{Fl^3}{3\,EI}$$

$$\delta = \frac{Fl^3}{48\,EI}$$

$$\delta = \frac{Fl^3}{192\,EI}$$

where $I = \pi \times r^4/4$; r = radius of the beam; F = the load; E = modulus of elasticity; and l = length of the beam.

The first equation holds for a cantilever beam, the second equation for three-point loading of a beam, and the third for a loaded beam fixed at both ends (Fig 5).

## Results

The results of the photoelastic experiments clearly demonstrated a reduction of stresses in the "bone" (resin) portion of the model when the "precision" titanium frameworks were mounted on the implants, as compared to the "nonprecision" frameworks. The differences are illustrated in Figs 6a and 6b. The dark lines represent stress concentration areas in the resin. When the nonprecision frameworks were mounted, stress concentration was observed in the "bone" between implants A and B (Fig 6a). Corresponding indications of stress were not observed when precision frameworks had been mounted (Fig 6b). The fringes along the vertical surfaces of the implants are interpreted in part as a torque effect that developed when the prosthetic retaining screws were tightened and in part as a result of stresses that developed during the placement of the implants into the resin

**Table 1** Measured and Calculated Loads (N) to Close the Gaps (µm) Between Implants B and C and the Cast Titanium Framework†

| | Situation | | | | |
|---|---|---|---|---|---|
| | Cantilever at C | | Three-point loaded beam at B | Fixed beam at both ends | |
| | Measured | Calculated | Calculated | Measured | Calculated |
| Radius (r) of the beam (mm) | 1.75 | 1.80/2.0/2.2 | 1.8/2.0/2.2 | 1.75 | 1.8/2.0/2.2 |
| Gap distance (um) | | | | | |
| 50 | — | 15/23/34 | 141/215/315 | 300 ± 26 | 565/861/* |
| 80 | — | 25/38/55 | 226/344/504 | — | 904/1379/* |
| 180 | 41 ± 4.3 | 55/84/124 | 508/776/1135 | — | 2035/3102/* |

†See Figs 4 and 5.
*Values too high to be meaningful.

models. The fringe orders were 2.3 and 1.8 when the nonprecision frameworks were mounted, and 1.1 and 1.0 when the precision frameworks were mounted on the same models.

When the nonprecision frameworks were attached to implants A and B in the brass model, ie, a cantilever beam situation (Fig 4), a gap of 180 and 30 µm, respectively, was measured between the framework and implant C (Fig 4). After the implant C retaining screws were tightened, the gaps were closed. The load to close the 180-µm gap was measured to 41 ± 4.3 N (Table 1), and the load to close the 30-µm gap was 8 ± 8.0 N. The data obtained from the test of the framework with the 30-µm misfit were rejected because of the low load value and low reproducibility of the measurements. The measurements from the tests with the precision frameworks resulted in recordings close to zero (< 5), ie, no obvious strains were detected in the frameworks after the tightening procedure.

The applied load to close the artificially created framework misfit (gap) of 50 µm at the middle implant (B) (Fig 4), ie, a fixed beam at both ends situation (Fig 5), was measured at 300 ± 26 N (Table 1).

The results from the mathematically calculated predictions of loads transferred to the implants from frameworks with different dimensions and with various degrees of misfit between implants and framework are presented in Table 1. Three situations are depicted: the cantilever, the three-point loaded beam, and the loaded beam fixed at both ends.

## Discussion

Although the influence on bone response of the prosthesis fit to implants has not yet been demonstrated in experimental in vivo studies,[14] there seems to be consensus on the importance of passive fit between dental implant components and the superstructure framework. The rationale for this is that osseointegrated implants have no resilience in the bone, and therefore cannot adapt to a misfitting framework without generating tension in the bone as well as in the metal framework. As a result of the contraction (distortion) during the cooling phase of all metal casting procedures, a certain degree of misfit between the framework and the implant components cannot be avoided.

