In the diversified literature on occlusion and its role for functional patterns of the masticatory system, two conflicting concepts stand out: (1) canine protection as described by D’Amico and others is said to favor a vertical chewing pattern and to prevent wear of teeth, as in lateral occlusion where the canine guides the mandibular movement directly through contact or indirectly through periodontal receptors; and (2) group function as discussed by Beyron following his observations on Australian Aborigines implies contact and stress on several teeth in lateral occlusion and indicates abrasion as a positive and inevitable adjustment.

Telemetric studies have proved tooth contacts to occur during chewing, contacts initiating periodontal receptor signals. These guiding contacts are considered to be irregular without sliding into occlusion. The cranial part of the chewing cycle motion is analyzed with different methods, and various opinions prevail. Thus, Jankelson et al report lack of uniformity of the cranial part of the cycle, while Suit et al report contradictory observations.

The effect of the type of occlusion on the general chewing pattern has been the object of many investigations. Ahlgren reports more regular mandibular movements in test subjects with “normal” occlusion. Shepherd as well as Koivumaa found a relationship between the pattern of mandibular movements and the type of occlusion. However, only occasional studies deal with the effect of changes in the occlusal pattern on the masticatory motion. Beyron reported observations of the change to the bilateral chewing pattern after alteration of the occlusion. Butler and Zander found a difference in the tooth contact pattern in two test subjects rehabilitated with two types of fixed partial dentures. Such observations indicate adaptability in the masticatory system to changes in the occlusal pattern. However, there are rarely any detailed reports on the shape and pattern of the masticatory cycle following a change in the occlusal pattern in the individual.

The present study was designed to test the effect of two distinctly different occlusal designs on the general chewing pattern as well as the movement in the terminal part of the chewing cycle. Test persons were chosen in this pilot study from patients who had received complete fixed implant dentures in the maxillae and had a natural mandibular dentition.

TEST PERSONS

Five test subjects (two men and three women; mean, 57 years of age; range, 39 to 70 years of age) were chosen for the present study. All had received osseointegrated oral implant fixed complete dentures in the maxillae. They had their own teeth or fixed restorations in the mandible, including at least the first molars.

The reasons for rehabilitation with osseointegrated fixed complete dentures were poor denture function or psychologic problems associated with complete
maxillary dentures. All the fixed complete implant dentures were constructed with rigid gold frameworks and acrylic resin occlusal surfaces. The occlusion in all five patients was given the pattern of a distinct canine protection (Fig. 1). After an adaptation period of 4 months, registration of the jaw movements was affected as described below. Thereafter the occlusion was modified to group function. A second registration was performed 5 months later.

The original plan to test the effect of changing the occlusion back to canine protection after the second registration was not possible for more than two of the five test persons, as the remaining three lived at some distance from Gothenburg and were unwilling to undertake yet another series of journeys. The remaining two test subjects (Nos. 1 and 4) participated in the third experiment, and the final registrations were made 6 months after occlusal rearrangement.

METHODS

Jaw movements during chewing were registered with light-emitting diodes (LED) described in detail by Karlsson 14 and Jemt and Karlsson. 15

Three reference LED attached on a spectacle frame were placed on the test subjects. The frame has been shown to be very stable during chewing function. 15 One mobile LED was placed on a tooth in the mandible by means of adhesive resin. The light signals from the LED were recorder by two cameras placed in a right angle to each other. White bread cut in pieces of different sizes was used as the test food. The test subjects had a free choice of bolus size and chewing side.

Measurements

The movements of the diodes were recorded on a digital tape recorder and then analyzed by a computer. The analyses of the chewing performance regarding chewing rhythm, mandibular displacement, and velocity were performed as described by Jemt et al 16 and Jemt and Karlsson. 15 The first, third, and then every third chewing cycle were used.

The most cranial position in the chewing cycle (y axis) was determined. At this position also the lateral and sagittal positions of the mandible were noted. The approach angles and angles of departure were measured from the vertical line to a line drawn between the most cranial position in the cycle and a point vertically 1.5 mm before and after this position (Fig. 2). Lateral and sagittal angles are thus obtained for both approach and departure. The results were compared intrindividually, and the Student t test for paired observations was used for statistical analysis.

RESULTS

Registration with canine protection occlusion

The mean lateral and sagittal approach angles at closing were greater than corresponding angles of departure (Table I). This difference was significant for the lateral angles ($P < .05$).

