Recording the Path of Insertion of Removable Partial Dentures: A Comparison of Six Methods

Dimitri Perdikis

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RECORDING THE PATH OF INSERTION OF REMOVABLE PARTIAL DENTURES
A COMPARISON OF SIX METHODS

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D.D.S., Aristotle University of Thessaloniki, Greece 1993
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RECORDING THE PATH OF INSERTION OF REMOVABLE PARTIAL DENTURES
A COMPARISON OF SIX METHODS

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# TABLE OF CONTENTS

I. Introduction ........................................................................................................... 1

II. Objectives ............................................................................................................. 3

1. Specific Objectives ............................................................................................. 3

2. Hypothesis ............................................................................................................ 4

III. Literature Review ............................................................................................... 5

1. Overview .............................................................................................................. 5

2. Transferability of the Record of the Path of Insertion ........................................ 8

3. Literature Review of Recording Method Proposals ............................................ 11

4. Literature Review of Recording Method Tests .................................................... 17

IV. Materials and Methods ....................................................................................... 20

1. Description of Six Recording Methods ............................................................... 20

2. Armamentarium .................................................................................................. 23

2.1. Working Cast, Tilt Table, Judging Station ....................................................... 23

3. Procedure ............................................................................................................. 26

3.1. Preparation of Testing Procedures .................................................................. 26

3.2. Procedure by Evaluators ................................................................................ 27

3.3. Utilizing the Recordings ................................................................................... 28

V. Results .................................................................................................................. 31

1. General ................................................................................................................ 31

2. Preferences .......................................................................................................... 32

3. Statistical Analysis ............................................................................................... 33

3.2. Discussion of Analysis ..................................................................................... 45
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI. Discussion</td>
<td>47</td>
</tr>
<tr>
<td>VII. Discussion of Surveying Practices</td>
<td>54</td>
</tr>
<tr>
<td>VIII. Discussion of RPD Usage</td>
<td>58</td>
</tr>
<tr>
<td>IX. Current RPD Design and Future Research</td>
<td>62</td>
</tr>
<tr>
<td>X. Conclusions</td>
<td>64</td>
</tr>
<tr>
<td>XI. Bibliography</td>
<td>65</td>
</tr>
<tr>
<td>XII. Appendices</td>
<td></td>
</tr>
<tr>
<td>Appendix A Pictures</td>
<td>71</td>
</tr>
<tr>
<td>Appendix B Distribution of Data</td>
<td>79</td>
</tr>
<tr>
<td>Appendix C Conclusions of Krusker-Wallis</td>
<td>81</td>
</tr>
</tbody>
</table>
### LIST OF TABLES

<table>
<thead>
<tr>
<th>Tables</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Steps in Removable Partial Denture Fabrication</td>
<td>5</td>
</tr>
<tr>
<td>2. Ease of Use by Method</td>
<td>32</td>
</tr>
<tr>
<td>3. Suspected Accuracy by Method</td>
<td>32</td>
</tr>
<tr>
<td>4. Summary Statistics of Error in Degrees</td>
<td>33</td>
</tr>
<tr>
<td>5. Summary Statistics of Time by Method Used</td>
<td>33</td>
</tr>
<tr>
<td>6. Summary Statistics of Error in Degrees by Operator</td>
<td>36</td>
</tr>
<tr>
<td>7. Summary Statistic of Time in Seconds by Operator</td>
<td>36</td>
</tr>
<tr>
<td>8. Summary Statistics of Logarithm of Error in Degrees by Method</td>
<td>37</td>
</tr>
<tr>
<td>10. Summary Statistics of Logarithm of Error in Degrees by Operator</td>
<td>37</td>
</tr>
<tr>
<td>11. Summary Statistics of Logarithm of Time by Operator</td>
<td>37</td>
</tr>
<tr>
<td>12. Results of Post Hoc Tests for Log Degrees Error</td>
<td>42</td>
</tr>
<tr>
<td>13. Results of Post Hoc Tests for Log Time Seconds</td>
<td>44</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

1. Box Plot of Error in Degrees by Method Used.................................34
2. Box Plot of Time by Method Used..................................................34
3. Box Plot of Error in Degrees by Operator.......................................35
4. Box plot of Time in Seconds by Operator........................................35
5. Box Plot of Error of Logarithm of Error in Degrees by Method Used......38
6. Box Plot of Logarithm of Time by Method Used...............................38
7. Box plot of Logarithm of Error in Degrees by Operator......................39
8. Box Plot of Logarithm of Time by Operator.....................................39
9. Box Plot of Mean Degree Error by Operator by Method Used...............40
10. Box Plot of Mean Time by Operator by Method..................................40
11. Distribution of Variable of Error in Degrees...................................80
12. Distribution of Logarithm of Error in Degrees..................................80
13. Distribution of Variable Time in Seconds.......................................81
14. Distribution of Logarithm of Time in Seconds..................................81
LIST OF PICTURES

1. New method proposals for recording the path of insertion...............................71
2. Dental cast with embedded receptacle for pointer..............................................71
3. Measurement station with target disk lowered onto pointer.................................72
4. Close view of target disk on pointer.....................................................................72
5. Method 1. Circular level gauge with base...............................................................73
6. Method 1. Circular level gauge positioned on cast...............................................73
7. Method 2. Circular level gauge without base..........................................................74
8. Method 2. Circular level gauge positioned on cast...............................................74
9. Method 2. Underside view of index.......................................................................75
10. Method 3. Indexed base with embedded alignment pin........................................75
11. Method 3. Placement on cast.................................................................................76
12. Method 3. Positioned on cast.................................................................................76
13. Method 4. Tripod Marks.......................................................................................77
14. Method 4 and Method 5. Vertical lines and Vertical grooves...............................77
15. Method 5. Alignment procedure............................................................................78
16. Method 6. Alignment ............................................................................................78
I. INTRODUCTION

Removable partial dentures continue to be prescribed with great frequency by dentists to replace missing teeth. One of the advantages of removable partial dentures (RPDs) is their relatively low cost compared to the alternative treatments with fixed partial dentures or implant restorations. Approximately 8% of the United States adult population wears an RPD, and usage rises to 20% in the over 55 age group. It is therefore distressing that over half of all RPDs have problems, with lack of stability being cited as the most commonly encountered problem during the prosthodontic evaluation component of the National Health and Nutrition Examination Survey (M. Redford).

The importance of surveying a cast of the dental arch for RPD fabrication has been emphasized repeatedly in the prosthodontic literature and in all dental schools. Areas of interference and retention are identified by surveying, and the preferred path of insertion is then selected. The teeth are marked at their height of contour on the surveyor and the path of insertion is then recorded directly on the cast. This recording allows the dental lab to reorient the cast to the previously selected path of insertion. Despite great emphasis on actual surveying, recording the path of insertion and reorientation is only briefly described in dental school curricula. Since frameworks returning from the dental lab, occasionally do not fit the patients' dental arch, we need to examine which steps in the numerous stages of partial denture framework fabrication might be responsible for the problems. If surveying had been done correctly and a desirable path of insertion was originally selected, there is a possibility that the cast was not reoriented to the proper path of insertion at a later stage in framework fabrication. The method used for recording the path of insertion may play a role in the accuracy of the reorientation.
An ideal method should be simple and allow accurate reorientation so that all subsequent steps can be done at the selected path of insertion. The procedures of identifying clasp tip termination points, wax block-out of undesirable undercuts and location of inflexible components above the heights of contour, can be affected if the cast is reoriented improperly. Errors at these steps will frequently lead to an inaccurately fitting framework.

Beyond providing for accurate reorientation, a recording method for the path of insertion could also be more versatile by allowing the reorientation of duplicate casts to the same path of insertion. Recording the path of insertion directly on the cast allows the reorientation of that cast, but not of any other cast. During the framework wax-up on the refractory cast, if clasp ledging was not adequately performed and there is a need to confirm clasp arm placement, it is necessary to have a transferable recording of the path of insertion that can be used to reorient the refractory cast. If more than one definitive cast is used for the fabrication of multiple surveyed restorations, it again becomes necessary to have a transferable recording of the path of insertion. Such a record can be used to reorient multiple similar casts to the same path of insertion and can provide a permanent record if one is needed.

A transferable path of insertion record consisting of an indexed tray with an embedded alignment pin repositioned by the vertical arm of the surveyor and two types of a transferable path of insertion record with a circular air bubble gauge will be compared with the current methods of recording the path of insertion: the tripod method, the vertical line method and the vertical groove method for accuracy of reorientation, time elapsed for reorientation and practitioner preference.
II. OBJECTIVES

II. 1. SPECIFIC OBJECTIVES

The first objective of this study is to assess the accuracy of operator reorientation of a dental cast using each of six methods of recording the path of insertion. The operators are dental school undergraduates, residents, faculty members and laboratory technicians.

The second objective is to evaluate time required for each method to complete the reorientation. The third objective is to evaluate operator preference for each method.

The final objective is to critically examine the investigation and determine if further research is needed or if a change in current dental procedure is indicated.

The methods are:

1. Circular level gauge with acrylic base and silicone occlusal index.
2. Circular level gauge with silicone occlusal index but without an acrylic base.
3. Acrylic tray with an embedded alignment mandrel and a silicone occlusal index
4. Tripod method
5. Vertical Lines method
6. Vertical Grooves method
II. 2. HYPOTHESIS

There is no difference between the accuracy of reorientation of a transferable record of the path of insertion utilizing a circular level gauge with an indexed acrylic base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is no difference between the accuracy of reorientation of a transferable record of the path of insertion utilizing a circular level gauge with a silicone index without a base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is no difference between the accuracy of reorientation of a transferable record of the path of insertion utilizing an embedded alignment mandrel into an indexed acrylic tray versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is no difference between the time of reorientation of a transferable record of the path of insertion utilizing a circular level gauge with an indexed acrylic base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is no difference between the time of reorientation of a transferable record of the path of insertion utilizing a circular level gauge with a silicone index without a base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is no difference between the time of reorientation of a transferable record of the path of insertion utilizing an embedded alignment mandrel into an indexed acrylic base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is no difference in evaluator preference for ease of use for method used to reorient a cast on a tilt table.
III. LITERATURE REVIEW

III. 1. OVERVIEW

A removable partial denture is a prosthesis that replaces one or more but not all missing natural teeth and associated oral structures and can be removed by the patient. The steps involved in removable partial denture fabrication are listed in table 1.

<table>
<thead>
<tr>
<th>Table 1. Steps in RPD fabrication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examination of patient, oral structures</td>
</tr>
<tr>
<td>Articulated diagnostic casts, preliminary survey and design</td>
</tr>
<tr>
<td>Preprosthetic treatment</td>
</tr>
<tr>
<td>Mouth preparations</td>
</tr>
<tr>
<td>Impressions, Interocclusal registration</td>
</tr>
<tr>
<td>Survey and final design</td>
</tr>
<tr>
<td>Framework fabrication and finishing</td>
</tr>
<tr>
<td>Framework try-in, altered cast, Interocclusal registration</td>
</tr>
<tr>
<td>Wax set-up</td>
</tr>
<tr>
<td>Wax try-in</td>
</tr>
<tr>
<td>Acrylic Resin Processing and finishing</td>
</tr>
<tr>
<td>Insertion</td>
</tr>
</tbody>
</table>

In RPD fabrication, the design of the framework and the selection of a path of insertion are interdependent. Together these two processes are factors of the proper function of the subsequently fabricated RPD, whereby proper function includes properties of stability, retention, support, esthetics, ease of hygiene maintenance and preservation of remaining oral structures.
O. Applegate had stated that “no step in the construction of a clasp retained partial denture has more direct bearing upon the ultimate result than that of surveying the model of the dental arch for which the appliance is to be made”.

