CASTING DISTORTION OF FIVE-FIXTURE SUPPORTED IMPLANT FRAMEWORKS FABRICATED ON MASTER CASTS

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Dentistry in the branch of Prosthodontics.

Johannesburg, 2007.

DECLARATION

I, Tasneem Mitha declare that this research report is my own work. It is being submitted for the degree of Master of Dentistry in the branch of Prosthodontics in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination at this or any other University.

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…………………day of …………………month, 2007.

To Anu, for believing in me,

and to my parents and family, for your encouragement and unwavering support.

ABSTRACT

Statement of the problem: Conventional techniques for implant framework fabrication have been shown to produce errors that are inconsistent with the passive-fit requirement for osseointegrated implant frameworks.

Purpose: The aim of this study was to assess the three-dimensional distortion inherent in casting of full arch, screw-retained titanium implant frameworks.

Materials and methods: A conventional commercial laboratory one-piece casting, using the lost-wax technique was used. Five wax patterns were fabricated on a die-stone cast poured from a plaster impression of a five-fixture brass analogue. A reflex microscope was used to determine the three-dimensional casting error, by measuring horizontal and vertical distances for each wax pattern and its corresponding cast titanium framework, as well as offset distances from the horizontal reference plane.

Results: Significant differences were found in the amount of distortion between wax patterns and cast frameworks, with the castings being approximately 416 µm to 477 µm larger than the wax frameworks. The greatest amount of distortion occurred at the terminal implant abutments, and in the vertical dimension. However, there was inconsistency in these differences, indicating the three-dimensional nature of the overall distortion of the cast frameworks.

Conclusions: It is doubtful whether any conventionally cast framework can be made to the degree of accuracy required to fit passively on its abutments because of the multiple variables inherent in this process. It is therefore recommended that all full-arch, cast titanium frameworks be cast in sections, or alternatively be sectioned, indexed and soldered before being seated intraorally.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

One of the most important objectives in making an implant-supported prosthesis is the production of a superstructure that exhibits a passive fit when connected to multiple abutments (Adell et al, 1981; Zarb and Schmitt, 1990; Goll, 1991). Unfortunately, this goal has been difficult to achieve using conventional framework fabrication techniques. Skalak (1983) has described the biomechanical consequences of the connection of nonpassive frameworks that include stress in the prosthesis, the fixtures, and the bone. The suggested biological response to excessive and undetected stress is implant interface failure (Jemt and Book, 1996).

The degree of adaptation of implant superstructures to the underlying abutments has been examined, and a vertical variability of 20µm has been shown for the transfer of implant position from the mouth to a master cast for a five-implant mandibular model (Carr, 1991). The combined horizontal and vertical error attributable to casting full-arch high palladium alloy frameworks was measured and averaged 130µm (Carr and Stewart, 1993). Jemt (1991) proposed that a maximum of half a screw turn, which corresponds to a misfit of approximately 150µm, could be considered clinically acceptable.

The cause of fixed implant-supported framework misfit is multifactorial. Implant prosthesis fabrication makes use of techniques and materials borrowed from conventional prosthodontics, and distortions of implant superstructures arise throughout the procedures involved in their fabrication. These include the type of material used in making the implant impression, the impression technique, fabrication of the master cast, wax pattern fabrication, and dimensional changes inherent in the investing and casting process. Consequently, a number of methods have been described to reduce the distortion of the implant framework and thus improve passivity of fit. These include the use of different impression techniques (Spector, Donovan and Nicholls, 1990; Interregui et al, 1993; Herbst et al, 2000) and materials (Wee, 2000), laser welding of titanium implant frameworks (Riedy, Lang and Lang, 1997; Jemt et al, 2003) spark erosion treatment (Eisenmann et al, 2004), casting frameworks in sections (McCartney and Pearson, 1994), sectioning and soldering of completed frameworks (Zervas et al, 1999), the use of CAD-CAM (Procera) (Takahashi and Gunne, 2003), and passive abutments and cementation techniques (Goossens and Herbst, 2003).

Despite the techniques that have been developed to improve passivity of fit, one-piece castings are still being used routinely, without any efforts to improve their as-cast accuracy (Tan et al, 1993). Whilst casting accuracies using high palladium alloys (Carr and Stewart, 1993; Tan et al, 1993; Zervas et al, 1999) and gold alloys (Jemt and Lie, 1995; Takahashi and Gunne, 2003) have been examined, to date no three-dimensional studies demonstrating the casting accuracy of one-piece pure titanium frameworks has been found. Furthermore, most of the methods used have involved linear distortion measurements only (Carr and Stewart, 1993; Jemt and Lie, 1995; Zervas et al, 1999).

One study by Tan et al (1993) attempted to define the three-dimensional distortions of one-piece cast implant frameworks of two designs (L-shaped and U-shaped), using silver-palladium alloy. They did this by comparing the positions of the gold cylinders when on the master model prior to pattern fabrication, to that of the gold cylinders when cast into the prosthesis frameworks, using a coordinate measuring machine. Distortion was defined by five displacement variables for the central points, or centroids of each of five gold cylinders incorporated in each casting. The relative distortion of the five cylinders that were incorporated in the casting was determined by mathematics overlaying the initial and final positions of the centroids. Then, three translational displacements and two rotational displacements were computed and compared for each gold cylinder. They found an overall mean distortion of the centre points of 20µm, and that an overall shrinkage of the arch occurred. They also found that rotational displacements could result in potential vertical gaps, which may be hidden, depending on the direction of tilt and the moment arm length. This study relied upon locating a plane of contact (reference plane) between the gold cylinder and the titanium abutment, and a calculation of the centre point of the circular gold cylinders.

Another three-dimensional distortion study analysed the precision of fit between cast gold-alloy frameworks and master casts (Jemt and Lie, 1995) using photogrammetry. They observed distortions of cylinders mostly in the horizontal plane (x- and y-axis), whilst the vertical aspect (z-axis) seemed to be more stable. The measurements revealed a range of centre point distortions from 15 to 165µm. A correlation was found between centre point distortion and the width, as well as the curvature of the implant arch, indicating greater displacement the wider and the more curved the arch was. This measurement technique also used references which were mathematically calculated values.