Mean cycle duration was calculated to 0.7 second (range, 0.58 to 0.87 second) (Table II). The closing phase had the longest duration of the three phases of the chewing cycle (Table II). Maximal lateral shift was mostly found in the closing phase and at a mean of 3.3 mm. In addition, total displacement of the mandible was most often found to be greater in the closing phase (Table III). The mean velocity of the opening phase was higher than the mean closing velocity, and the maximal peak velocity was most often found in the opening phase (Table IV).

Registration with group function occlusion

With group function occlusion the lateral and sagittal approach angles were larger than those angles of
departure, although these differences were not statistically significant (Table I). Mean cycle duration was found to be 0.67 second (range, 0.63 to 0.78 second). The duration of the different phases of the cycle was again longer for the closing phase and shortest for the occlusion phase (Table II). With regard to mandibular displacement (Table III) and mandibular velocity (Table IV), the opening phase was the shorter, and the maximal lateral shift mostly occurred in the closing phase where the mean velocity was lower.

Differences between the two occlusion designs

It was possible to distinguish an individual chewing pattern that was repeated in the group function registration. There were no significant differences between the two occlusion patterns regarding the lateral and sagittal angles in the approach to or departure from occlusion (Table I). When the mean values (Table I) were analyzed, a slightly steeper movement path could be noted in the canine protection design.

The most cranial position in the chewing cycles varied naturally during the chewing period and was never exactly repeated in all three dimensions simultaneously (Table V). This variation, expressed as the standard deviation (SD) in Table V, was greater in group function occlusion than in canine protection occlusion for all but one test subject (subject No. 1) in all three dimensions and in two dimensions for the fifth test subject (subject No. 1). This patient showed a greater SD in canine protection than in group function protection occlusion for all but subject No. 1 and in two dimensions for subject No. 4. This patient showed a steeper movement path than the other test subjects.

The mean cycle duration did not change with change of occlusion pattern, nor did the durations of the different parts of the cycle (Table II). All test subjects maintained the same chewing rate from the first registration to the second registration.

With group function occlusion the test subjects had a greater total opening and closing mandibular movement as well as lateral shift when compared with canine protection occlusion (Table III). These differences were significant \(P<.05\). In addition, the mandibular velocity was greater in the group function registration \(P<.01\) (Table IV).

The difference between the mean opening and closing displacement was slightly less for the canine protection occlusion than for the group function occlusion for most of the test subjects, indicating a more even displacement (Table III). All five test subjects preferred the group function occlusion, which felt more comfortable than the canine protection occlusion.

Third registration after return to canine protection occlusion

The cycle duration was stable for both test subjects. Only minor changes could be noted in the chewing rhythm after the occlusal change. This was valid for the general pattern as well, where it was still possible to recognize general individual features of the mastication pattern throughout the whole test period. Both subjects returned to the original canine protection occlusion where the opening displacement approximated the closing displacement and where indications were observed for reestablishing a more vertical chewing pattern, compared to the group function registration.

The approach angles and angles of departure decreased, resulting in a steeper terminal movement similar to or steeper than the first canine protection registration, with the exception that the lateral angles of subject No. 1 were slightly increased.

The results of the two test subjects differed, and test subject No. 4 fit well into the pattern of the first canine protection registration. This test subject showed a slight decrease in opening and closing displacement as well as in maximal lateral displacement. The variation in the most cranial position of the chewing cycle decreased in all three dimensions. The other test subject (No. 1) showed a slight increase in the mandibular

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Table II. Mean duration (\(x \pm SE [\bar{x}]\)) of chewing cycles and part of chewing cycle during chewing of bread (in seconds)

<table>
<thead>
<tr>
<th>Duration</th>
<th>Cycle duration</th>
<th>Opening</th>
<th>Closing</th>
<th>Occlusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canine protection</td>
<td>0.7 ± 0.05</td>
<td>0.26 ± 0.02</td>
<td>0.33 ± 0.03</td>
<td>0.11 ± 0.01</td>
</tr>
<tr>
<td>Group function</td>
<td>0.67 ± 0.07</td>
<td>0.26 ± 0.02</td>
<td>0.32 ± 0.02</td>
<td>0.09 ± 0.01</td>
</tr>
</tbody>
</table>

---

Table III. Mean maximal (\(x \pm SE [\bar{x}]\)) lateral shift and mean total mandibular movement (\(x \pm SE [\bar{x}]\)) at opening and closing during chewing of bread (displacement in millimeters)

<table>
<thead>
<tr>
<th>Maximal lateral shift</th>
<th>Total opening movement</th>
<th>Total closing movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canine protection</td>
<td>3.3 ± 0.9</td>
<td>15.9 ± 1.5</td>
</tr>
<tr>
<td>Group function</td>
<td>4.8 ± 0.9</td>
<td>19.4 ± 1.7</td>
</tr>
<tr>
<td>Difference</td>
<td>(P&lt;.05)</td>
<td>(P&lt;.05)</td>
</tr>
</tbody>
</table>
displacement, and only the variation in the sagittal dimension of the most cranial position showed a decrease.