The usual procedures included with surveying are: marking the height of contour on all abutment teeth, recording the path of insertion directly on the surveyed cast and writing the work authorization. The definitive cast is then sent to the dental laboratory. The laboratory technician should reorient the cast to the originally selected path of insertion based on the information supplied (most commonly tripod marks). The technician then proceeds to identify areas of interference, block out undercuts, form a clasp ledge and locate positions for clasp arm placement. If the cast was not reoriented properly then all the previous lab steps may not effectively contribute to a well fitting framework. This could be the start of an inadequate framework. The failure to properly position the cast may be due to the way the path of insertion was recorded or to lack of accuracy in the reorientation procedure. The magnitudes of problems emanating from the inadvertent change in cast tilt are dependent on the shape of the teeth.

In 1996, S. Lechner reexamined common survey lines of teeth as originally described by L. Blatterfine in the early 50's, for the purpose of recommending clasp designs. In his article Lechner identifies that survey lines drawn on teeth by different practitioners after each performed their own surveying, diverge greatest when the slope of the undercut is small. That is to say the position of the height of contour is more sensitive to small changes in cast tilt at teeth with relatively flat surfaces where the undercut is less than .25mm. For such teeth the variation in height of contour position was found to be 1mm or greater.
For steeper undercuts, the survey line will be less likely affected by changes in the path of insertion. Small changes in cast tilt would only affect certain areas of a cast.

The significance of these findings is greater for the rigid components than for the flexible clasp tips. Locating rigid components on non-undercut surfaces is more critical for teeth with minimal slope and depends on accurate surveying and reorientation. If a rigid component is planed on a surface with minimal slope above the height of contour but inadvertently the path of insertion is changed, then that component would be waxed and built into an undercut. This would guarantee a misfitting framework.

Our investigation evaluates the accuracy of reorientation for the common methods of recording the path of insertion: tripod marks and vertical lines and vertical grooves and further compares the former methods to the accuracy of three newly presented methods of recording the path of insertion. The new methods use a level gauge or an alignment pin to facilitate reorientation and have the added advantage of being transferable between duplicate casts.

If the new methods are found to be accurate then we may be able to use them when accurate reorientation or transferability is desired.
III. 2. TRANSFERABILITY OF THE RECORD OF THE PATH OF INSERTION

Tripod markings or vertical lines are not transferable since they are marked directly on the definitive cast. If the recording of the path of insertion was transferable then it could be used to orient two duplicate casts or the refractory cast to the same path of insertion.

A brief review of routine partial denture procedures is necessary to further assess the need for a transferable record of the path of insertion.

Removable partial denture casts are surveyed by the dentist, who will identify the retentive undercuts, decide on the final design and then should tripod the cast. The laboratory technician will reorient to the tripod marks, re-identify the retentive undercuts, block-out undesirable undercuts, wax clasp ledges, duplicate the cast in refractory investment stone and wax-up the framework. If the technician’s reorientation was not accurate, then the clasps may be placed in lesser or greater undercuts. For lab prescriptions, beyond tripoding it is recommended to specifically state the depth of undercut for each clasp. The technician must then not only reorient to the tripod marks, but also confirm that the desired undercut is present at that path of insertion. Following the clasp ledges, the wax-up of the framework should be straight forward on the refractory cast. Only in instances of poor block-out or inadequate clasp ledging is it unclear how the clasp arms should be waxed. For these cases resurveying the refractory cast is possible but difficult since it has already been partially blocked out. If a transferable recording of the path if insertion was available it could certainly be useful to reorient the refractory cast and identify height of contour and clasp arm placement.
Another example for needed transferability occurs with survey crowns that will serve as abutments for an RPD. In these cases the final result may be improved and certainly time and effort spent for repeated surveying would be conserved, if the selected path of insertion remains the same during the crown fabrication and during the RPD framework construction. This would be possible if a transferable recording of the path of insertion was utilized from the beginning.

A situation can occur when the tooth preparations of multiple survey crowns are not successfully impressed by a single impression. In such a situation there are multiple master casts that need to be oriented to the same path of insertion. This would only be possible if there is a transferable record of the path of insertion and if orientation of the casts can be done accurately. The currently used methods of recording path of insertion, tripod markings or vertical lines are not transferable and would not allow this.

J. Ivanhoe and G. Mahanna in 1994 presented a cast orientation index that is transferable. They described an acrylic tray lined with silicon to index the occlusal stops and with an embedded pin for orientation to the path of insertion. They noted that the dies of the prepared teeth could be used as stops for the occlusal index, if care was taken not to damage them during the index fabrication. They did not present any information regarding the accuracy of cast reorientation with this technique. Accuracy of the reorientation becomes more significant for surveyed restorations because of the numerous times reorientation will be needed and the additive effect of errors. Crowns that will serve as abutments for a removable partial denture must be surveyed during fabrication on their master cast. The survey will be done at the proposed future path of insertion of the removable partial denture.
Each abutment crown would need to be surveyed during the wax-up, the porcelain contouring (if porcelain fused to metal crown) and at the end stage for verification of proper contours. Each time the crown or crowns are surveyed the definitive cast must be reoriented to the originally selected path of insertion. This repetitive procedure is time consuming and if not performed adequately could lead to inadequate contours of the final restoration.
III. 3. LITERATURE REVIEW OF RECORDING METHOD PROPOSALS

**O. Applegate** in JADA 1940 gave credit for the development of the surveyor to G. Fortunati who in 1918 pointed out that a “mechanical device could be used for charting correct clasp outlines”. In the same article it was reported that Weinstein and Roth had designed the first commercial surveyor in 1921. O. Applegate opined “no step in the entire procedure is more beclouded with uncertainty and confusion than that of using the model surveyor”. Regarding the method of recording the path of insertion Applegate stated that vertical grooves would be preferable to vertical lines since grooves are “less likely to be accidentally removed and also because it will be transferred to a duplicate model. Of these grooves one should be on the dorsal aspect of the model and one on each lateral side. Also when the master model is duplicated the grooves will reappear on the base of the casting model. Then if during the making of the wax pattern, a recheck of some area on the instrument seems necessary, it is possible quickly and accurately to place this casting model in precisely the same position on the instrument as occupied by the master model. This frequently occurs if cast clasps are being utilized because it is necessary to know exactly the degree of undercut in which the terminus of the cast clasp is being placed.”

Tripod mark method on the tissue area of the cast is the most frequently encountered method of recording the path of insertion. In all comparative studies of accuracy it has been used as the gold standard by which all newer methods are judged. There are numerous references to this method in classic textbooks and in the dental literature:

McCracken's Removable Partial Prosthodontics G.P. McGivney 10th ed. 2000 Mosby,
Minor variations exist in the making of the tripod markings, e.g. dots made by the carbon marker; or 1-3mm short lines; or slight carvings made by the wax trimmer or analyzing tool. Tripod marks can also be made on the art portion base of the cast, but this is less frequently practiced.

**T. Kaloyiannides** in 1973 presented a technique to record the path of insertion using a protractor attached to the vertical arm of the surveyor. The tilt table would be locked and the operator selected four points on the cast. By lowering the vertical arm and attached protractor onto the cast and aligning it first with one pair of dots and then the other pair (so that intersecting lines were formed) two angle measurements were read on the protractor. These numerical angle measurements described the orientation of the cast to the vertical. The benefit of the method appears to be that the path of insertion could be recorded and transferred just with numbers and point descriptions however a prerequisite would be the manufacture and availability of this device.

**J. Knapp, J. Shotwell and W. Kotowicz** in 1979 described a cemented pin method that could be used for recording the path of insertion. The pin was a bur shank that was embedded into a hole filled with acrylic resin in the center of the cast. This pin represents the path of insertion and could be used for realignment of the cast at the dental laboratory. The reorientation technique they described involved the following simple procedure: lock the vertical arm of the surveyor onto the alignment pin, release the ball joint of the tilt table, lift the cast and tilt table up by raising the vertical arm of the surveyor, with the tilt table base hanging loosely, lower the unit of cast and tilt table back down until the tilt table base touches flat and squarely onto the surveyor platform, lock the ball joint and the cast-tilt table has been reoriented to the original path of insertion.
This method works best if the pin is embedded in the center of the cast, however this becomes a drawback with a maxillary cast. Embedding the pin in the palate may interfere with wax up of the framework. This article cited in its bibliography Wagner and Forgue’s test results of the cemented pin comparison, which will be reviewed in the next section.

O. Sykora in Halifax in 1980 described a novel procedure that used an air bubble level indicator named the MS level and made by Unident. The proposed procedure was luting the MS level to the cast with extra hard sticky wax at the selected path of insertion. The technician later could then reorient the cast to the same path by aligning the air bubble in the exact center of the cross hairs of the ring. Sykora described this new method because “tripod marks are often inaccurate or difficult to see because of various laboratory procedures such as cast trimming, cast soaking and duplication for refractory cast fabrication”. The company Unident and the MS level could not be located in 2001. It is possible that a level gauge was used by technicians even earlier than Sykora’s presentation of the technique based on personal communication with local laboratory technicians.

In 1981 in the Journal of Prosthetic Dentistry another new proposal was described to record the cast orientation. A. Sarnat described the “position recorder device” as simple, accurate, easy to manage and requiring minimal time for repositioning of the cast back on the surveyor. It consisted of a triangular plastic plate with a handpiece mandrel inserted into the plate, which would be held by the vertical arm of the surveyor. The relationship of the plastic plate to the cast is recorded by indexing the occlusal surfaces of a few teeth using modeling compound.
Reorientation is accomplished by placing the “device” on the cast (on the tilt table) and with the ball joint loose, adjusting the tilt of the table until the mandrel is perfectly vertical and the vertical arm of the surveyor can slide down over it. Once accomplished the tilt table can be locked and the device lifted off the cast. Sarnat said that an added advantage of this method is that it provides an inexpensive permanent recording of the selected path of insertion.

S. De Fiori working in Brazil in 1983 utilized an acrylic plate similar to Sarnat’s method to record the path of insertion. De Fiori felt that acrylic could be used safely instead of silicone to index the teeth. This meant relining the acrylic plate to the cusp tips with self-cure acrylic. The vertical arm of the surveyor held the plate by a recording pin similar to Sarnat’s mandrel. He recommended this recording plate to be used to transfer the recording from cast to cast. However as a permanent record he preferred the cemented pin method.