The problems of such complex mathematical analyses in three-dimensional distortion studies could be simplified by direct measurements in all planes of specific reference points incorporated into a framework. The reflex microscope is an instrument which allows for such measurement in three dimensions to a high degree of precision (Scott, 1981). An artificial measuring mark in the form of a floating dot (from a single strand of optical fibre) is created in space and controlled by the operator's depth perception (Owen, 1985; Owen, Wilding and Adams, 1992). Data for spatial positioning of each reference point are collected as three point coordinates in the *x*-, *y*- and *z*- axes. A three-coordinate system creates a high degree of accuracy of measurement, magnification of the object being through a three-dimensional binocular microscope (Owen, 1985; Owen et al, 1992).

Thus the purpose of this investigation was to measure the three-dimensional distortion of one-piece, as-cast titanium frameworks using a reflex microscope.

2.0 AIM AND OBJECTIVES

The aim of this study was to measure the differences, in three dimensions, between wax patterns and finished castings of one-piece titanium implant frameworks fabricated using the conventional lost-wax technique.

The objective was to ascertain whether the as-cast accuracy of cast titanium frameworks was within the 150 μm limit proposed by Jemt (1991). The casting error would be determined using a reflex microscope to measure the horizontal and vertical distances between reference points on the wax patterns and comparing them with those on the cast frameworks.

3.0 MATERIALS AND METHODS

3.1 Wax pattern fabrication

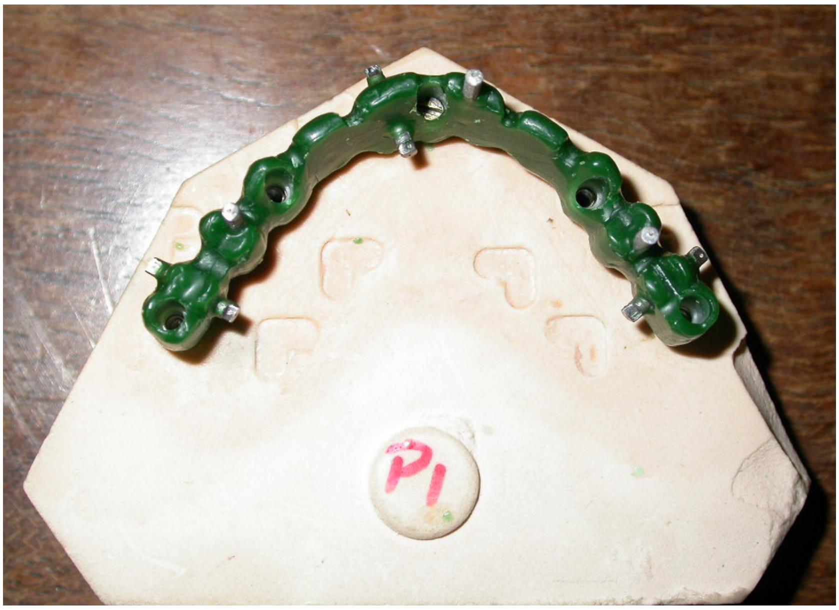
In a preceding study (von Berg, 2005), thirty impressions of a brass analogue model containing five implants (Southern Implants, Irene, South Africa) were taken at the fixture level to compare the distortion of master casts produced with different impression materials. One of the stone casts (poured with Velmix stone (Kerr Co, MI, USA)) from that study served as the master cast (Figure 1) from which five standardised wax patterns were fabricated in the present study.

Figure 1. Stone master cast

All laboratory procedures in this study were performed by a single technician in a commercial laboratory. These procedures included waxing up, investing, casting, and finishing of the titanium frameworks according to a strict standardised laboratory procedure. Batch numbers for all materials were followed for each framework in order to limit the variables from these procedures.

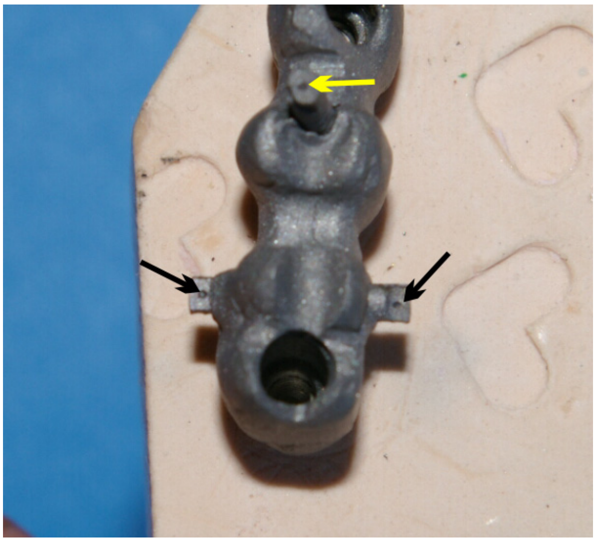
The wax patterns were made using inlay wax (Maves inlay wax, Maves Co, Cleveland, OH) on UCLA non-hex sleeves (SB5, Southern Implants, Irene, South Africa) (Figure 2).

Figure 2. Wax framework on plaster model secured by a single brass screw in the central incisor area



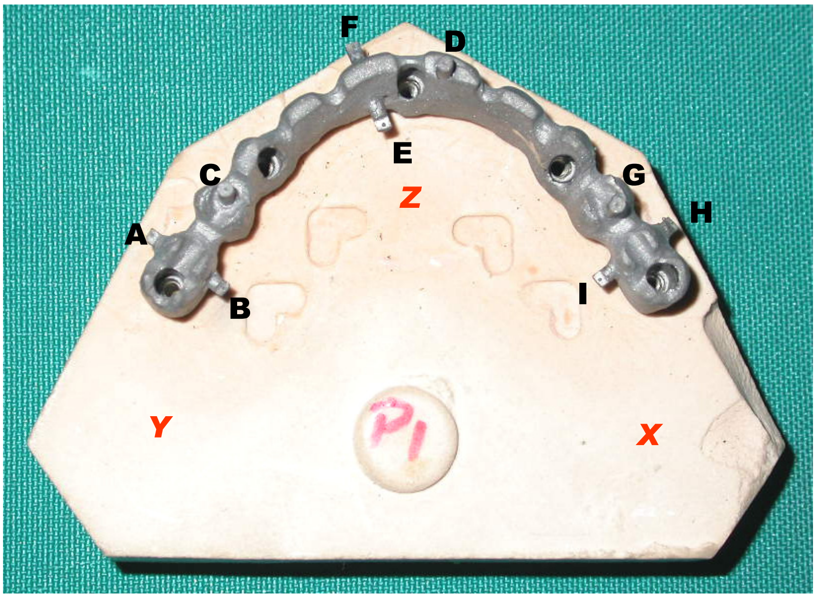
Three horizontal and three vertical pins cast from titanium were incorporated into each framework. Indentation points were made on the terminal ends of the pins using a Vickers indentation apparatus (Leco M-400 Hardness Tester, St Joseph, MI), and these served as reference points during the measuring of the frameworks on the reflex microscope (Figure 3).