Thus, it seems obvious that standard methods for correcting the misfit ought to be available for use on a routine basis. Conventionally, a subjective, and usually inaccurate,[15] visual evaluation in the dental laboratory or by the prosthodontist seems to be the basis for decision concerning a correction procedure, usually a separation and soldering technique.[10] However, the soldering technique is not suitable for titanium. The CrescoTi Precision method presented here, based on a laser-welding technique, is proposed as a standard method for correcting distortion generated during the titanium-casting procedure. Theoretically, the method should give the stated results, and the experiments reported in the present investigation confirm that the method is reliable for fabrication of frameworks with passive fit to implant analogues in master casts. It should be pointed out that not any misfit resulting from the impression-making process is corrected for by this method. However, by optimizing the impression-taking technique, it is considered possible to obtain master casts with a high standard of accuracy.[16]

The possibility that titanium frameworks can be fabricated with passive fit on a routine basis questions the rationale for the concept of abutments as shock-absorbing and misfit-compensating middle components between the framework and implants.[17] From a technical perspective, the "precisioning" method should make it possible to exclude the abutment in most clinical cases, ie, the framework may be attached directly to the implants. Preliminary results from a 3-year longitudinal clinical study on abutmentfree implant-supported prostheses fabricated according to the CrescoTi Precision method corroborate the statement (Holmgren and Fornell, in preparation).

The use of model experiments to assess clinically and biologically relevant conclusions regarding stress and loads in the bone has its limitation. The framework and the implants in the present experiments were made of titanium, while the models were in resin or brass. The resin is isotropic and has an E-modulus 4 GPa, and brass has a 70 GPa.

The E-modulus of bone depends on the part of the bone being examined; cortical bone has a value of about 15 GPa, and trabecular bone around 2 GPa. Moreover, the bone is anisotropic, and shape and dimension play a role in its physical behavior. This implies that the elastic deformation of bone around the implant is influenced by its form. When the two elements (framework and resin block) in this study were attached to each other via the implants, the deformation could occur partly in both elements, ie, similar to the clinical situation. When the brass block was used, deformation occurred only in the framework. This experiment was a prerequisite for the theoretic calculations of the loads presented in Table 1. Another such prerequisite was that no angle deflection occurred in the butt joint between the implants and framework. Angle deflection must be considered, however, if the joint consists of a conical or otherwise shaped adapting zone.

The photoelastic and strain-gauge experiments presented in this article may be interpreted as a demonstration of *(1)* casting distortion, which causes misfit and thereby generates stress transformed to bone, implant components, and framework, and *(2)* the need for correction of the misfit. The experiments also illustrate that the CrescoTi Precision method for correction of cast titanium framework distortion leads to similar passive fit as may be achieved after sectioning and subsequent soldering of gold frameworks.[2,7] As a matter of fact, the soldering procedure also causes a certain degree of distortion during the cooling phase. The CrescoTi Precision method based on laser-welding technique is interesting not only because it is an easy and rational method for correcting distortion in titanium, but also because the method offers optimal conditions for strong distortion-free weldings. The absolute closeness and parallelism of the surfaces to be assembled[11] constitute the optimal conditions.

The magnitude of generated stresses depends not only on the misfit, but also on the dimensions of the framework. The relations between misfit gap, framework dimension, and load were calculated by use of the elementary beam equations (presented in Table 1). When the gap occurred at implant C (Fig 4), the framework could be compared to a cantilever beam. In the case of a gap at implant B, the elementary equation for a three-point loading of a beam and the equation for a beam fixed at both ends are applicable to estimate loads necessary to close the gap. In extensive frameworks, the latter formula is probably more accurate. It should be noted that calculations of loads and stresses are theoretical. Distribution of the effects and tissue reactions in the biologic situation are influenced by bone quality,[18] and therefore more uncertain to predict. To minimize such uncertainty, methods to optimize passive fit between framework and implants must be used. The CrescoTi Precision method has been shown to be an accurate method for that purpose.

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