G. Polyzois in 1986 described using either circular or straight air bubble gauges and high viscosity putty silicone to record and create a transfer index of the path of insertion. Polyzois said the method “allows for a quick accurate interchange and repositioning of the diagnostic, master and refractory casts on the surveyor table”. The technique was similar to Sykora’s in using the MS level by Unident, but by using a silicone index instead of wax, the transfer index could be removed and repositioned on the same cast or a duplicate cast. In his description of the technique Polyzois said that the silicone putty could be placed on the model even on edentulous areas. This silicone would be the “underpadding” of the bubble gauge and while setting, the bubble gauge could be embedded and the air bubble centered. It is unclear if this is one batch of silicone setting or two.
A. Steas at Aristotle University of Greece in 1987 proposed a technique to record the path of insertion. He fabricated a three pronged instrument that was held by the surveyor and each of the three prongs could be extended to contact a specific selected point on the cast. The prongs would then be locked in position by tightening three little bolts. This method could transfer a recording from cast to cast. Possible reason for the lack of further development may be the need to manufacture the instrument since it does not exist in the dental market. Another problem may be that if a nut or bolt accidentally becomes loose then the recording is lost and given that the instrument would need to be sent to the dental lab along with the cast this becomes a risk during transportation.

I. Ansari in 1994 in his proposal described a recording of the path of insertion that could be transferable from master to duplicate to refractory cast as needed. The technique Ansari described is similar to Sarnat's. It utilizes an acrylic impression tray lined with impression material that indexes the occlusal surfaces of the remaining teeth at the selected path of insertion. The acrylic tray is related to the vertical arm of the surveyor by having a receptacle portion at the top of the tray, like a socket, for the vertical arm to slide into directly. Reorientation is achieved by tilting the cast with tray until the vertical arm of the surveyor can slide directly onto into the tray without interference. The fabrication of the acrylic tray as described by Ansari does appear complex, but he states that, at completion of the case, the indexing impression material can be removed and the tray reused with the next case.
In the same year 1994 J. Ivanhoe and G. Mahanna described a tray like Ansari’s but recommended embedding a long shank bur into the tray instead of making a socket receptacle as Ansari had recommended. In this respect the tray is related to the surveyor by the bur shank similar to Sarnat’s original description. The lining material for the indexing of the occlusal surfaces is again impression material. It is interesting to note that neither Ivanhoe and Mahanna’s article nor Ansari’s article cited each others or Sarnat’s article as a reference. Ivanhoe and Mahanna’s article stated that this technique was most useful for situations where multiple fixed prosthodontic preparations require surveyed restorations and a single master cast is not available. An orientation index that could be transferred from cast to cast could facilitate such cases.
A. Wagner and E. Forgue in 1976 published the classic study that compared four methods of recording the path of insertion. The methods tested are the tripod marks in the anatomic areas of the cast, the vertical lines on the base of the cast, the tripod marks on the base of the cast and the cemented pin method. Ten technicians who reoriented each cast three times for a total of thirty measurements tested the four methods. The results of their study showed that the cemented pin method was the most accurate and required the least time for reorientation. The tripod marks and vertical lines were not significantly different from one another. The tripod marks on the art portion of the base were the worst in all respects. In their conclusion the authors felt that the cemented pin method was superior and that the other methods could still be used since they were “reasonably accurate”.

In reviewing their study I did not find any recommendation for what constitutes reasonably accurate reorientation. In their study it is interesting to note that four different casts were used, though one cast and one tilt table may have been sufficient to test all three methods. In the article Wagner and Forgue do not mention the origin of the cemented pin method but this may be the first time it’s described in the literature. Last, the design of this study has been the basis for all subsequent studies: a long metal pointer inserted into the cast during the error calculations points to a target, the distance from the original center is the error in degrees from the original path of insertion.
In 1990 J.C. Davenport et al in the International Journal of Prosthodontics published “An Evaluation of a Bubble Gauge for Recording the Path of Placement of Removable Partial Dentures”. This comparative study of recording methods tested the accuracy of a bubble gauge method and compared it to the more common methods of tripoding and vertical lines. Davenport stated that the original intention was to test a circular bubble gauge as described by Polyzois, however they could not locate a satisfactory circular gauge. Instead two straight bubble gauges at a right angle to each other were used in the study. The gauges were attached to a disposable impression tray that was lined with impression material, which indexed the occlusal surfaces of the teeth. The cast was permanently attached to the fixed tilt table of the Dyer surveyor and the groups of clinicians, technicians, and students reoriented the cast using each of the recording methods. Accuracy was measured by similar methodology as in the Wagner and Forgue study. A long stylus pointed to a target disk from which error in degrees from the original path of insertion was calculated. In their results the bubble gauge method was rated as most preferred and by the measurements it was found to be the most accurate and least time consuming, followed by tripoding and last the vertical lines. Davenport noted that lab surfaces had to be checked and verified to be horizontal prior to the start of the study. The results of the Davenport et al study are in agreement with the results of the Wagner and Forgue study in respect to the tripoding and vertical lines method. A slight difference shows more accuracy in the original Wagner and Forgue study.
J. Bowley and D. Cipra in 1992 evaluated cast reorientation by three prosthodontic residents using tripod marks. This study assessed only tripod marks and was innovative in its methodology. A single cast had widely spaced tripod marks placed on its base. Each resident reoriented the cast four times using the tripod marks and worked on a Ney surveyor. Residents used as much time as they wanted since there was no time measurement. After reorientation a machinists' digital height gauge was used to measure the vertical discrepancy between the original position and the reoriented position of the tripod marks. The results show that tripod markings can be used very accurately in reorientation. The mean vertical discrepancy per location was only .2mm which the authors translate to .17 degrees of error. The authors suggest that the difference in their results compared to the Wagner and Forgue study are due to time not being a factor in this new study. In the discussion they also mention that though a vertical discrepancy of 0.2mm appears small, it may be significant in relation to .01 inch undercut.

It is interesting to note the high degree of precision that this study was done with. The tripod marks were placed with a scalpel, engraved into the stone. The reorientation was accomplished not with the analyzing tool but with the .01 undercut gauge placed in the vertical arm of the surveyor. In seems that the approximation of the thin edge of the undercut gauge to the scalpel mark would automatically confer greater accuracy than the blunt ended analyzing tool approximated to a carbon mark. Having only three qualified residents would also predispose the study to greater accuracy. Finally error was measured for each location in vertical millimeters and by geometry the angle from the known position to the reoriented position was calculated. It is unclear how these angles correspond to the single angle measurement of error of the Wagner or Davenport study.
IV. MATERIALS AND METHODS

IV.1. DESCRIPTION OF SIX RECORDING METHODS

The purpose of this study was to compare the accuracy of survey model reorientation using the following six methods:

1. **Circular level gauge on an acrylic record base with a silicone occlusal index.**

   It was fabricated by using a perforated methyl methacrylate u-shaped record base lined with silicone putty (Reprosil, Dentsply/Caulk, Milford, DE). During this step the cast and tilt table were on the Ney surveyor. The master knob of the tilt table was locked holding the cast in its final position in relation to the selected path of insertion. A layer of silicone was placed on the underside of the record base indexing the occlusal surfaces of the remaining teeth. After the silicone set, the record base was removed, excess trimmed and repositioned on the cast. A second layer of silicone was placed over the record base and a circular level gauge was embedded into it. The air bubble of the level gauge was maintained centered during the setting of the second layer of silicone. The circular level gauge used was an ordinary hardware store model Pro Crafter (Macklenburg-Duncan, Oklahoma City, Oklahoma USA).

2. **Circular level gauge embedded into a silicone index of the remaining teeth without an acrylic record base.** It was fabricated in two steps. A silicone occlusal index was made first by mixing a 3cm diameter ball of silicone putty and placing it onto the occlusal surfaces of the remaining teeth.
After it set, the silicone putty was removed, excess was trimmed and it was repositioned on the cast. Then a second layer of silicone was mixed and placed on top of the first with a level gauge embedded into it and the level gauge was held level (air bubble centered) until the silicone set.

3. **Acrylic tray with an embedded pin and silicone occlusal index.** It was made similar to the first method by lining the underside of the acrylic tray with silicone to index the occlusal surfaces of the remaining teeth. The tray was removed, excess silicone trimmed and then repositioned on the cast. The vertical arm and spindle of the Ney surveyor was then used to approximate a mandrel with a 1.0 inch shank, which will serve as our alignment pin, to the surface of the acrylic base. In this position a fresh mix of methyl methacrylate was used to connect (embed) the pin to the tray permanently. Method referred to as Mandrel with base.

4. **Tripod method.** The traditional tripod method, which is the most frequently utilized method of recording the path of insertion, will be compared and will serve as our control. The recording was made by using the .03inch Ney undercut gauge and mildly carving three widely spaced marks on the surface of the stone cast. Each mark was about 2mm long, on a non-critical surface, within the area of the palate of the model. The carving was made by carefully moving the working cast and tilt table against the locked vertical survey arm. Each thin carving was then traced with blue pencil precisely and circled.
5. **Three vertical lines method.** The base of the stone cast had originally been trimmed on a model trimmer and had adequate height to the base for using the vertical lines method. The straight analyzing rod was placed in the surveyor arm. The vertical surveyor arm with analyzing rod was positioned next to the cast base. A sharp line was drawn on the base with a pencil keeping the angle of the pencil steady as it made contact with the base and with the analyzing rod. Three such vertical lines were drawn on the model at widely spaced points.

6. **Vertical grooves method.** At the posterior aspect of the cast where the base had a height of at least 2cm a vertical groove was carved into the base. At the lateral aspects of the cast two more grooves were placed. The grooves had a height of 15 mm, a width of 3mm and depth of 2.5mm. They were made by using a parallel sided milling bur in a straight handpiece which was held fixed to the locked vertical arm of the surveyor with the Ney surveyor-milling adapter. The stone cast and tilt table were moved against the spinning bur to create a clean precise groove with no chipping at the borders. The milling bur was initially verified to be parallel to the surveyor’s analyzing rod. After the grooves had been prepared and with the tilt table still in the same position, the 3mm analyzing rod was checked and confirmed to have a good fit into the grooves.
IV. 2. ARMAMENATARIUM

IV. 2.1. WORKING CAST, TILT TABLE, SURVEYOR, JUDGING STATION

The dental cast selected for the project was a maxillary cast with eight remaining teeth. This partially edentulous cast can be classified as a class I modification I according to the Kennedy classification system. The cast represented an ordinary definitive cast for removable partial denture framework fabrication poured in type IV stone.

The modifications for the project were:

In the center of the palate, a milled metal tube was embedded into the cast with a fresh mix of stone. The milled tube had a length of 2 cm and an internal diameter of 1 cm. The tube served as a receptacle for a pointer rod. The machining was precise and there was no movement of the rod once positioned in the milled tube. The pointer rod was 20 cm in length and 1 cm in diameter. The rod ended with a stylus.

The surveyor selected for the project was a Ney Surveyor. It has a flat smooth surveying platform and a vertical arm whose height can be adjusted during the surveying procedures. There is a separate tilt table for holding and orienting the dental cast. The tilt table has a universal ball joint for changing the orientation and a vice to hold the working cast in place. The vice was not needed in our project and was removed.

The dental cast was placed onto the Ney surveying tilt table and fixed permanently to it with dental stone. The base of the tilt table was confirmed to be flat, smooth and even. The tilt table has one master knob that controls the universal ball joint and that when loosened allows the table to tilt and change orientation of the cast. The master knob was confirmed to function well in locking the table and without needing any excessive force to loosen and retighten.
The milled tube had been set into the working cast in such a manner as to be in line with the universal ball joint. The pointer rod could then arc, during the reorientation attempts, as if it was a radius and the center of rotation was the center of the universal ball joint.