Figure 3. The arrows show the indentation points on the reference pins which are identified in the reflex microscope.



The outside horizontal pins were labelled *A*, *F* and *H*. The inside horizontal pins were labelled *B*, *E* and *I*. The vertical pins were labelled *C*, *D*, and *G*. In addition, three points labelled *X*, *Y*, and *Z* were measured on the flat surface of the model, representing the horizontal reference plane (Figure 4).

Figure 4. Titanium framework on master cast, demonstrating the positioning of reference pins and points on the framework and master cast.



The wax frameworks were packaged with sponges in order to prevent damage, and transported in a cooler bag at all times to avoid temperature extremes. The frameworks were allowed to settle to room temperature for approximately four hours before measurements were taken. This was in order to limit any distortion of the wax due to temperature changes.

3.2 Measurement of the wax patterns – the reflex microscope

The wax frameworks were numbered from one to five prior to being measured. Each wax pattern was secured onto the master model with a single brass screw (BSS2, Southern Implants, Irene, South Africa) in the implant, in the central incisor area. In order not to create any distortion as a result of over-tightening the screw, a torque wrench was not used. Instead, the screw was fastened using a hand-operated screw-driver, until tactile feedback indicated that the screw had started to engage. The same operator tightened all screws in this manner.

Using a reflex microscope (Reflex Measurement Ltd, London, United Kingdom) (Figure 5), nine distances were measured for each wax specimen between the points on the reference pins (Table 1).

Figure 5. Measuring distances on the wax framework on the reflex microscope

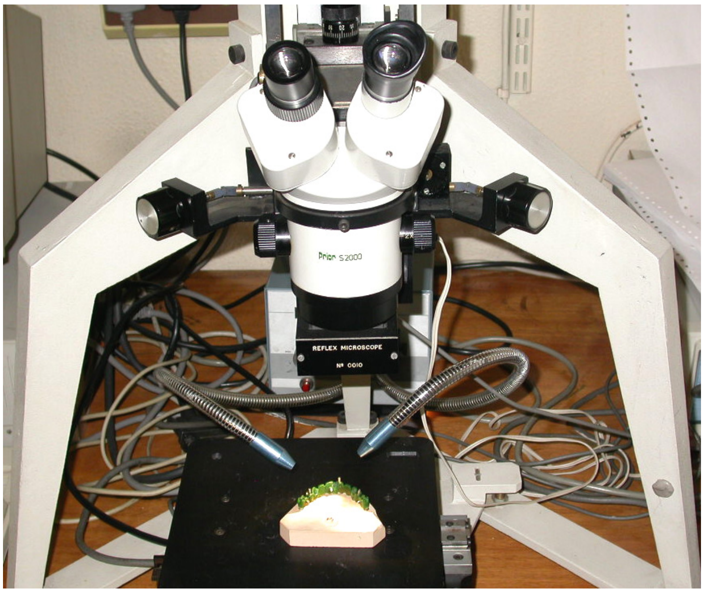


Table 1. Measurements made for each wax and cast specimen (see Figure 4).

PIN POINT POSITION	MEASUREMENTS MADE
Outside horizontal	A-F, F-H, A-H
Inside horizontal	B-E, E-I, B-I
Vertical	C-D, D-G, C-G
Offsets from the XYZ reference plane	Each pin point was measured relative to the reference plane

The relative distortion model has been described as more valid for the consideration of clinically significant distortions in dentistry (Nicholls, 1977; 1978; 1980). It uses the prosthesis itself as its own reference system of axes and thus allows the calculation of distortion relative to points within the prosthesis itself. This model formed the basis for the measurements in this study.

All wax pattern measurements were made by the same operator and were used as a baseline to determine changes in the degree of misfit after casting. After measuring, the wax frameworks were sent to the laboratory where they were cast in titanium using the conventional lost wax technique.

3.3 Spruing and investing of the wax frameworks

The technique described below for spruing, investing and casting has been developed and used daily at a commercial dental laboratory, and was followed for this study.

The wax pattern was checked for accuracy before sprue attachment by individually tightening each gold cylinder and assessing fit by the lack of cylinder displacement. Ten 8-gauge round wax sprues (2-3mm long) were attached to each tooth on the wax pattern, and connected to a 5mm runner bar. The runner bar was split into three sections, and connected to a 5mm feeder bar.

The sprued patterns were left screwed onto the master model for a minimum of thirty minutes before investing. Each pattern was invested immediately after it was removed from the master model.

The investment material (Titavest CB Investment, J. Morita Man Corp, Japan) was mixed according to manufacturer’s directions, at the same temperature and humidity each time. The investment material was used at a powder:liquid ratio of 380g to 51ml of special liquid, per 6x round ring. Each invested pattern was allowed to bench set for 90 minutes before casting.

3.4 Casting of the wax frameworks

The invested ring was placed in a cool oven (room temperature) and raised to 830ºC in 2 hours 25 minutes. The ring was held at 830ºC for 1 hour 30 minutes, then allowed to cool completely to room temperature before casting.

The frameworks were then cast by induction casting under argon conditions, using pure grade 2 titanium.

The ring was allowed to bench cool before devesting. The castings were sandblasted to remove the remaining investment material, and great care was taken to avoid damaging the cylinder interface surface and the pins. Table 2 outlines the pattern, investment, burnout and casting protocol followed in this study.