**DISCUSSION**

The aim of the present study was to observe the influence of two distinctly different occlusion patterns and the masticatory movement of the mandible. Consequently, individuals with removable prostheses could not serve as test subjects. Subjects with a natural dentition and/or a fixed restoration were thus necessary, provided that the occlusion pattern could be readily altered. A suitable type of test subject was a patient treated with a complete fixed implant maxillary denture where the occlusal surfaces were acrylic resin, which is easy to reshape. They were also to have a natural lower dentition, possibly restored by fixed partial dentures on natural teeth. Because most patients in the Gothenburg study\textsuperscript{13} of osseointegrated oral implant fixed complete dentures received implants in the mandible, the above requirement was met by only a few subjects, five of whom were asked to participate in this study.

The conscious selection of test subjects from those treated with osseointegrated maxillary fixed complete dentures was based on the assumption that long-time wear of complete maxillary dentures had eliminated the nervous memory of mandibular movements of their earlier complete natural dentition. Thus a new baseline would be set up with the new occlusion, allowing for more nondisturbed comparisons within the present experiment.

The Selspot system has been shown to be suited for analyzing mandibular movements in single clinical situations\textsuperscript{15} as well as in repeated situations over longer time spans.\textsuperscript{18} For analyses of the general chewing pattern the precision of the method has proved suitable, and Jemt\textsuperscript{17} has furthermore shown that analyses of smaller movements, such as differences in the terminal positions in the chewing cycle, coincide well with comparable results reported by others using different methods.

In this study uniformity of the angles of approach or departure through the chewing period was not found. This coincides with observations by Jankelson et al.\textsuperscript{6} The angle inclination seems to vary from cycle to cycle, and no systematic guidance could be noted, which also is in accordance with the findings of Atkinson and Shepherd.\textsuperscript{19} These findings are probably due to an effect of the test food. This could also explain the differences in results compared with Suit et al.,\textsuperscript{7} who deliberately selected a very soft test food. With the type of test food used in the present study there does not seem to be any repeated terminal position into centric occlusion (Table V). It indicates a “functional occlusal area” for contact during chewing.\textsuperscript{17}

However, lateral terminal tooth contacts cannot be disregarded and have been reported by others.\textsuperscript{5} These lateral terminal cycles were not excluded in the analysis, as they were in the study by Suit et al.,\textsuperscript{7} who paid attention only to the cycles that attended full centric occlusion closure. Because these lateral terminal cycles were included in the analysis, they decreased the differences between the mean angles (Table I) in two occlusions. Nevertheless, the occlusion seems to affect the terminal occlusal pattern by decreasing the variation of the $x$, $y$, and $z$ coordinates for the terminal position in the canine protection occlusion (Table V), which would be an expected change in relation to the design of the occlusion.

The adaptation to this decreased “occlusal area” must have been developed through numerous lateral contacts during mastication and empty movements.

The aim of denture occlusion is to obtain as balanced an occlusion as possible, and this occlusion ought to be maintained when rehabilitating with osseointegrated

### Table IV. Mean and mean maximal ($\bar{x} \pm SE [\bar{x}]$) mandibular velocity at opening and closing during chewing of bread (in millimeters per second)

<table>
<thead>
<tr>
<th></th>
<th>Maximal Opening phase</th>
<th>Maximal Closing phase</th>
<th>Difference between opening and closing phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canine protection</td>
<td>98 $\pm$ 8.8</td>
<td>62 $\pm$ 4</td>
<td>53 $\pm$ 5.5</td>
</tr>
<tr>
<td>Group function</td>
<td>126 $\pm$ 9</td>
<td>77 $\pm$ 5.1</td>
<td>65 $\pm$ 6.2</td>
</tr>
<tr>
<td>Difference</td>
<td>$P&lt;.01$</td>
<td>$P&lt;.01$</td>
<td></td>
</tr>
</tbody>
</table>