The judging station was a modification of a microscope stand originally built by Barnes Engineering (Stamford, Connecticut). The base platform had been modified to allow the precise repositioning of the tilt table to the same spot on the platform for each attempt. Lateral motion of the tilt table was not possible but since the tilt table has a round base, it could rotate on the platform while still remaining centered in the same spot. This rotation would not affect the accuracy of the measurements but rather was expected and dealt with. There is also the possible rotation of the universal ball joint in its housing inside the tilt table base. This would be a similar movement-rotation and again is expected and dealt with by the design of the project.

The entire microscope lens system had been removed and in its place a single clear Plexiglas disk had been attached. By turning the microscope’s focusing knob, the Plexiglas disk could be raised or lowered. The up and down movement of the disk was very precise with no side-to-side motion of the disk possible. Concentric circles around a center point, increasing in radius by 1mm each from the center point had been drawn by a CAD/CAM computer and printed onto a transparency sheet. The circles were verified to be true by a compass and properly spaced by a millimeter ruler. This sheet was affixed by glue to the Plexiglas disk.
The measurements of error were read from these concentric circles, which neutralized the effects of any rotation. Distance from the center was error while any rotation would be an equidistant arc around the center that would not affect the reading.

The cast was surveyed on the Ney surveyor, the path of insertion was selected and the tilt table was locked at this position. All six recordings were then made on the Ney surveyor. The tilt table was never loosened. The table with cast was then moved to the Judging station and positioned onto the platform. The metal rod with stylus was placed into the cast and the Plexiglas disk lowered to make contact with the stylus of the metal rod. This marked the center for the correct orientation of the cast or the “zero error” reference point. At this center, the transparency sheet’s center was superimposed. The sheet was permanently glued to the topside of the disk with clear glue.

The surveying station (Ney Surveyor) and the judging station were on laboratory benches that were examined and found to be horizontally level. The stations were not changed locations for the duration of the project.
IV. 3. PROCEDURE

IV. 3.1. PREPARATION OF TESTING PROCEDURE

The tilt table with the dental cast was placed on the surveyor. The cast was surveyed to select a path of insertion for a removable partial denture. A path of insertion was then selected and the tilt of the table was locked. This represents the selected orientation of the cast in relation to the vertical direction. This selected path of insertion was recorded with six different methods (six recordings). The selected path of insertion was then “lost” and subsequently dental professionals (evaluators) attempted to reorient the cast to the previously selected path of insertion by using each of the six recordings. Utilizing each recording method, the tilt table and cast was reoriented to the original path of insertion. This was performed on the Ney surveyor, at the original location where the records were fabricated. After each recording method was used, the tilt table position was locked by tightening the universal knob. The table and cast was then moved to a judging station where the metal stylus was placed into the cast. A Plexiglas disk was lowered to contact the stylus. A reading was taken from the concentric circles on the disk which represented the distance in millimeters from the center to the point were the stylus was touching. The greater the failure in orientation, the further from the center the stylus pointed. This was error in millimeters. Once the error was recorded, the rod was removed and the “judge” Dimitri Perdikis DDS loosened the universal knob and then the tilt table was given back to the evaluator. The evaluator proceeded at the survey station to reorient the cast with the next recording method until all six recording methods were utilized. The method used first was chosen by random number tables and the other records were then used in rotation.
IV. 3.2. PROCEDURE BY EVALUATORS

The evaluators tested each of the six methods, a total of 47 dental professionals that formed four groups. The evaluators were 12 dental school students, 12 post-graduate residents of prosthodontics or general dentistry, 12 dental laboratory technicians and 11 faculty members. Each evaluator was given a brief description of the project and a demonstration of cast reorientation using each of the six recording methods. The evaluators were also informed that their reorientation attempts would be timed and also that at the end of the testing they would be asked to rank the recording methods by order of preference. The method used first was determined by a random order table and the remaining methods were used in consecutive order. Each evaluator was given the tilt table with the universal screw loose and was asked to work at the survey station using the reorientation recordings. When the reorientation with each method was achieved, the “judge” moved the tilt table with its universal screw tightened to the judging station. During the measurement at the judging station, the evaluator could not see the deviation of the metal stylus and received no knowledge of the accuracy of the previous attempts. At the conclusion of all reorientation attempts, error in millimeters had been measured, time in seconds had been counted and order of preference listing most preferred first had been noted.
IV. 3.3. UTILIZING THE RECORDINGS

All evaluators were familiar with reorienting a cast utilizing tripod markings, however the new methods were unknown and instructions were given to the evaluators. Instructions and a demonstration were given for all six methods.

Reorienting a cast with either of the air bubble level gauges on silicone occlusal indexes is performed as follows: The index is placed on the cast, ensured that it is seated all the way and is stable. The tilt of the table is then adjusted until the air bubble is centered in the gauge, which has a scribed center circle. Standing provides an advantage to the evaluator since it allows the best view of the air bubble as it being centered.

Reorienting the cast with the indexed tray with embedded pin is performed as follows: The pin of the occlusal index is placed into the surveyor arm spindle. The alignment pin is held stable in place by tightening the small lockscrew on the spindle. The index is thus suspended above the cast.

The tilt table is loose and can be adjusted as needed. As one hand lowers the vertical arm, lowering the occlusal index onto the cast surface, the other hand supports the cast so that the seating force is uniform around the arch. The hand that supports the cast proceeds to grip both the index and the cast, clamping them together. The upper hand then moves to the universal knob and tightens it completing the reorientation. A simple verification of the orientation could be performed: Releasing the pin from the vertical arm, the vertical arm could be raised away and with the occlusal index seated properly on the cast, the orientation of the pin was checked. If correct, the vertical arm of the surveyor would be able to slide down over the pin without any problem.
Reorientation using the tripod marking is performed as follows: The analyzing tool is placed in the surveyor and is lowered until it reaches the first of the tripod markings. It is then approximated to the next tripod marking without changing the height of the analyzing tool but only the tilt of the cast. Then the third mark is also compared to the height of the analyzing tool. If all three marks are on the same horizontal plane with the height of the analyzing tool then the reorientation is complete. If any of the marks are off, then the height of the analyzing tool must be changed and the reorientation procedure continued. Verification is simple by repeatedly checking all tripod marks to the height of the analyzing tool with the vertical arm locked. Difficulties arise because both the tilt of the cast and the height of the vertical arm must continually be adjusted during this procedure. Tripod markings are the most commonly used method of recording the path of insertion yet it is possible to have difficulty utilizing the marks for reorientation. If the vertical arm is moved when it should have been locked, to get it to touch all three marks, it would obviously ruin the reorientation attempt. The purpose of keeping the analyzing tool at one height is because it should represent one point on the horizontal plane delineated by the three tripod markings.

Reorientation using the three vertical lines is performed as follows: The straight analyzing tool is placed in the vertical arm of the surveyor. The cast is positioned next to the analyzing tool. Then the vertical line is compared to the analyzing tool and corrections are made to the tilt of the cast until the vertical line and the analyzing tool appear to have the same direction. By consecutively comparing each of the three lines to the analyzing tool, we evaluate the tilt from three different perspectives.
Each time gradually correcting the anterior-posterior or left-right tilt of the cast. Verification is accomplished by repeating the comparison until we feel no further corrections are needed to the tilt of the table to make it match the direction of the analyzing tool, as viewed from different directions.

Reorientation using the three vertical grooves is similar in procedure to the three lines method. However there are some differences. Instead of the regular Ney analyzing tool, a 3 mm diameter analyzing tool was used that closely matches the diameter of the milling bur. When the groove is approximated to this analyzing tool, corrections are made to the tilt of the cast so that the groove can be centered to the analyzing tool. The goal is the positioning of the tool entirely within the groove passively and without cast damage. The placement of the tool is viewed from different angles to verify that it is centered in the groove at both its top and bottom aspect.
V. RESULTS

V. 1. General

At the conclusion of the testing procedure the cast on the tilt table had been reoriented six times by each of 47 evaluators for a total of 282 reorientations. The results could be further examined by groups: resident, faculty, student and technician. Each of the six methods was tested once by each evaluator and the mean, median and standard deviation was calculated from the results. The variables were degrees of error and seconds of time for reorientation. Evaluators also listed their preferred method.

The results of the testing showed that the conventional methods of recording the path of insertion were the least accurate methods when reorienting a cast. The mean error for the classic tripod was 1.29 degrees with the vertical lines and the vertical grooves at 1.28 and 1.4 respectively. The three newer methods, which are the two bubble gauge methods and the mandrel with base method, are significantly more accurate than the older methods. Average error for the bubble gauge methods was 0.33 and 0.39 and for the mandrel with base 0.49 degrees. They also require less time to reorient and have the added advantage of being transferable from cast to cast. The time in seconds for reorientation is not supposed to be an indication of laboratory bench time used up, but rather a further indication of accuracy. If for example an inaccurate method is used with painstaking patience it may yield an acceptably accurate final result but it would show long reorientation times. The combination of high degree of accuracy and short reorientation times reinforce each other and show the advantage of the newer methods.
V. 2. PREFERENCES

Evaluators also responded to two questions at the conclusion of their reorientation attempts: 1) Which was their preferred method of reorientation based on ease of use?

2) Which method did they suspect was the most accurate?

The results for “ease of use” showed an equal preference for the bubble gauge method and the mandrel with base method with a few evaluators expressing preference for the vertical grooves method. The horizontal tripod method and the vertical lines method was the preferred method of only one evaluator each.

The evaluators were similarly divided in their responses for which method they suspected was the most accurate, without of course having the actual results. Most evaluators felt the mandrel with base method was the most accurate with just a few less listing the bubble gauges: 25 versus 19. The remaining 2 evaluators felt the vertical grooves were the most accurate. Vertical lines and horizontal tripod methods only had one supporter. Most evaluators did not make a distinction between the two bubble gauge methods, therefore bubble gauge positive responses are grouped together.

Table 2. Ease of use

<table>
<thead>
<tr>
<th>bubble gauge</th>
<th>mandrel with base</th>
<th>horizontal tripod</th>
<th>vertical lines</th>
<th>vertical grooves</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>14</td>
<td>1</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 3. Suspected Accuracy

<table>
<thead>
<tr>
<th>bubble gauge</th>
<th>mandrel with base</th>
<th>horizontal tripod</th>
<th>vertical lines</th>
<th>vertical grooves</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>25</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
V. 3. STATISTICAL ANALYSIS

Methods Used:

A factorial ANOVA analysis was performed on the primary outcome variables, degrees of error and time (sec), since more than two groups were being compared. In order for this particular analysis to be valid, a certain set of assumptions must be met: 1) that the variances between groups being compared are equal and 2) the variable being measured is normally distributed. As can be seen, degrees of error violated equality of variances, while the outcome time seems to satisfactorily conform to this assumption. For both variables, the distribution is greatly skewed. Thus, a natural logarithmic transformation of the outcome variables was made.

Given below are the summary statistics prior to the logarithmic transformation which follows this initial section:

Table 4: Summary statistics of Error in Degrees by method used.