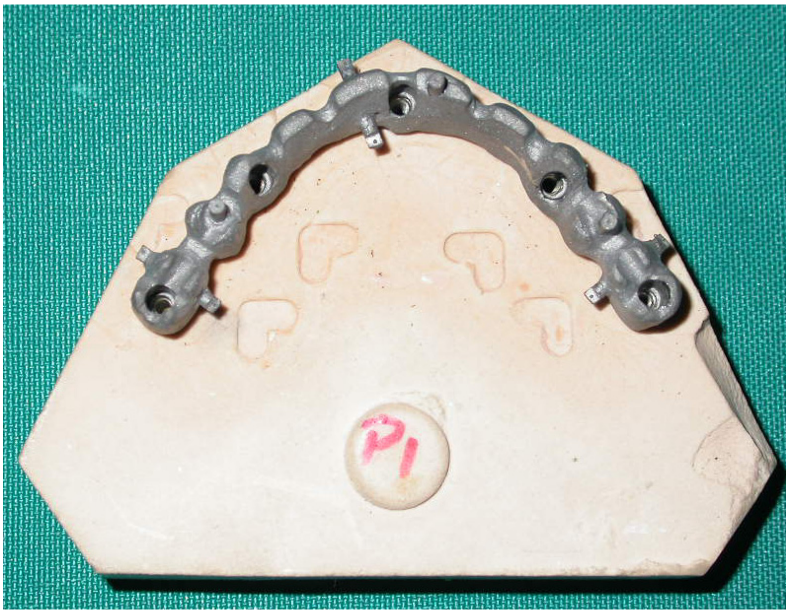
Table 2. Pattern, Investment, Burnout, and Casting Protocol

Pattern	
Material:	Green inlay casting wax hard (Maves inlay wax, Maves Co, Cleveland,OH)
Sprues:	10 sprues (2-3mm) attached at 10 locations, reservoir runner bar 5mm length, attached to 5mm feeder bar.
Investment	
Material:	Titavest CB Investment (J. Morita Man Corp, Japan) batch no: 9082872.
Quantity:	380g powder: 51ml special liquid (Titavest spinel/spinel secondy 50:50 mix).
Method:	Spatulation under vacuum for 40secs. Bench set for minimum 90 mins.
Burnout	
Oven:	1 ring placed in cool oven, temperature raised to 830ºC in 2hrs 25mins.
Time:	Constant at 830ºC for 1hr 30 mins, cooled completely to room temperature.
Casting	
Materials:	Ceramic crucible, Grade 2 titanium, Centrifugal casting under argon atmosphere
Devesting:	Bench cooled, devested and sandblasted with cylinder and pin protection.

3.5 Measuring the cast frameworks

The completed titanium frameworks were not sectioned and soldered, but were seated passively on the plaster model. A single brass screw was used to secure the framework to the model prior to measuring (Figure 6). Tightening of the screw was done by hand until first resistance was met. For each cast framework, measurements were taken of the same reference points as was done for the wax patterns, using the reflex microscope.

Figure 6. The cast framework seated on the master cast, without screw retention.



Measurements between reference points on the wax patterns and as-cast titanium frameworks were analysed statistically for significant differences with use of paired sample t-tests, and three-way analysis of variance (ANOVA).

4.0 RESULTS

The distances between the reference points were measured for each wax and cast specimen (Table 3).

The three-way ANOVA procedures were carried out in order to test the overall difference between the pooled wax and cast specimens, for both distance measurements and offsets (Appendix 1). The random effects (or ID) were each of the specimens; the fixed effects were the wax vs. cast frameworks (frame), and the d-type (distance measures A-F, F-H etc. or the offset measures), as per Table 1.

Table 3. Distances (in millimetres) measured for each wax and cast specimen.

	Outside horizontal			Inside horizontal			Vertical			Offsets from XYZ								
	A-F	F-H	A-H	B-E	E-I	B-I	C-D	D-G	C-G	A	B	C	D	E	F	G	H	I
Wax 1	26.688	35.357	50.321	21.16	24.545	36.804	24.696	21.19	37.298	-6.362	-6.394	-11.233	-13.508	-6.467	-5.03	-12.451	-7.367	-7.25
Wax 2	25.956	34.689	50.748	21.356	24.588	36.428	23.844	20.728	36.855	-6.959	-6.86	-12.024	-13.072	-6.048	-6.209	-12.182	-6.785	-6.692
Wax 3	27.323	33.867	50.738	22.169	24.811	36.872	23.09	20.565	37.906	-7.315	-7.212	-11.52	-12.892	-6.239	-6.395	-11.389	-5.794	-5.698
Wax 4	26.351	34.096	50.473	21.236	25.374	36.742	24.161	19.693	36.995	-6.976	-6.079	-12.48	-13.663	-6.535	-6.672	-11.701	-6.495	-6.364
Wax 5	27.603	35.088	51.421	20.608	25.585	37.177	23.878	19.414	37.112	-6.062	-6.178	-11.929	-13.424	-7.005	-6.391	-11.713	-6.742	-6.588
Cast 1	27.533	35.454	50.754	22.859	25.678	37.419	25.077	21.331	37.895	-6.28	-6.184	-10.863	-13.336	-5.739	-5.241	-11.914	-6.032	-5.9
Cast 2	27.39	36.115	51.141	21.174	25.015	36.935	24.29	21.424	37.633	-6.203	-5.622	-11.092	-12.407	-5.996	-5.5	-11.228	-6.032	-5.918
Cast 3	27.469	34.318	51.072	21.667	24.796	37.235	24.394	21.252	38.401	-6.614	-6.367	-11.181	-12.542	-5.329	-5.844	-11.489	-5.815	-5.871
Cast 4	26.586	34.3	50.755	21.644	25.644	37.145	24.563	19.888	37.326	-6.184	-5.794	-11.256	-13.336	-6.644	-6.586	-11.946	-6.742	-6.906
Cast 5	27.572	35.315	51.81	21.081	26.072	37.595	24.435	20.021	37.594	-5.888	-6.074	-11.597	-13.182	-6.53	-6.166	-11.27	-6.482	-6.473

For the distance measurements, the results showed that the ID (P=0.0446), frame (P<0.0001) and d-type (P<0.0001) were all statistically significant, indicating that the distance measurements between the wax and cast frameworks were significantly different. Overall, the wax models were 477μm smaller than the castings, indicating that expansion of the castings had occurred. For the offset measurements (from the reference plane), the ID ($P=0.0684$) was not significant, whereas the frame ($P<0.0001$) and d-type ($P<0.0001$) were statistically significant. Overall, the wax models were 416μm smaller than the castings in the offset from the reference plane.

