Occlusal stability is maintenance of the position of the teeth as a result of the equilibrium of all factors, including those associated with the adaptive capacity of the masticatory system. The term is not generally considered in the dental literature as a subject entity but rather as a point to be considered in orthodontic and occlusal adjustment therapy. Although occlusal stability is a desirable characteristic of the dentition, it is not universally accepted as a goal or principle in occlusal adjustment therapy.\textsuperscript{1-8}

Shifting of the teeth as an unavoidable or desirable consequence of an occlusal adjustment appears contrary to the principle of occlusal homeostasis.\textsuperscript{9, 10} The objective of this investigation was to determine whether or not an occlusal adjustment technique based on the principle of occlusal stability will result in shifting or movement of the teeth.

METHODS AND MATERIALS

Stereophotogrammetry, with some modifications, has been applied to dentistry chiefly as a volumetric determination tool.\textsuperscript{11-19} It was used in the present study to determine tooth movement following an occlusal adjustment.

Eight subjects were selected from those who underwent an initial screening examination at The University of Michigan School of Dentistry. The subjects chosen were those who presented the following characteristics: (1) at least 80 percent of the posterior teeth in opposition in centric occlusion in both maxillary and mandibular jaws, (2) no fixed or removable prosthetic appliances, (3) at least 18 years of age, and (4) no clinically detectable periodontal disease.

The functional analysis and occlusal adjustment followed the outline suggested by Ramfjord and Ash.\textsuperscript{9}

In order to accurately measure and study changes in occlusal stability represented by serial stone casts, it was necessary to scribe reference points on the teeth with restorations. The points for reference were made by precisely drilling a small hole with a number \( \frac{1}{2} \) round bur in the dental fillings deep enough to allow the
penetration of the impression material. One point on each tooth involved in the occlusal adjustment was called the “tooth point” (TP), and points on two different reference teeth were called “reference points” (RP).

A maxillary stone cast was made for each patient (1) immediately upon completion of the occlusal adjustment and marking of the reference points (base line), (2) six weeks later, and (3) twelve weeks later.

The photographic system employed was designed and built by Cotter and adapted so that a three-dimensional picture of dental casts could be produced (Fig. 1).

Casts were oriented to the back of the calibrated glass grid with the occlusal surfaces of the teeth facing the camera. The grid in which casts were in contact was perpendicularly oriented to the optical axis of the camera lens. The calibrated glass grid constituted the reference plane from which linear and angular values could be determined. The stone casts were stereoscopically photographed and negatives of the two photographs were converted into 64 by 64 mm. glass diapositives by contact printing. A schematic drawing of a diapositive is shown in Fig. 2.

For the purpose of this study, measurements were made on stereopairs of diapositives—one expressing the X coordinate and the other representing the Y coordinate for each point marked on the teeth, each grid line intersection, and each corner of the film. The measuring instrument used was a Mann comparator (Fig. 3).

Once the casts were photographed in two different positions, the TP and RP
points appeared in a slightly different relationship to the glass grid on each stereopair. The difference between $X$ and $Y$ coordinate values was used to establish $Z$ coordinates for each of the points. The $Z$ coordinates were considered the three-dimensional representation of those points. Consequently, mathematical computation could be used to calculate the distances between the $TP$ and $RP$ points.

**ANALYTICAL PHOTOGRAMMETRY**

The desired measurements are made from a stereopair of photographs. Fig. 4 illustrates the coordinate system and the terminology for a single photograph. The fiducial marks are made on the film format of the focal plane, and they define the $x$- and $y$- axes from which all measurements on the photograph are referred. The
Fig. 4. Schematic drawing of coordinate system.

The focal length is the distance from the perspective center to the focal plane. The principal point is the intersection of the lens axis and the focal plane. The image point \( P \) is the intersection of the focal plane and a ray from the object point through the perspective center.

The relative positions of the principal point and the image point are referred to the \( x \)- and \( y \)-axes. The plate coordinates of all image points must be transferred from the fiducial axes to a set of axes with its origin being the principal point.

After all image coordinates have been transferred, they must be corrected for lens distortion. Fig. 5, A, illustrates a typical graph of radial distortion with respect to angles from the optical axis. Radial distortion is a “shift” of an image along a radial line from the principal point to the image point. Fig. 5, B, illustrates the tangential distortion which is a “shift” of the image point normal (perpendicular) to the radial line.

If two pictures from two different camera positions are taken and if the camera’s focal planes are not coplanar (this is the usual case), the general geometric conditions will occur as shown in Fig. 6.

Two constant conditions may arise from situations represented in Figs. 4 and 6: (1) collinearity condition—the line from the object point \( P \) to the image point \( P_{pl} \) and to the perspective center \( C_1 \) is straight (same is true for the line \( P - P_{p2} - C_2 \)); (2) coplanarity condition—the lines \( P - P_{p1} - C_1 \) and \( P - P_{p2} \) form a unique plane, and the points are said to be coplanar.

Either the collinearity or coplanarity condition is required for the formulation of analytical photogrammetry. A few of the object points have one, two, or three ground reference parameters \((X, Y, Z)\) coordinates. With the knowledge of the plate coordinates of many image points and the ground coordinates of a few of
these image points, the ground coordinates of the remainder can be determined by analytical methods.

The actual computation is the method described by Cotter. However, a digital computer is employed for two reasons: (1) speed of computation and (2) reduction of round-off error.