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean degrees of error</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble with Base</td>
<td>0.3398806</td>
<td>0.2081546</td>
</tr>
<tr>
<td>Bubble without Base</td>
<td>0.3912128</td>
<td>0.3205200</td>
</tr>
<tr>
<td>Mandrel with Base</td>
<td>0.4951362</td>
<td>0.3460167</td>
</tr>
<tr>
<td>Horizontal Tripod</td>
<td>1.2924213</td>
<td>1.5001072</td>
</tr>
<tr>
<td>Vertical Lines</td>
<td>1.2875319</td>
<td>0.7328357</td>
</tr>
<tr>
<td>Vertical Grooves</td>
<td>1.4073191</td>
<td>0.8459368</td>
</tr>
</tbody>
</table>

Table 5: Summary statistics of time (sec) by method used.

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean time in seconds</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble with Base</td>
<td>23.0212766</td>
<td>12.3859832</td>
</tr>
<tr>
<td>Bubble without Base</td>
<td>23.1489362</td>
<td>13.4907033</td>
</tr>
<tr>
<td>Mandrel with Base</td>
<td>44.9148936</td>
<td>27.6867805</td>
</tr>
<tr>
<td>Horizontal Tripod</td>
<td>99.1063830</td>
<td>63.8436385</td>
</tr>
<tr>
<td>Vertical Lines</td>
<td>56.5531915</td>
<td>33.6399145</td>
</tr>
<tr>
<td>Vertical Grooves</td>
<td>54.5957447</td>
<td>62.8347244</td>
</tr>
</tbody>
</table>

We see that the mean degree error is approximately one-third for the newer methods compared to the conventional methods. The mean time required for reorientation is greatest for the tripod method.
Looking at Primary Outcomes by Method Used

Fig. 1. Box-plots of error in degrees by method used.

The horizontal tripod method has the greatest variance. A possible explanation is that there were evaluators that were not familiar with the reorientation technique, even though all operators had the opportunity to practice beforehand and all who proceeded with the reorientation said they were comfortable with the method.

Fig. 2. Box-plots of time (sec) by method used.

Vertical grooves being a virtually unused method at UCONN may have been a challenge for most evaluators since they had little prior experience to ascertain when the orientation was complete. This would explain the long reorientation times of a few operators.
Looking at Primary Outcomes by Operator

Resident  Faculty  Student  Technician

Fig. 3. Box-plots of error in degrees by operator.

The faculty members appear to be the most consistent in reorientation accuracy compared to the other three groups with the residents showing the greatest variance.

Resident  Faculty  Student  Technician

Fig. 4. Box-plots of time (sec) by operator.

A further surprise was that students are fast operators.
Table 6: Summary Statistics of error in degrees by operator.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Mean degrees</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident</td>
<td>1.0009917</td>
<td>1.1740851</td>
</tr>
<tr>
<td>Faculty</td>
<td>0.7217939</td>
<td>0.6029138</td>
</tr>
<tr>
<td>Student</td>
<td>0.8035472</td>
<td>0.7779254</td>
</tr>
<tr>
<td>Laboratory Technician</td>
<td>0.9370749</td>
<td>0.9663823</td>
</tr>
</tbody>
</table>

Table 7: Summary Statistics of time (sec) by operator.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Mean time</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident</td>
<td>51.9861111</td>
<td>43.9745423</td>
</tr>
<tr>
<td>Faculty</td>
<td>51.7121212</td>
<td>46.2207962</td>
</tr>
<tr>
<td>Student</td>
<td>44.2222222</td>
<td>34.4862586</td>
</tr>
<tr>
<td>Laboratory Technician</td>
<td>53.0972222</td>
<td>64.2778212</td>
</tr>
</tbody>
</table>
A natural logarithmic transformation of the outcome variables was made.

Table 8: Summary statistics of the Logarithm of error in degrees by method used.

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble with Base</td>
<td>-1.2520040</td>
<td>0.7034259</td>
</tr>
<tr>
<td>Bubble without Base</td>
<td>-1.1456369</td>
<td>0.6885602</td>
</tr>
<tr>
<td>Mandrel with Base</td>
<td>-0.9421960</td>
<td>0.5855421</td>
</tr>
<tr>
<td>Horizontal Tripod</td>
<td>-0.1661801</td>
<td>0.9374491</td>
</tr>
<tr>
<td>Vertical Lines</td>
<td>0.0867780</td>
<td>0.6078813</td>
</tr>
<tr>
<td>Vertical Grooves</td>
<td>0.1459786</td>
<td>0.6665353</td>
</tr>
</tbody>
</table>

Table 9: Summary statistics of the Logarithm of time (sec) by method used.

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble with Base</td>
<td>2.9888775</td>
<td>0.5706980</td>
</tr>
<tr>
<td>Bubble without Base</td>
<td>2.9824227</td>
<td>0.5721178</td>
</tr>
<tr>
<td>Mandrel with Base</td>
<td>3.6370722</td>
<td>0.5855421</td>
</tr>
<tr>
<td>Horizontal Tripod</td>
<td>4.3356979</td>
<td>0.8215755</td>
</tr>
<tr>
<td>Vertical Lines</td>
<td>3.8608971</td>
<td>0.6086219</td>
</tr>
<tr>
<td>Vertical Grooves</td>
<td>3.7009820</td>
<td>0.7378333</td>
</tr>
</tbody>
</table>

It can be seen that the standard deviations are more nearly equal.

Table 10: Summary Statistics of the Logarithm of error in degrees by operator.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident</td>
<td>-0.4440762</td>
<td>1.0326668</td>
</tr>
<tr>
<td>Faculty</td>
<td>-0.6508299</td>
<td>0.8339774</td>
</tr>
<tr>
<td>Student</td>
<td>-0.6086325</td>
<td>0.9538561</td>
</tr>
<tr>
<td>Laboratory Technician</td>
<td>-0.4620607</td>
<td>0.9252521</td>
</tr>
</tbody>
</table>

Table 11: Summary Statistics of the Logarithm of time (sec) by operator.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident</td>
<td>3.6691948</td>
<td>0.7521989</td>
</tr>
<tr>
<td>Faculty</td>
<td>3.6276285</td>
<td>0.8106772</td>
</tr>
<tr>
<td>Student</td>
<td>3.4983159</td>
<td>0.7820631</td>
</tr>
<tr>
<td>Laboratory Technician</td>
<td>3.5457691</td>
<td>0.8875961</td>
</tr>
</tbody>
</table>
The results seem satisfactory. To see a visual representation of the data, consult figures (5-8)

Fig. 5. Box-plots of logarithm of error in degrees by method used.

Fig. 6. Box-plots of logarithm of time by method used.
Checking if Variance Stabilization has been achieved by operator

Fig. 7. Box-plots of logarithm of error in degrees by operator.

Checking if Variance Stabilization has been achieved by operator

Fig. 8. Box-plots of logarithm time by operator.
Lastly, the mean value for each operator by method was plotted to see if there could be an interaction between the method used and the level of expertise the individual operator.

Fig. 9. Plot of means (degrees of error) of operator by method used.

Fig. 10. Plot of means (time) of operator by method used.

Figures 9 and 10 do suggest a possible interaction, with the effect appearing to be more pronounced in Figure 9 with respect to the variable, degrees of error. Thus, when performing the two-way ANOVA, a test for an interaction between main effects, in this case, method used and operator will be tested.
Post-hoc analysis was done using Scheffe’s Criterion. While this is more conservative than Tukey’s Criterion, other contrasts were also tested.

A factorial ANOVA was performed for the variables degree of error and time, in seconds, and the interaction term was tested for.

**Results for Degree of Error**

The ANOVA table is given below:

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>23</td>
<td>112.4578627</td>
<td>4.8894723</td>
<td>9.36</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Error</td>
<td>255</td>
<td>133.2438213</td>
<td>0.5225248</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>278</td>
<td>245.7016840</td>
<td>1.0346849</td>
<td>2.00</td>
<td>0.0171</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type I SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>method_1</td>
<td>5</td>
<td>94.78170312</td>
<td>18.95634062</td>
<td>36.28</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>rater2</td>
<td>3</td>
<td>2.15588622</td>
<td>0.71862874</td>
<td>1.38</td>
<td>0.2508</td>
</tr>
<tr>
<td>method_1*rater2</td>
<td>15</td>
<td>15.52027334</td>
<td>1.03468489</td>
<td>1.98</td>
<td>0.0171</td>
</tr>
</tbody>
</table>

The test for operator effect fails to reject the null hypothesis that there exists a difference among operators ($\alpha=0.05$, $p=0.2508$). The effect of method used was found to be significant ($\alpha=0.05$, $p<0.0001$) and there is evidence of an interaction effect ($\alpha=0.05$, $p<0.0171$).

Post-hoc tests revealed that the following pair-wise differences:

**Bubble with Base vs.**
- Horizontal Tripod
- Vertical Line
- Vertical Groove

**Bubble with out Base vs.**
- Horizontal Tripod
- Vertical Line
- Vertical Groove

**Mandrel with Base vs.**
- Horizontal Tripod
- Vertical Line
- Vertical Groove
Table 12. Summary of the results of post-hoc tests for the logarithm of degrees of Error

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Ratio of Means</th>
<th>95% Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble with Base</td>
<td>Horizontal Tripod 0.3376</td>
<td>0.2195, 0.5193</td>
</tr>
<tr>
<td></td>
<td>Vertical Lines 0.2622</td>
<td>0.1705, 0.4032</td>
</tr>
<tr>
<td></td>
<td>Vertical Grooves 0.2471</td>
<td>0.1607, 0.3800</td>
</tr>
<tr>
<td>Bubble without Base</td>
<td>Horizontal Tripod 0.3755</td>
<td>0.2441, 0.5775</td>
</tr>
<tr>
<td></td>
<td>Vertical Lines 0.2917</td>
<td>0.1896, 0.4485</td>
</tr>
<tr>
<td></td>
<td>Vertical Grooves 0.2748</td>
<td>0.1787, 0.4227</td>
</tr>
<tr>
<td>Mandrel with Base</td>
<td>Horizontal Tripod 0.4602</td>
<td>0.2189, 0.5180</td>
</tr>
<tr>
<td></td>
<td>Vertical Lines 0.3574</td>
<td>0.3574, 0.5496</td>
</tr>
<tr>
<td></td>
<td>Vertical Grooves 0.3368</td>
<td>0.2992, 0.7079</td>
</tr>
</tbody>
</table>

The following additional contrast was tested using Scheffe’s Criterion:

(Bubble with Base, Bubble without Base, Mandrel with Base) vs. (Horizontal Tripod, Vertical Lines, Vertical Grooves)

A significant difference was found in the ratio between the methods 1-3 and methods 4-6 ($\alpha=0.05$, $p<0.001$, estimated ratio, 0.3213 95% CI {0.2403, 0.4295}).

The null hypothesis for degrees has been disproved. There is a significant difference in the degree error between any of the first three methods (newer methods) and the conventional methods of tripoding, vertical lines and vertical grooves.