In order to ascertain exactly where the expansion occurred, 18 paired t-tests (Appendix 2) were conducted separately for each of the nine distance measurements and each of the nine offset measurements, to test for differences in the average wax and cast measurements of each pair.

The results of the paired t-tests for the distance measures (Table 4) showed that expansion occurred between the wax and cast specimens, with significant differences at the terminal abutments *A-H* ($P=0.0001$) and *B-I* ($P=0.0003$). Significant differences were also found in the measurements for the vertical distances *C-D* ($P=0.0119$), *D-G* ($P=0.0096$) and *C-G* ($P=0.0019$). The results of the paired t-tests for the offset measures from the reference plane (Table 5) indicated that significant changes occurred at points *A* ($P=0.0155$), *B* ($P=0.0345$), *C* ($P=0.013$), and *D* ($P=0.0071$).

Table 4. Results of paired t-tests for distance measures (in millimetres) (* = significant)

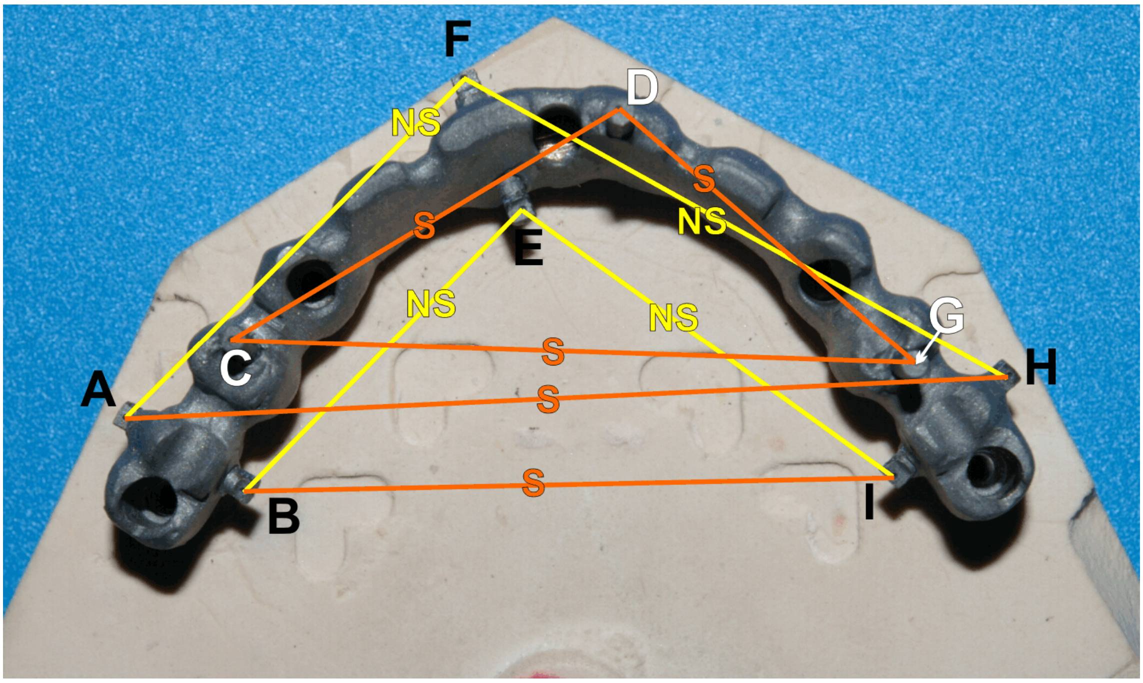
ID	A-F	F-H	A-H	B-E	E-I	B-I	C-D	D-G	C-G
Cast-Wax 1	0.845	0.097	0.433	1.699	1.133	0.615	0.381	0.381	0.597
Cast-Wax 2	1.434	1.426	0.393	-0.182	0.427	0.507	0.446	0.446	0.778
Cast-Wax 3	0.146	0.451	0.334	-0.502	-0.015	0.363	1.304	1.304	0.495
Cast-Wax 4	0.235	0.204	0.282	0.408	0.27	0.403	0.402	0.402	0.331
Cast-Wax 5	-0.031	0.227	0.389	0.473	0.487	0.418	0.557	0.557	0.482
Mean	0.5258	0.4810	0.3662	0.3792	0.4604	0.4612	0.6180	0.4651	0.5366
SD	0.6053	0.5474	0.0580	0.8431	0.4232	0.1008	0.3894	0.2741	0.1650
p-value	0.0620	0.0595	0.0001*	0.1857	0.0359*	0.0003*	0.0119*	0.0096*	0.0009*

Table 5. Results of paired t-tests for offsets from the reference plane (in millimetres) (* = significant)

ID	A	B	C	D	E	F	G	H	I
Cast-Wax 1	0.082	0.21	0.37	0.172	0.728	-0.211	0.537	1.335	1.35
Cast-Wax 2	0.756	1.238	0.932	0.665	0.052	0.709	0.954	0.753	0.774
Cast-Wax 3	0.701	0.845	0.339	0.35	0.91	0.551	-0.1	-0.021	-0.173
Cast-Wax 4	0.792	0.285	1.224	0.327	-0.109	0.086	-0.245	-0.247	-0.542
Cast-Wax 5	0.174	0.104	0.332	0.242	0.475	0.225	0.443	0.26	0.115
Mean	0.5009	0.5364	0.6394	0.3511	0.4112	0.272	0.3178	0.416	0.3047
SD	0.3435	0.4858	0.4137	0.1891	0.4338	0.3670	0.4898	0.6350	0.7572
p-value	0.0155*	0.0345*	0.013*	0.0071*	0.0507	0.0864	0.1102	0.1084	0.2095

Figure 7 illustrates the significant distortions between the wax and cast frameworks.

Figure 7. Graphic illustration of the distortions between wax and cast frameworks. S = statistically significant differences. NS = not statistically significant.



5.0 DISCUSSION

Titanium is the most widely accepted metal used in implantology, and it currently seems to be the most appropriate, mainly in view of its biocompatibility and resistance to corrosion. Although titanium frameworks have been manufactured via casting procedures, a series of laboratory limitations restricted their applications (Hruska and Borelli, 1991). Clinical observation and extensive research have shown that cast prostheses show large variations in accuracy of fit when returned introrally (Morey, 1991).