### Table V. Variation in positions in three dimensions at most cranial position for each cycle (expressed as SD)

<table>
<thead>
<tr>
<th>No. of test subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canine protection</td>
<td>1.02</td>
<td>0.38</td>
<td>0.25</td>
<td>0.39</td>
<td>0.33</td>
</tr>
<tr>
<td>Group function</td>
<td>0.83</td>
<td>0.67</td>
<td>1.07</td>
<td>1.71</td>
<td>0.71</td>
</tr>
<tr>
<td>Vertical position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canine protection</td>
<td>0.53</td>
<td>0.45</td>
<td>0.7</td>
<td>1.11</td>
<td>0.68</td>
</tr>
<tr>
<td>Group function</td>
<td>0.98</td>
<td>0.65</td>
<td>1</td>
<td>1.95</td>
<td>0.84</td>
</tr>
<tr>
<td>Sagittal position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canine protection</td>
<td>0.44</td>
<td>0.29</td>
<td>0.61</td>
<td>0.4</td>
<td>0.43</td>
</tr>
<tr>
<td>Group function</td>
<td>1.88</td>
<td>0.68</td>
<td>0.86</td>
<td>1.26</td>
<td>0.91</td>
</tr>
</tbody>
</table>
restorations. Thereby, it is possible to have an unchanged occlusal area, avoiding an increase of lateral stress that should be avoided in new osseointegrated restorations.

Klineberg\(^\text{20}\) has pointed out the importance of the feedback mechanism between mechanoreceptors in the temporomandibular joint and the functional mandibular movement pattern. These receptors seem to control to some extent the uniformity and degree of displacement of the chewing cycle. In addition, a probable change in the input signals from the periodontal receptors after occlusal adjustment seems to affect the functional movement of the mandible by an increase in the lateral excursion during the closing phase.\(^\text{21}\) This latter study indicates an adaptability in the masticatory system to changes in the occlusal pattern that is in accordance with the conclusions of other studies.\(^\text{11,12}\)

Furthermore, in this study there seems to be an adaptation to the occlusal change with greater lateral movements in group function occlusion, a change in accordance with Hannam et al,\(^\text{21}\) as well as a greater movement pattern in general.

All but subject No. 1 showed a very stable duration of the chewing cycle between the recordings.\(^\text{18}\) With this stable rhythm and increased movement in group function is an increased velocity of the mandible (Table IV). Thus there seems to be a basic individual chewing rhythm for the same bolus type and size, and this rhythm is not so easily changed as the degree of mandibular displacement, which is more unstable.\(^\text{18}\) In this study this variation of displacement and mandibular velocity seems to be obviously randomly varied, as there is a tendency for an increase in group function (Tables III and IV).

In accordance with other studies, the present pilot study shows that the occlusal pattern has a certain influence of the mandibular movement pattern during chewing. This is especially obvious when a test subject shows extreme variation of occlusion, compared with “normal” occlusion. The tendency in this limited population was that, compared with a canine protected occlusion, the mandibular pattern in group function occlusion showed a greater degree of movement and higher mandibular velocity. The test subjects also seemed to use a greater functional occlusal surface, indicating that the teeth to some extent influenced the terminal occlusal part of the chewing cycle.

**SUMMARY**

The effect of the type of occlusion on mandibular chewing patterns was tested on five subjects rehabiliated with fixed complete implant dentures in the maxillae. The chewing pattern was registered by LED (Selspot system) attached on a mandibular tooth and on spectacle frames as a reference, and the light impulses were analyzed in a computer.

The test subjects received a canine protection occlusion, and the chewing pattern was recorded after a 4-month adaptation period. The occlusion was altered to group function, and a second registration was made after 5 months. An analysis of the recordings indicated certain common findings for most of the test subjects.

1. The angle of departure was steeper than the approach angle, and these angles were slightly greater with group function occlusion than with canine protection.
2. The mean maximal lateral displacement, as well as the total displacement of the mandible, was greater with group function occlusion than with canine protection.
3. The mandibular velocity was greater with group function occlusion than with canine protection.
4. The variation in the most cranial position of the chewing cycle was greater at group function than at canine protection.
5. The duration of the chewing cycle varied among the test subjects but was stable intraindividually between the two registrations.

All these results indicate that the chewing pattern may be influenced by the type of occlusion irrespective of the existence of the maxillary canines. Two of the test subjects received a canine protection occlusion a second time, and a registration was made after 6 months. The results for one of the subjects fit well in the expected pattern, while those for the other person were in some part contradictory.

**REFERENCES**