There is a significant difference between the accuracy of reorientation of a transferable record of the path of insertion utilizing a circular level gauge with an indexed acrylic base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is a significant difference between the accuracy of reorientation of a transferable record of the path of insertion utilizing a circular level gauge with a silicone index without a base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is significant difference between the accuracy of reorientation of a transferable record of the path of insertion utilizing an embedded alignment mandrel into an indexed acrylic base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.
Results for Time

The ANOVA table is given below

Dependent Variable: log sec

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>8</td>
<td>65.8735865</td>
<td>8.2341983</td>
<td>19.11</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Error</td>
<td>273</td>
<td>117.6592276</td>
<td>0.4309862</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>281</td>
<td>183.5328141</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R-Square: 0.358920  Coeff Var: 18.31573  Root MSE: 0.656495  log sec Mean: 3.584325

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type I SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>method_1</td>
<td>5</td>
<td>64.59155921</td>
<td>12.91831184</td>
<td>29.97</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>rater2</td>
<td>3</td>
<td>1.28202728</td>
<td>0.42734243</td>
<td>0.99</td>
<td>0.3972</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type III SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>method_1</td>
<td>5</td>
<td>64.59155921</td>
<td>12.91831184</td>
<td>29.97</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>rater2</td>
<td>3</td>
<td>1.28202728</td>
<td>0.42734243</td>
<td>0.99</td>
<td>0.3972</td>
</tr>
</tbody>
</table>

The test for operator effect fails to show a difference among operators ($\alpha=0.05$, $p=0.3972$). Also, the interaction term was not significant ($\alpha=0.05$, $p=0.7495$). The effect of method used was found to be significant ($\alpha=0.05$, $p<0.0001$). Post-hoc tests revealed that the following pair-wise differences:

Horizontal Tripod vs. Bubble with Base
Bubble without Base
Mandrel with Base
Vertical Lines
Vertical Grooves

Bubble with Base vs. Mandrel with Base
Vertical Lines
Vertical Grooves

Bubble without Base vs. Mandrel with Base
Vertical Lines
Vertical Grooves
Table 13. Summary of the results of post-hoc tests for the logarithm of time (sec)

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Ratio of Means</th>
<th>95% Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bubble with Base</td>
<td>3.8451</td>
</tr>
<tr>
<td></td>
<td>Bubble without Base</td>
<td>3.8702</td>
</tr>
<tr>
<td></td>
<td>Mandrel with Base</td>
<td>2.0109</td>
</tr>
<tr>
<td></td>
<td>Vertical Lines</td>
<td>1.6077</td>
</tr>
<tr>
<td></td>
<td>Vertical Grooves</td>
<td>1.8865</td>
</tr>
<tr>
<td>Horizontal Tripod</td>
<td>Mandrel with Base</td>
<td>0.5229</td>
</tr>
<tr>
<td></td>
<td>Vertical Lines</td>
<td>0.4181</td>
</tr>
<tr>
<td></td>
<td>Vertical Grooves</td>
<td>0.4906</td>
</tr>
<tr>
<td>Bubble with Base</td>
<td>Mandrel with Base</td>
<td>0.5197</td>
</tr>
<tr>
<td></td>
<td>Vertical Lines</td>
<td>0.4154</td>
</tr>
<tr>
<td></td>
<td>Vertical Grooves</td>
<td>0.4874</td>
</tr>
<tr>
<td>Bubble without Base</td>
<td>Mandrel with Base</td>
<td>0.5197</td>
</tr>
<tr>
<td></td>
<td>Vertical Lines</td>
<td>0.4154</td>
</tr>
<tr>
<td></td>
<td>Vertical Grooves</td>
<td>0.4874</td>
</tr>
</tbody>
</table>

The null hypothesis for time has been disproved. There is a significant difference between the first two bubble gauge methods and all other methods for the time for reorientation. There is a significant difference between tripoding and all other methods for time utilized for reorientation.

There is a significant difference between the time of reorientation of a transferable record of the path of insertion utilizing a circular level gauge with an indexed acrylic base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is a significant difference between the time of reorientation of a transferable record of the path of insertion utilizing a circular level gauge with a silicone index without a base versus the conventional recording techniques of tripoding, vertical lines and vertical grooves.

There is a significant difference between the time of reorientation of a transferable record of the path of insertion utilizing an embedded alignment mandrel into an indexed acrylic base versus the conventional recording techniques of tripoding but no significant difference versus vertical lines and vertical grooves.
V. 3.2 DISCUSSION OF ANALYSIS

The use of the natural logarithm has implications for the interpretation of the results. Typically, the difference in means is the parameter that is estimated, however when a log transformation is applied to data, the parameter that is being estimated is the ratio of the means of the groups being compared.

From the above analyses, it can be discerned that for both primary outcomes, degrees of error and time, the operator alone did not have a significant effect.

The Horizontal Tripod method had approximately 3 times the degrees of error as the Bubble with and without Base method. The Horizontal Tripod method had approximately 2.2 times the degree of error than the Mandrel with Base method. The Vertical Lines and Vertical Groove methods had 4 times the degree of error than the Bubble with and without Base method and the Vertical Lines and Vertical Groove methods had approximately 3 times the degrees of error than the Mandrel with Base method.

Overall it appears that the degrees of error was larger for the Horizontal Tripod, Vertical Lines, and Vertical Groove methods than for the Bubble with Base, Bubble without Base, and Mandrel with Base methods. A comparison of these two groups was carried out and it was found that the former group had approximately 3 times the degree of error than the latter group.

The Horizontal Tripod method takes approximately 4 times longer than the Bubble with Base and Bubble without Base methods; approximately 2 times as long as the Mandrel with Base method. Overall, the Horizontal Tripod Method had the longest times and the Bubble with Base and Bubble without Base methods had the shortest times. The Horizontal Tripod method took the longest. The Horizontal Tripod, Vertical Line and Vertical Groove methods appear to be the most error prone.
For the outcome: error in degrees, of interest is the interaction effect that was found between the evaluator and method used: evaluator classes performed differently for different methods. Inspection of Fig. 9 suggests that the Bubble with Base, Bubble without Base, and Mandrel with Base do not exhibit as great an interaction than the other three groups. Given that the aforementioned groups exhibited smaller degree of error this may make sense, and may speak to the issue of which method is the easiest, and which are more inconsistent and therefore, most difficult.

A non-parametric Krusker-Wallis analysis was also performed and the results are similar and further reinforce the normalized factorial ANOVA. The summary of the Krusker-Wallis analysis is Appendix C.

**During the evaluation of the results, there was concern with the variance of the tripod method for degrees error.** A possible explanation was that certain operators were not familiar with the technique even though they claimed to be so. The analysis was repeated a second time with all tripod errors greater than 7mm omitted from the raw data. The limit of 7mm was selected arbitrarily based on the assumption that very few reorientation attempts gave such a skewed result and therefore these must be due to operators without adequate working knowledge of the technique. Based on the repeated analysis the same differences were found to exist as when observations greater than 7mm are retained, but the difference is slightly smaller. Once again degree of error was found to be significantly different depending on method used.

Distribution of the results show that over 75% of all reorientation attempts yielded accuracy of 1.2 degrees or better with only 5% yielding 2.5 deg error. Distribution of data appears in Appendix B.
VI. DISCUSSION

Recording the path of insertion is admittedly an important step in removable partial denture fabrication. The tripod method is the most frequently taught and used method for this task, possibly because placing tripod marks is quick and easy and usually done properly. An exception of course should be made for a few practitioners that forget to lock the vertical arm of the surveyor when making the marks. Beyond this group that is not aware of the proper procedure, the small number of clinicians that tripod their casts are possibly adding a component of error to their frameworks. If the laboratory reorients to their marks with an approx. 1.3 degree error, which we found in our study, it is questionable if tripoding should be used at all. In selecting a method for recording the path of insertion more emphasis should be placed on reorientation and not on ease of initial placement.

Tripoding's accuracy is dependent on the skill of the operators and their persistence in accurately reorienting the cast. The group of students that had recently completed the removable partial denture course, primarily third year students achieved a 0.6 degree accuracy in their reorientation which was the best performing group. Comparatively, the residents had 1.8 degrees of error, the highest of all groups. This may be explained by the fact that the residents come from different schools with varying levels of instruction on tripoding and also an average of three years have lapsed from the time that the residents were taught tripoding and tripoding reorientation. The other group that had a large error in tripod reorientation was the group of laboratory technicians. Being professional lab technicians each with a different area of expertise does not automatically give them as a group the skill or persistence to achieve error free reorientations.
Vertical lines and vertical grooves also come with the same error as the horizontal tripod.

The three new methods have as a group significantly less error during reorientation. The air bubble or circular level gauges had the least error and were the favorite by practitioner preference. Davenport et al in their 1990 study also found a similar preference. In their study they had not located a suitable circular gauge to test and instead used two straight gauges at right angles to each other. Their study showed that level gauges were the most accurate. Polyzois' original recommendation of a circular gauge remained untested as also were the numerous proposals (Sarnat, Ansari, Ivanhoe) for a transferable recording index with an embedded alignment pin.

Our study was modeled similar to the Wagner and Forgue study and to the Davenport study. In the Davenport study a Dyer surveyor was used that had a fixed tilt table and was further modified by the attachment of a target disk for the error measurements. We requested and received this surveyor from England to use in our study. Preliminary testing however showed that the hinged arm of the surveyor allowed too much tilt and flex to be used in a precise study. In 1991 in the Journal of Dentistry (British) I. Ahmed and N. E. Waters published a report on the accuracy of dental surveyors. In their study they found that lateral loads of 81 - 110 cN (100gms) are applied to the arm of a surveyor during routine surveying procedures by an operator. Tilting error of a movable hinged arm can be approximately 0.2 degrees for a 100gm lateral force and as high as 0.5 degrees if trimming block-out wax with approximately 200gm lateral force. This represents a deflection of the surveying rod of at least 0.15mm during routine surveying which is about half of the commonly utilized .01 undercut.
The surveyors tested in the Ahmed study were the Krupps model and the Nesor surveyor but the results may be applicable to all movable hinged arm surveyors. Thus the Dyer surveyor was abandoned and we redesigned our study as described in the materials and methods section. The final result was more similar to the Wagner and Forgue testing design with the added advantage of a target disk that could be moved up and down very precisely without any lateral play as mentioned earlier. This feature allowed the approximation of the target disk to the tip of the stylus for exact measurements of the error in millimeters. This error was converted to degrees by basic trigonometry where the error in millimeters was the opposite side of the triangle and where the distance from the tilt table to the target disk was the adjacent, sides of a right angle triangle. The angle of error \( \theta \) was calculated: 
\[
\tan \theta = \frac{\text{opposite}}{\text{adjacent}}
\]
This angle of error is the angle the tilt table and affixed dental cast moved through, from the reorientation attempt.

In comparing our results to the Wagner and Forgue study we see that we found greater error in our reorientations for the tripod method: 1.29 degrees +/- 1.5 standard deviation compared to 0.76 degrees +/- 0.36 standard deviation of their study. The difference may be explained by different calibrations of the concentric circles of the target disk or different calculation methods. The greater error and standard deviation that we have may also be attributable to having a larger number of operators with different levels of experience. The Wagner and Forgue study was done in 1976 by only ten experienced laboratory technicians that may have been more accustomed to fabricating removable partial dentures in an era prior to implants. Furthermore there is no mention of the length of the stylus nor if the target disk could be lowered to meet the stylus in the Wagner and Forgue study.
The stylus that we used was the same one that was used in the Davenport study and both study designs allow the disk to be lowered to meet the stylus. Their results for tripoding error: 1.2 degrees error are similar to our results: 1.29 degrees error.