Distortion during casting has been related to variables such as wax pattern distortion and burnout protocol, investment-setting expansion, hygroscopic and thermal expansion, type of investment, powder/special liquid/water ratio, spatulation technique, ring size and confining effects of the casting ring, type of material involved in framework construction, casting shrinkage of alloy, and length of castings. The heat cycle used and the effects of the sprue design and reservoirs may also provide a significant contribution to the distortion pattern observed (Phillips and Biggs, 1950; Schwartz, 1986; Tan et al, 1993; Morey, 1991a; 1992a; Zervas et al, 1999).

Solving such problems has required modifications and improvements in casting equipment, materials and techniques. Techniques such as casting in separate units, or vertical sectioning of cast frameworks followed by indexing on the master cast or in the mouth have been described (Hellden and Derand, 1998; Zervas et al, 1999). In addition, laser welding techniques have also been recommended for improving the fit of cast titanium frameworks (Hellden and Derand, 1998; Jemt et al, 2003).

All such modifications and innovations in the fabrication of implant superstructures have been made with the ultimate aim of achieving passive fit. The term passive fit characterises the connection between the cast framework and the abutment or implant, and has been defined as the "circumferential and simultaneous contact of all the abutments on their respective implants, and of all the gold cylinders of the prosthesis on their respective abutments" (Iglesia and Moreno, 2001). Whilst translational distortions definitely occur (Tan et al, 1993; Jemt and Lie, 1995), the magnitude of displacement that separates a "passive" or acceptable fit from an "inadequate" fit remains to be defined.

Clinical evaluation of fit has been subjective and has been described in terms of visual and tactile methods (Kan et al, 1999), both extraorally on the master cast, and intraorally. The earlier literature lacked a clear definition of an acceptable level of clinical fit. The criterion proposed by Klineberg and Murray (1985) allowed for an error of no greater than 30 μm over 10% of the abutment-cylinder interface. This, however, was set arbitrarily, and there was no description of the exact method of evaluation. Jemt (1991) proposed that a maximum of half a screw turn, which corresponds to a vertical misfit gap of approximately 150 μm, would be clinically acceptable.

The possibility of inaccuracies in fit that cannot be detected visually, or are impossible to verify clinically has been recognised. Jemt and co-workers (1991) found loads of 80N and 15N-cm bending moments with seemingly accurately fitting fixed prostheses.

Whilst the degree of inaccuracy in the fit of multi-unit conventional prostheses has not been apparent because of the inherent mobility of the periodontal ligament, which can accommodate this distortion (Tan et al, 1993), implant-supported prostheses do not have the adaptive movement potential of natural abutment teeth, and thus the accuracy of fit of the screw-retained implant prosthesis remains a cause for concern.

Prosthetic complications related to component failure or fracture, including gold screw and abutment screw failures, gold cylinder fractures, framework fractures, implant fractures and possible delayed loss of integration between bone and implant have been reported in several long-term studies (Zarb and Schmitt, 1990a). Distortion inherent in implant prostheses has been implicated as a possible cause of these delayed component failures (Tan et al, 1993). The prosthesis may appear to fit when tightened onto the intraoral abutments, but this screw tightening may hide the existence of a prestress within the components and framework.

The biomechanical impact of fit between implants and superstructures is complex. Physiologic bone remodelling may provide a mechanism that helps reduce the stress on implants and bone from distorted implant prostheses (Tan et al, 1993). However, it is still not known how long it would take for this bone remodelling to reduce the stress. Thus it is advisable not to rely upon bone physiological mechanisms to compensate for ill-fitting implant prostheses, as the prestress still exists, and contributes to a lower fatigue life for the prosthesis and its components.

Measurements of *x*, *y*, and z translational displacements indicated that an overall expansion of the castings occurred. A statistically significant difference was detected in the amount of horizontal distortion at the terminal implant abutments *A-H* and *B-I*, and in the vertical dimension at points *C-G*. With the master cast used as a reference, the average distortions for points *A-H* were 0.3662mm, for *B-I,* 0.4612mm and for *C-G,* 0.5366mm. In general, the castings were oversized in comparison to the wax specimens. This is in contrast to Tan et al's study (1993) in which shrinkage of the (silver- palladium alloy) castings occurred. This variability can probably be attributed more to the distortion inherent in the casting procedure than the differences in the distortion related to the alloys used. Furthermore, by measuring points away from the cylinders, this study has clarified the three dimensional nature of the casting distortion.

Although the sample size in this in-vitro study was limited due to financial constraints, every effort was made to standardise the procedures involved in the casting process. Despite this, distortions between wax and cast specimens were consistently well above the 150µm limit proposed by Jemt (1991). The ultimate production of a passively fitting prosthesis is the culmination of several clinical and laboratory steps, each with its own potential for contributing to the overall distortion. Thus, it can be concluded from the results of this study that it will probably not be possible to produce passively fitting full-arch titanium castings in the clinical situation, and that alternative approaches to framework fabrication such as casting in sections, or post-ceramic sectioning and re-soldering of all titanium frameworks should take place routinely. Two-piece substructure and superstructure castings have been suggested as being easier to cast accurately due to decreased bulk of metal, compared to one-piece castings (Tan et al, 1993).

In addition to the small sample size and distortions inherent in the casting process, another limitation of this study was that a single screw was used to secure the frameworks to the model. The one-screw test is commonly recommended for assessment of clinical fit (Jemt, 1991), and appears to be very sensitive for certain types of distortion, such as rotational displacements that lift opposing cylinders (Tan et al, 1993). This method of securing the framework to the model could explain the multidimensional pattern of distortion noticed in this study, particularly the distortion occurring at the terminal abutments. Furthermore, the one-screw test has been criticised as not being able to detect horizontal distortions between framework and cylinders (Tan et al, 1993). Thus the evidence produced by this three-dimensional distortion analysis cautions against absolute reliance on the one-screw test.

6.0 CONCLUSION AND RECOMMENDATIONS

Under the conditions of this study, the results of the investigation show that as-cast titanium frameworks are inaccurate and imprecise when judged against the 150µm requirement for passivity of fit proposed by Jemt (1991). These distortions are three-dimensional and can be attributed to factors inherent in the casting process.