**RESULTS**

Distances between tooth points and reference points were analyzed for differences in measurements taken before treatment (base line) and 45 and 90 days after treatment, respectively. Since the observations were not independent, the mean differences of the individual tooth and reference points were analyzed by means of the paired
t test. It was found that the mean differences between the base-line and 45 day measurements and between the base-line and 90 day measurements were not statistically significant (p > 0.20).

The analysis of tooth movement per subject is shown in Table I. The variation of the observations within and between the subjects was analyzed by means of an $F$ ratio to test the significance of difference among the rows and columns. It was found that there was no statistically significant difference among means of the different rows and columns (Table II).

**DISCUSSION**

Although the results indicate that a proper execution of an occlusal adjustment provides tooth positions which are stable up to 0.1 mm., it is possible that shifting of teeth occurred which the stereophotogrammetric system was not able to detect because of the error of the system (+0.106 mm.).

Considering the fact that the error of the system was determined to be ±0.106 mm., and this is of the same magnitude as the mean differences between the base line and each of the two groups, it appears that the mean differences represent only the error of the system. However, the mean differences after 45 and 90 days of treatment could also be twice as much as that which was obtained or there could be no movement at all. Even with a small sample, it is very unlikely that the error would be exclusively negative or positive.

A sign test was carried out to determine if any trends in individual tooth scores could be determined. There was no indication that there was a trend in the data which might indicate a shifting of the teeth.

One limitation of this study is caused by the time interval between measurements. A tooth might shift immediately after the occlusal adjustment, due to the redistribution of forces, and then shift back to its original position prior to the observation time. Further investigations with the use of additional and more closely spaced observations, as well as additional subjects, are indicated.
Table I. Analysis of tooth movement (eight subjects)*

<table>
<thead>
<tr>
<th>Subject</th>
<th>0-45 Days</th>
<th>0-90 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.065</td>
<td>-0.025</td>
</tr>
<tr>
<td>2</td>
<td>+0.075</td>
<td>+0.036</td>
</tr>
<tr>
<td>3</td>
<td>+0.776</td>
<td>+0.775</td>
</tr>
<tr>
<td>4</td>
<td>+0.081</td>
<td>+0.134</td>
</tr>
<tr>
<td>5</td>
<td>-0.453</td>
<td>-0.552</td>
</tr>
<tr>
<td>6</td>
<td>+0.613</td>
<td>+0.616</td>
</tr>
<tr>
<td>7</td>
<td>+0.178</td>
<td>+0.100</td>
</tr>
<tr>
<td>8</td>
<td>+0.220</td>
<td>+0.262</td>
</tr>
<tr>
<td>Total</td>
<td>+1.425</td>
<td>+1.336</td>
</tr>
<tr>
<td>Mean</td>
<td>0.178</td>
<td>0.167</td>
</tr>
</tbody>
</table>

*The formula used is:

$$\bar{\Delta} = \frac{\sum di}{n}$$

where $n = \text{Number of differences per subject}$, $di = \text{differences between mean distances}$, and $\bar{\Delta} = \text{mean of differences per subject}$.

Table II. Analysis of variance*

<table>
<thead>
<tr>
<th>Sum of squares</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row means</td>
<td>2.162</td>
<td>7</td>
</tr>
<tr>
<td>Column means</td>
<td>0.001</td>
<td>1</td>
</tr>
<tr>
<td>Residual</td>
<td>2.179</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>4.342</td>
<td>15</td>
</tr>
</tbody>
</table>

*F(7,7) = 0.99; F(1,7) = 0.003. Accept the hypothesis of no difference among means rows and columns.

Unless all the teeth are evaluated, it is impossible to know whether or not some teeth not involved in the adjustment have shifted. However, on the basis of the present study, it can be stated only that those teeth involved in the occlusal grinding did not shift (±0.106 mm.). The method of photogrammetry can be used for all teeth, but the large number of reference points needed can create a problem when restorations are to be replaced because of the drilled points. Contour lines can be used instead of reference points, but they require special equipment. Holographic methods can also be used, but they have the same requirements for interpretation. Common to all systems is the need for a known reference plane which does not shift as a result of the occlusal adjustment. Possible movement in the vertical plane can negate data derived from just two planes.

SUMMARY

An investigation of occlusal stability of teeth after occlusal adjustment was conducted. The eight patients who participated in this study presented occlusal prematurities and interferences (interceptive and deflective contacts) which were eliminated by selective grinding according to the principle of obtaining and maintaining occlusal stability.

To measure changes in occlusal stability, reference points were scribed on the
teeth; base-line, 45 day, and 90 day serial stone casts were obtained. Each cast had one point on each tooth involved in the occlusal adjustment (tooth point) and one or two different teeth not involved in the grinding procedure (reference points).

Each cast was photographed from two camera positions. The stereopairs thus obtained were placed on the stage of a Mann comparator to determine X and Y coordinates. The Z coordinates were mathematically computed. Likewise, the measurements of the distances from reference points to tooth points were determined by means of analytical photogrammetry.

The statistical analysis disclosed that the mean differences between the base-line and 45 day measurements and between the base-line and 90 day measurements were not statistically significant.

CONCLUSIONS

Within the limits of the study the following conclusions were made:
1. Tooth movement is not an unavoidable sequel of an occlusal adjustment which is performed according to the principle of providing or maintaining occlusal stability.
2. Stereophotogrammetry is suitable for measuring tooth movement within an error of ±0.106 mm.

References

Dr. Vale
Faculty of Dentistry
Federal University of Rio/Grande/Do/Sul
Porto Alegre, Brazil, S. A.

Dr. Ash
Department of Occlusion
The University of Michigan
School of Dentistry
Ann Arbor, Mich. 48104