In comparing the results of the Davenport study to our results for the method of air bubble gauges we again see similarities. They found 0.2 degrees error where we found 0.33 degrees error. This difference might be due to their testing of two straight bubble gauges at right angles to each other while we tested a circular bubble gauge, or possibly this difference may simply be a small numerical discrepancy since the study designs were similar but not identical. An important point to note is that both in our study and in the Davenport study, the standard deviation for the bubble gauge method was very small which represents the consistently accurate reorientations achieved by many different operators. The bubble gauges or circular gauges as stated previously were the overall most preferred method and most accurate. A slight but insignificant advantage was found in our study for the circular gauge with the acrylic tray compared to the circular gauge without an acrylic tray. Since the difference is very small .33 degrees compared to .39 degrees average error, we can recommend using the circular level gauge without an acrylic base. Taking advantage of this would save some time and allow the construction of a "bubble gauge index" in the time it takes for silicone to set. The simplicity of the method is very impressive and it offers all the advantages mentioned of transferability, accuracy, long term recording and amazing ease of use. The weakness of the method is that it can only be used on surfaces that have previously been verified to be flat.

In our laboratory certain benches were found to be horizontally flat while other benches, indistinguishable to the eye, were found not to be flat.
In some cases only sections of a bench were horizontally flat. The easiest way to address this "weakness" is to place surveyors only on lab benches that have previously been verified to be flat.

The first reference of a transferable tray, recording of the path of insertion, indexed to the occlusal surfaces of the remaining teeth and related to the surveyor with an embedded pin was in 1981 by Sarnat. Though similar proposals were made by DeFiori in 1983, Ansari in 1994 and Ivanhoe in 1994, no testing had been done as part of their proposals. Each of these authors used different terminology to name their method. In our project the transferable acrylic record base with an embedded alignment pin and a silicone occlusal index has also been referred to as mandrel with base for short. A more descriptive name and possible suggestion for future use would be "indexed tray with alignment pin "a transferable device for recording the path of insertion. Its construction consisted of starting with a flat acrylic tray, which was lined with Reprosil (Dentsply/Caulk Milford, DE) to the occlusal surfaces of the remaining teeth. Previous proposals that recommended using modeling compound or acrylic for the indexing might risk damage to the cast and may not have any benefits. Once the silicone index is completed, a pin stabilized by the surveyor arm is embedded or luted to the tray with acrylic. Construction time is not great after an operator becomes familiar with the procedure and materials are easily found in the clinical or laboratory setting, however it is one more step and may not be welcomed by busy practitioners. The benefits of using the method are its accuracy, transferability, ease of reorientation and long-term recording of the path of insertion. A further use may be as a teaching tool since its orientation for seating resembles a framework being lowered towards the cast.
The indexed tray with alignment pin method in our testing had an average error of .49 degrees with +/- .34 S.D. Its accuracy was less than the bubble gauges but still considerably better than all the other methods tested. The small SD gives confidence in the methods' applicability. As Ivanhoe pointed out a transferable path of insertion record becomes more important in cases with surveyed abutment crowns. It may be appropriate to select the path of insertion recording method depending on the type and needs of each case.

The vertical lines method and the vertical grooves method all gave poor results and performed similar to the tripod method. Mean degrees error of 1.28 for the lines and 1.40 for the grooves (1.29 for tripoding). In our preliminary tests we tried a single milled groove in just one side of the cast with reorientation achieved by approximating a matching diameter pin to the groove until the operator was satisfied by the fit. The preliminary results showed unsatisfactory reorientation. The pin would break or chip the side walls of the groove during reorientation attempts if the fit was exact or if we used an undersized pin for reorientation then it would fit too easily even before good reorientation was accomplished and thus give poor results. The single groove method was thus abandoned. Applegate had recommended the three vertical grooves method but our results for the vertical grooves as well as Wagner and Forgue and Davenport's results for the vertical lines all showed weakness with these methods. A possible explanation of the difficulties with vertical lines and grooves is that when the cast is tilted, the analyzing rod is at an angle to the sides of the cast making assessment of parallelism difficult.
The study by J. Bowley and D. Cipra "Evaluation of the accuracy of cast reorientation to a surveyor by prosthodontic residents", tested only tripoding reorientation. The methodology of their study had a new approach. They used a machinist's digital height gauge to measure the vertical discrepancy of the three marks after the reorientation attempts and from these three vertical discrepancies calculate a single angle deviation. It is unclear if this single angle calculation is numerically equivalent to degrees error calculated in our study or the Davenport or Wagner study. Our assumption is that the numerical values of the Bowley and Cipra results do not correlate to the numerical value of all other studies since the design and methodology is so different. It is possible that the error we found and identified as 1.29 degrees may have been more or less depending on the methodology and the calculations. Taking this thought to its logical conclusion, none of the numerical results from different studies should be compared directly to each other.

The other possible interpretation is that the numbers are equivalent and therefore their residents achieved superbly accurate reorientations of 0.17 degrees error with +/- .14 SD utilizing the tripoding method.

The goal of all these studies is to evaluate the accuracy of reorientation methods and make recommendations on their use. This requires comparative results of different methods from within the same study. Such results would be comparable and based on them recommendations could be made for clinical and lab usage of a method.

Our study was designed to achieve this goal and modeled to include a large group of operators and a large number of methods (six) tested within one study. Despite the results found by Bowley and Cipra, we feel tripoding is a difficult and often imprecise method.
VII. DISCUSSION OF SURVEYING PRACTICES

Though our results have found improved reorientation with the newer methods, the significance must be evaluated based on expected utilization and current surveying practices. Clinicians unfortunately often leave surveying, design and recording the path of insertion to the laboratory technicians. A review of the literature shows that this is a common practice among general dentists.

T.D. Taylor et al in 1984 in a two part survey confirmed that at 51 U.S. Dental Schools the curriculum was consistent in subject matter and technique recommendations. There was some variation on hours-spent on teaching RPD design, but all responding dental schools taught that RPD design is the dentists' responsibility. In striking contrast are the responses from 303 dental laboratories that showed that 78% of laboratory technicians designed most or all of the RPDs.

Different reasons have been given to explain the decreased compliance with dental school education. W. Schwartz and M. Barsby in 1979 published on their concerns with the dichotomy between what was taught at the schools and what practitioners subsequently performed. The authors found surprising similarities in instruction among 18 British Dental Schools. Their conclusions were that the National Health Service fee structure was insufficient to allow practitioners to spend adequate time with removable prosthodontics and thus the dentist omitted basic steps or delegated them to the technicians.
J. Cotmore et al. in 1983 addressed whether the difference between teachings and clinical practice is due to lack of financial incentive or lack of adequate knowledge. A study of two groups of practicing dentists having graduated seven years apart reported on their RPD procedures. More than half (combined groups) felt that their level of dental school education for removable partial prosthodontics was inadequate. Significant differences were found between the two groups as far as surveying and design of their RPDs. The more recent graduates by a ratio of 2:1 surveyed and designed the framework as compared to the group of earlier graduates. These findings suggest that the level of knowledge of the practicing dentists influences their clinical procedures.

A Swedish study by Von Steyern et al. in 1995 similarly concluded that level of dental education determined dentists' RPD treatment procedures. The survey of 584 Swedish dentists showed that the graduates from the Umea Dental School were comfortable with their removable partial denture education while graduates from the Gothenburg Dental School disagreed with the adequacy of their education. Dentists that deferred design to lab technicians cited that the technicians design RPDs more frequently and were therefore more competent at it. In their study the authors state that 64% of dentists delegate surveying, determination of the path of insertion and design to the dental technician. Participants declared that the opportunity to attend small post graduate courses in the subject is desirable.
O. Sykora in 1995 published on removable partial denture practices after receiving responses to a questionnaire sent to 15 dental laboratories. The laboratories reported that very few dental casts (0-30%, median 10%) are surveyed and tripoded by the dentists. On a more positive note, there was a decrease in the number of frameworks designed by the laboratories at the dentists' request and an overall improvement in understanding the fundamental principles of removable partial denture design compared to McCrackens' 1962 report and to Sykora and Calikkocaoglu's 1970 report.

J. Wolfaardt et al in 1996 reported on the results from a questionnaire of 439 dentists, including 11 prosthodontists in Alberta, Canada. The responses showed that 75% owned a surveyor and 88% felt that surveying is important to the construction of a removable partial denture. A large number 89% "frequently" or "always" provided a design prescription, however only 14% "always" surveyed their cast. In response to the question "Technician surveys as they are more familiar with procedure?" 70% of the general dentists agreed with this, but 91% of the prosthodontists disagreed. Ten out of eleven prosthodontists reported that they frequently or always surveyed the cast. Half the respondents stated that continuing education courses in RPDs had improved their confidence and 79% desired further small group hands-on continuing education courses.

A questionnaire was distributed at the 1987 American College of Prosthodontics annual meeting, the results of which were published in 1989 by Burns et al. The survey examined RPD design and procedures of 195 prosthodontic specialists present at the meeting who anonymously completed the questionnaire. The results of concern are: 92% survey and tripod the master cast; 90% write a work authorization with a detailed description of the framework; 66% mark the retentive undercuts on the definitive cast.
Based on these reports we can conclude that less than a third of general dentists survey and record the path of insertion but there is a desire from general dentists to improve their knowledge level in regards to RPDs. The trend for improvement is already taking place from the observations that general dentists design their partials more frequently in recent years than in previous decades. Most prosthodontists already survey and record the path of insertion. They are more likely to incorporate the new recording methods into their practice in situations where a transferable record of the path of insertion is needed. Alternately in cases, which require the transfer of the path of insertion between two master casts, laboratory technicians can be requested to do so with one of these recording methods. A prerequisite is that lab technicians are informed of these methods through routine means.

The further utilization of the new recording methods as a replacement of traditional tripodding is difficult to ascertain and will depend primarily on education and perceived benefit. In 2001, R. Rudd and K. Rudd published a three-part review of possible errors during the fabrication of RPDs. 243 possible errors were listed. It is therefore obvious that recording the path of insertion and subsequent accurate reorientation is just one of many important steps that need to be performed for a proper RPD. If errors are occurring with surveying and reorientation, it would be difficult to identify the cause or source of error. The symptom of a misfitting framework can be caused by many of the 243 possible errors. Thus misfitting frameworks are simply remade with a better outcome hoped for in the second attempt.
VIII. DISCUSSION OF RPD USAGE

All review studies have found problems with retention, stability and framework integrity. Whether or not improved clinical and lab procedures need to be implemented depends on the prevalence of these problems with removable partial dentures. A goal for future research efforts may be to elucidate the origin of these problems and improve on them.

Benson and Spolsky (1979) at UCLA followed-up 135 RPDs over 7 years with a mean life span of 38 months and found that 60% had retention problems and 40% had poor or only fair fit.