Although many of the difficulties of casting implant frameworks have been resolved, the technique of casting titanium frameworks still requires much research and improvement. Based on the results of this study, it is therefore recommended that all full-arch, cast titanium frameworks be cast in sections routinely, or after casting are routinely sectioned, indexed and soldered before being seated intraorally.

7.0 APPENDICES

7.1 APPENDIX 1

. anova distance id frame d_type, partial regress anova (DISTANCES)

Number of obs = 90

Source	SS	df	MS
Model	7856.23861	13	604.326047
Residual	18.9706159	76	.249613367
Total	7875.20922	89	88.4854969

F(13, 76)	=	2421.05
Prob > F	=	0.0000
R-squared	**=**	**0.9976**
Adj R-squared	=	0.9972
Root MSE	=	.49961

The table above gives the overall goodness of fit of three way anova. The F value =2421.05 with a corresponding p-value<0.0001, shows that the three way anova overall is a good fit. The R-squared (bold) value tells us that the variables id (1-5), frame (wax-cast) and d_type (AF to CG) combined account for 99.76% of the variability in the measured readings and the remaining 0.24% are explained by other factors which shows that these three variables are very good predictors of the measured outcome.

Number of obs = 90 R-squared = 0.9976
Root MSE = .499613 Adj R-squared = 0.9972

Source	Partial SS	df	MS	F	Prob > F
Model	7856.23861	13	604.326047	2421.05	0.0000
id	2.56499944	4	.641249861	2.57	0.0446
frame	5.1208338	1	5.1208338	20.52	0.0000
d_type	7848.55277	8	981.069097	3930.35	0.0000
Residual	18.9706159	76	.249613367		
Total	7875.20922	89	88.4854969		

The above ANOVA output shows further detail on the variables of interest. In the first table, we mentioned that the overall model was significant, whereas now we look at each individually. The results here show that id (p=0.0446) frame (p<0.0001) and d-type (p<0.0001) are all statistically significant. **However the question still remains exactly where are they different?** The regression model then addresses that :
Considering the variable id, they were all the same except the 4^{th} and 5^{th}, since all have been compared to the fifth (that is why it was dropped).

distance	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
_cons	37.83158	.1970501	191.99	0.000	37.43912	38.22404
id						
1	.1487774	.1665377	0.89	0.374	-.1829112	.4804661
2	-.1706667	.1665377	-1.02	0.309	-.5023553	.161022
3	-.0797778	.1665377	-0.48	0.633	-.4114665	.2519108
4	-.3560557	.1665377	-2.14	0.036	-.6877443	-.024367
5	(dropped)					
frame						
1	**-.4770667**	.1053277	-4.53	0.000	-.686845	-.2672884
2	(dropped)					
d_type						
1	-10.4544	.2234338	-46.79	0.000	-10.89941	-10.00939
2	-2.6416	.2234338	-11.82	0.000	-3.086607	-2.196593
3	13.4218	.2234338	60.07	0.000	12.97679	13.86681
4	-16.0061	.2234338	-71.64	0.000	-16.45111	-15.56109
5	-12.2907	.2234338	-55.01	0.000	-12.73571	-11.84569
6	-.4662994	.2234338	-2.09	0.040	-.9113065	-.0212924
7	-13.2587	.2234338	-59.34	0.000	-13.70371	-12.81369
8	-16.9509	.2234338	-75.87	0.000	-17.39591	-16.50589
9	(dropped)					

With regards to the wax and cast frameworks, we find that there were significant differences in the two and also that overall wax was **0.477** smaller than cast and this difference was statistically significant (p<0.0001)

. anova distance id frame d_type, partial regress anova (xyz PLANE)

Source	SS	df	MS
Model	701.151002	13	53.9346925
Residual	13.389649	76	.176179591
Total	714.540651	89	8.02854664

Number of obs =	90
F(13, 76) =	306.13
Prob > F =	0.0000
R-squared =	**0.9813**
Adj R-squared =	0.9781
Root MSE =	.41974

The table above gives the overall goodness of fit of three way anova , the F value =306.13 with a corresponding p-value<0.0001 shows that the three way anova overall is a good fit. The R-squared (bold) value tells us that the variables id (1-5), frame (wax-cast) and d_type (A to I) combined account for 97.83% of the variability in the measured readings and the remaining 2.17% are explained by other- which shows that these three are very good predictors of the measured outcome.

```
Number of obs =      90     R-squared     =  0.9813
                           Root MSE      = .419738     Adj R-squared =  0.9781

                 Source |  Partial SS    df       MS           F     Prob > F
             -----------+----------------------------------------------------
                  Model |  701.151002    13  53.9346925     306.13     0.0000
                        |
                     id |   1.6061916     4  .401547899       2.28     0.0684
                  frame |  3.90583298     1  3.90583298      22.17     0.0000
                 d_type |  695.638977     8  86.9548722     493.56     0.0000
                        |
               Residual |   13.389649    76  .176179591
             -----------+----------------------------------------------------
                  Total |  714.540651    89  8.02854664
```

The above ANOVA output shows further detail on the variables of interest. In the first table we mentioned that the overall model was significant, now we look at each individually. The results here show that id (p=0.0684)was not significant, frame (p<0.0001) and d-type (p<0.0001) were statistically significant. **However the question still remains exactly where are they different?**. The regression model then addresses that:

Considering the variable id, they were all the same and they were compared to the fifth (that is why it was dropped).

```
------------------------------------------------------------------------------
    distance        Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
------------------------------------------------------------------------------
_cons           -6.230244   .1655467   -37.63   0.000    -6.559959    -5.90053
id
           1     .1190555   .1399125     0.85   0.397    -.1596044    .3977154
           2     .1591667   .1399125     1.14   0.259    -.1194932    .4378266
           3     .2326667   .1399125     1.66   0.100    -.0459932    .5113266
           4    -.1480555   .1399125    -1.06   0.293    -.4267154    .1306044
           5    (dropped)
frame
           1    -.4166444   .0884884    -4.71   0.000    -.5928844   -.2404044
           2    (dropped)


d_type
           1       -.1183   .1877123    -0.63   0.530    -.4921615    .2555615
           2     .0895999   .1877123     0.48   0.634    -.2842616    .4634614
           3      -5.1515   .1877123   -27.44   0.000    -5.525361   -4.777638
           4      -6.7702   .1877123   -36.07   0.000    -7.144062   -6.396339
           5        .1128   .1877123     0.60   0.550    -.2610615    .4866615
           6        .3626   .1877123     1.93   0.057    -.0112615    .7364615
           7      -5.3623   .1877123   -28.57   0.000    -5.736162   -4.988439
           8       -.0626   .1877123    -0.33   0.740    -.4364615    .3112615
           9    (dropped)
------------------------------------------------------------------------------
```

With regards to the wax and cast frameworks we find that there were significant differences in the two and also that overall wax was **0.4166** smaller than cast and this difference was statistically significant (p<0.0001)

7.2 APPENDIX 2

```
ttest af2== af1

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
     af2 |       5       27.31    .1836069    .4105575    26.80023    27.81977
     af1 |       5     26.7842    .3036094    .6788912    25.94125    27.62715
---------+--------------------------------------------------------------------
    diff |       5    .5258003    .2706987    .6053006   -.2257797     1.27738
------------------------------------------------------------------------------
     mean(diff) = mean(af2 - af1)                                 t =   1.9424
 Ho: mean(diff) = 0                              degrees of freedom =        4

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9380         Pr(|T| > |t|) = 0.1240          Pr(T > t) = 0.0620

. ttest fh2==fh1

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
     fh2 |       5     35.1004     .350235    .7831492    34.12799    36.07281
     fh1 |       5     34.6194     .283596      .63414    33.83201    35.40679
---------+--------------------------------------------------------------------
    diff |       5    .4809998      .24317    .5437446   -.1941483    1.156148
------------------------------------------------------------------------------
     mean(diff) = mean(fh2 - fh1)                                 t =   1.9780
 Ho: mean(diff) = 0                              degrees of freedom =        4

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9405         Pr(|T| > |t|) = 0.1191          Pr(T > t) = 0.0595

. ttest ah2==ah1

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
     ah2 |       5     51.1064    .1930157    .4315962     50.5705     51.6423
     ah1 |       5     50.7402    .1885049    .4215097    50.21683    51.26357
---------+--------------------------------------------------------------------
    diff |       5    .3662003    .0262933    .0587937    .2931983    .4392022
------------------------------------------------------------------------------
     mean(diff) = mean(ah2 - ah1)                                 t =  13.9275
 Ho: mean(diff) = 0                              degrees of freedom =        4

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9999         Pr(|T| > |t|) = 0.0002          Pr(T > t) = 0.0001
```

```
. ttest be2==be1

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
     be2 |       5      21.685    .3167189     .708205    20.80565    22.56435
     be1 |       5     21.3058    .2510668    .5614023    20.60873    22.00287
---------+--------------------------------------------------------------------
    diff |       5    .3791992    .3770252    .8430539   -.6675905    1.425989
------------------------------------------------------------------------------
     mean(diff) = mean(be2 - be1)                                t =   1.0058
 Ho: mean(diff) = 0                              degrees of freedom =        4

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.8143         Pr(|T| > |t|) = 0.3714          Pr(T > t) = 0.1857

. ttest ei2==ei1

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
     ei2 |       5      25.441    .2337778     .522743    24.79193    26.09007
     ei1 |       5     24.9806     .211271    .4724163    24.39402    25.56718
---------+--------------------------------------------------------------------
    diff |       5    .4603996    .1892713    .4232234   -.0651017    .9859009
------------------------------------------------------------------------------
     mean(diff) = mean(ei2 - ei1)                                t =   2.4325
 Ho: mean(diff) = 0                              degrees of freedom =        4

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9641         Pr(|T| > |t|) = 0.0718          Pr(T > t) = 0.0359

. ttest bi2==bi1

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
     bi2 |       5     37.2658    .1133164    .2533832    36.95118    37.58042
     bi1 |       5     36.8046    .1202017    .2687791    36.47087    37.13833
---------+--------------------------------------------------------------------
    diff |       5       .4612    .0450822    .1008069    .3360317    .5863682
------------------------------------------------------------------------------
     mean(diff) = mean(bi2 - bi1)                                t =  10.2302
 Ho: mean(diff) = 0                              degrees of freedom =        4

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9997         Pr(|T| > |t|) = 0.0005          Pr(T > t) = 0.0003
```

```
. ttest cd2==cd1

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
     cd2 |       5     24.5518    .1383912    .3094521    24.16756    24.93604
     cd1 |       5     23.9338    .2603596    .5821819    23.21093    24.65667
---------+--------------------------------------------------------------------
    diff |       5        .618    .1741729    .3894624    .1344186    1.101581
------------------------------------------------------------------------------
     mean(diff) = mean(cd2 - cd1)                                 t =   3.5482
 Ho: mean(diff) = 0                              degrees of freedom =        4

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9881         Pr(|T| > |t|) = 0.0238          Pr(T > t) = 0.0119

. ttest dg2==dg1

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
     dg2 |       5     20.7832    .3400598    .7603969    19.83904    21.72736
     dg1 |       5      20.318    .3314616    .7411706    19.39772    21.23829
---------+--------------------------------------------------------------------
    diff |       5    .4651997    .1226143     .274174    .1247677    .8056317
------------------------------------------------------------------------------
     mean(diff) = mean(dg2 - dg1)                                 t =   3.7940
 Ho: mean(diff) = 0                              degrees of freedom =        4

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9904         Pr(|T| > |t|) = 0.0192          Pr(T > t) = 0.0096

. ttest cg2==cg1

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
     cg2 |       5     37.7698    .1817509    .4064073    37.26518    38.27442
     cg1 |       5     37.2332    .1832105     .409671    36.72453    37.74187
---------+--------------------------------------------------------------------
    diff |       5    .5366013    .0737917    .1650031    .3317228    .7414797
------------------------------------------------------------------------------
     mean(diff) = mean(cg2 - cg1)                                 t =   7.2718
 Ho: mean(diff) = 0                              degrees of freedom =        4

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9991         Pr(|T| > |t|) = 0.0019          Pr(T > t) = 0.0009

. log close
      log:  C:\Program Files\Stata9\diffteeth.log
  log type:  text
 closed on:   4 Sep 2006, 20:07:07
-------------------------------------------------------------------------------
```

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