M. Redford et al (1996) published results of the US National Health and Nutrition Examination Survey II-Phase I, which included evaluation data of prosthodontic appliances examined in 1988-1991. RPDs were evaluated for framework integrity, stability, retention, excessive tooth wear and presence of reline material. 44% of all RPDs lack stability and 25% lack integrity. 21% of lower RPDs and 6% of upper RPDs lack retention. Of the total RPDs 60% had at least one problem (inclusive of problems with cracked or worn acrylic and presence of temporary reline materials). Such a high rate of problems needs to be addressed, especially when removable partial dentures continue to be prescribed with great frequency for patients.
In the NHANES the total number of non-institutionalized civilians examined at the Mobile Examination Center was 7374 adults between the ages of 18 and 74. Based on this group, the percentage of the population that wears any type of removable denture is 21.4%. 40% of these dentures are RPDs, which represents 14 million people. Usage is highest in the 55-64 year olds group, of which over 22% wear a RPD. Based on these studies we can conclude that RPDs continue to have very high rates of problems and that RPDs are used by a substantial portion of the adult population. The RPDs examined in the NHANES were cast framework RPDs, which account for the majority of all RPDs. A study by B. Owall in 1989 on the prevalence of cast framework RPDs in North America evaluated 1374 consecutive cases at five major dental labs. Approximately 90% of RPDs constructed were found to be cast framework RPDs. Therefore any improvement of clinical and lab procedures could benefit these partials.

Given that an estimated 14 million Americans wear RPDs and 60% of them have at least one problem, does this correlate with decreased patient satisfaction or lead to decreased usage?

R. Frank et al (1998) in Seattle Washington evaluated treatment outcome of mandibular RPDs by surveying patients up to five years post-insertion. Of 420 respondents to the survey 74% were either completely or moderately satisfied with their partial. The remainder responded as slightly satisfied 6% or 20% dissatisfied to varying degrees.

Benson and Spolsky had found that the patients that reported good or fair acceptance of their prosthesis were 85%.
R. Cowan et al conducted two and four year telephone interviews of patients that had received RPDs at the University of Missouri-Kansas City School of Dentistry. At the two year evaluation of 290 patients 258 patients wore their partials (20 with complaints) and 32 did not wear their partials. At the four-year evaluation of patients who had been wearing their partials the first two years, 169 patients were interviewed and 156 wore their partials (4 with complaints) and only 13 more had stopped wearing them. It seems a little over one-tenth stop wearing their partials by two years and another tenth by four years.

There are also numerous usage reports in the international literature.

G. Carlson et al (1965) in Sweden reported 36% do not wear their RPDs at four years.

N. Jepson et al (1995) in England found that at three years 25% of 393 RPDs were not worn by their recipients and another 15% wore them occasionally but this study included 25% all-acrylic RPDs that have a known shorter life span.

J. Nyhlin and J. Gunne (1989) at the University of Umea, Sweden, conducted telephone interviews of 35 patients that had worn 40 RPDs for 1-2.5 years. They found that only 2 of the 40 RPDs were not being used.

A. Derry and U. Bertram (1970) found that 91% of 65 patients continued wearing their RPDs at two years.

In another Swedish study by B. Germundsson et al (1984) 68 patients with RPDs were recalled and examined at the University of Gothenburg. 25% of RPDs evaluated were found to have retention problems and 18% of the patients complained of poor fit. Most patients wore their RPDs, 87% with satisfactory comfort.
A. Vermeulin et al (1996) followed 748 patients with 886 RPDs for up to ten years. They concluded that the survival rate for RPDs is 75% after five years and 50% after ten years. Maintenance was provided during the study.

Certainly, various authors have reached different conclusions on the rates of early RPD usage but what can be agreed on, is that even the most promising survey results still show numerous patients that do not wear their RPDs. It might benefit the non-wearers and probably wearers alike if stability and retention was improved. The research shows that patient dissatisfaction and usage does correlate to clinically observed problems. No studies showed dissatisfaction without concurrent problems or problems without dissatisfaction to some degree. On an everyday clinical basis we attempt to improve patient's dissatisfaction and poor RPD usage when we evaluate a poor fitting prosthesis and recommend a new RPD with improved qualities.

It seems that the number of non-wearers are less than the number of RPDs with problems. Patients are often tolerant and determined in wearing their RPDs, but this should not diminish the need for further improvement of RPD fabrication and standardization of quality.

Factors beyond the problems mentioned that may negatively influence patients' removable partial denture satisfaction are overall poor health, wearing two RPDs (upper and lower) by one patient and RPDs that may not be needed since the remaining natural teeth satisfy esthetic needs and provide adequate function. Appropriate patient selection is always important.
IX. CURRENT RPD DESIGN AND FUTURE RESEARCH

Removable partial denture fabrication rules are constantly being reevaluated. Previous positions that RPDs can have a negative effect on supporting teeth and tissues have been modified by research stressing the importance of oral hygiene maintenance.

B. Bergman et al reported on a two, six, ten and twenty five year review of patients fitted with RPDs in 1968-1969. His reports were significant for demonstrating that RPDs in the presence of good oral hygiene do not lead to periodontal deterioration or increased risk of caries at abutment teeth.

F. Kratchovil et al reported on a five year follow-up of 203 RPDs and found that pocket depth around abutment teeth was not increased and mobility at abutment teeth was not increased compared to control teeth.

H. Hosman et al (1990) in a clinical crossover study showed that regardless of mesial or distal clasp assembly orientation, leverage was not found to exist. Migration of the most distal abutment either did not occur or was in a mesial direction contrary to common beliefs. Much debate continues to exist about traditional design principles.

A critical analysis of the literature related to traditional biomechanical design principles was reviewed at a two day workshop in Copenhagen in June 1999. The report authored by B. Owall et al represents the consensus of all authors present at the workshop. The agreement was that there is little scientific support for much of the traditional design principles. The authors stressed the importance of oral hygiene maintenance and advocated RPDs with an open design to improve hygiene.
Neither conventional held design principles nor current recommendations for open hygienic designs diminish the importance of improving on commonly encountered problems of poor integrity, stability and retention. Future research efforts could be directed to identifying the source of these partial denture problems. What steps in partial denture fabrication account for them? Could more careful surveying, design and waxing of the framework achieve improvements in fit and retention?

In relation to our project, could surveying of the refractory cast as a routine step lead to improved fit? After block-out and duplication of the master cast, the current lab technique includes a transfer of the design drawing to the refractory cast to outline the wax-up or by "eyeballing" decide on component placement. Despite care taken by the labs at this stage, rigid components are still waxed and cast into undercuts and then need to be relieved at the finishing stages. Would labs benefit from using a transferable index of the path of insertion to reorient the refractory cast and correctly identify the areas of rigid component placement?

Review studies of RPDs in current service have found deficiencies in areas of stability, retention and integrity. Improvements in quality should be attempted. The majority of prosthodontists have reported that they tripod their casts and would be the most likely group to utilize the new methods for the added advantage of transferability. Dental laboratories that minimize time spent on proper block-out could benefit from using the new methods to reorient the refractory cast and identify correct positioning of rigid components.
X. CONCLUSIONS

The current techniques of recording the path of insertion: tripoding and vertical lines and the less common vertical grooves were compared to new alternate methods of recording the path of insertion. The new methods were a circular level gauge with and without a supporting tray for the occlusal index; and an indexed tray with an alignment pin. The new methods were found to enable more accurate reorientation of the working cast to the originally selected path of insertion. The new methods could have the added advantage of being transferable between duplicate models. This transferability can allow the orientation to the same path of insertion of the refractory cast of the partial denture or the orientation of duplicate casts used at earlier stages for survey crown fabrication. The new methods allowed all tested groups: students, residents, and faculty and lab technicians to achieve accurate reorientations. Operator preference was in favor of the new methods.
XI. BIBLIOGRAPHY


Besson OL, MattosGC, Ribero RF. Surveying removable partial dentures: the importance of guiding planes and path of insertion for stability. J Prosth Dent 1997; 78: 412


Hansson JG, Axinn S, Kopp EN. Surveying. JADA 1975;91: 826.


Miller EL. Removable partial prosthodontics. Williams & Wilkins, 1972; pg 116.


XII. APPENDICES
APPENDIX A

PICTURES

FIG. 1. NEW METHOD PROPOSALS FOR RECORDING THE PATH OF INSERTION

FIG. 2. DENTAL CAST WITH EMBEDDED RECEP'TICLE FOR POINTER
FIG. 3. MEASUREMENT STATION WITH TARGET DISK LOWERED ONTO POINTER

FIG. 4. CLOSE VIEW OF TARGET DISK ON POINTER
FIG. 5. METHOD 1: CIRCULAR LEVEL GAUGE WITH INDEXED ACRYLIC BASE

FIG. 6. METHOD 1: CIRCULAR LEVEL GAUGE WITH INDEXED ACRYLIC BASE POSITIONNED ON CAST
FIG. 7. METHOD 2: CIRCULAR LEVEL GAUGE ON SILICONE INDEX WITHOUT ACRYLIC BASE

FIG. 8. METHOD 2: CIRCULAR LEVEL GAUGE ON SILICONE INDEX POSITIONED ON CAST
FIG. 9. METHOD 2: UNDERSIDE VIEW SHOWING OCCLUSAL INDEX

FIG. 10. METHOD 3: INDEXED BASE WITH ALIGNMENT PIN
FIG. 11. METHOD 3: PLACEMENT ON DENTAL CAST

FIG. 12. METHOD 3: POSITIONED ON DENTAL CAST
FIG. 13. METHOD 4: TRIPOD MARKS AND ALIGNMENT TOOL

FIG. 14. METHOD 4: VERTICAL LINES
METHOD 5: VERTICAL GROOVES
FIG. 15. ALIGNMENT WITH METHOD 5: VERTICAL LINES

FIG. 16. ALIGNMENT WITH METHOD 6: VERTICAL GROOVES
APPENDIX B DISTRIBUTION OF DATA

The following figures show that the log transformation brings the distribution of the outcome variables closer to normalization. All assumptions were also tested during the ANOVA modeling step.

Fig 11. Distribution of variable: error in degrees

Fig. 12 Distribution of logarithm of error in degrees
Logarithmic transformation satisfactorily ‘normalizes’ distribution of error in degrees.
Fig. 13. Distribution of variable: time (seconds)

Fig. 14. Distribution of logarithm of time (seconds)

Logarithmic transformation ‘normalizes’ distribution time.
APPENDIX C

Statistical Analysis Non-Parametric

Comparison of mean SECONDS across METHOD:

Kruskal-Wallis test was significant, $p < 0.001$.

Pairwise comparisons of SECONDS across METHOD (each at the 0.05 level of significance):

- METHOD 1 was significantly different from each of METHOD 3 through 6;
- METHOD 2 was significantly different from each of METHOD 3 through 6;
- METHOD 3 was significantly different from each of METHOD 4 through 6.

Comparison of mean DEG_ERR (degree error) across METHOD:

Kruskal-Wallis test was significant, $p < 0.001$.

Pairwise comparisons of DEG_ERR across METHOD (each at the 0.05 level of significance):

- METHOD 1 was significantly different from each of METHOD 4 through 6;
- METHOD 2 was significantly different from each of METHOD 4 through 6;
- METHOD 3 was significantly different from each of METHOD 4 through 6.

Comparison of mean SECONDS and DEG_ERR by TYPE of reader:

One-way analyses of variance, no statistically significant mean differences were noted ($p = 0.680$ for SECONDS, and $p = 0.263$ for DEG_ERR).