Masticatory function before and after orthognathic surgery

Kauwfunctie voor en na chirurgische kaakcorrectie

(met een samenvatting in het Nederlands)

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De omgeving
van de mens is
de medemens

[J.A. Deelder]

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Chapter 1

Introduction

Introduction

The human craniofacial skeleton serves several functions. It gives shelter to the brain and the sensory organs. It contains entrances for air and food. Furthermore, it's the foundation for the masticatory muscles which enables us to use our lower jaw in order to chew, speak etc. Moreover, the muscles of the face which support our expression are attached to the skeleton.

During craniofacial growth and development each face obtains individual characteristics. Though the human face displays a wide variety of appearances, this variability stays within certain limits, so that the face is recognizable as typical human. Though these limits are not absolute, we do have feelings of awareness whether a face is normal. However, sometimes growth and development lead to such an aberrant result that it can be regarded as a deformity. The etiology of these deformities is not completely understood. As often occurs in history of life sciences, there has been some controversy whether genetic factors or environmental factors are responsible for growth and development. It seems plausible that both factors are involved in the regulation of craniofacial growth. It is postulated that growth of bone centers of chondral origin is predominantly controlled by genetic factors whereas growth of bone centers with a desmal background is controlled by local environmental factors (van Limborgh, 1972).

Deformities of the craniofacial skeleton in which the tooth bearing bones (*i.e.* the maxilla and the mandible) are involved, are specified as dentofacial deformities. Dentofacial deformities might influence the position and orientation of the maxilla and/or the mandible and the muscles of mastication. Therefore, the presumption is that occlusion and biomechanical factors are altered and masticatory function is affected. Deviations of occlusion may, in turn, have negative consequences for the periodontium, the teeth itself, speech, the temporomandibular joint and for facial aesthetics with subsequently the risk of psychological problems. Sometimes, proper closing of the lips is hampered.

Mandibular retrognathism

A normal masticatory system includes a regular upper and lower dental arch. The upper dental arch is a little wider than the lower dental arch and its position is slightly anterior with respect to the lower dental arch. The sagittal (anteroposterior) relationships between the upper and the lower dental arches were first classified by E.H. Angle. According to this classification, the sagittal molar relationship is normal, and thus defined as a class I, when the mesio buccal cusp of the first upper molar corresponds with the central buccal fissure of the first lower molar. When the position of the first lower molar is more dorsal than in a class I, the molar relationship is a class II malocclusion. When the lower molar is more ventral, the molar relationship is a class III malocclusion.

This Angle classification is exclusively based on the sagittal position of the permanent upper and lower first molars. Malocclusions, regardless the class type, may occur in patients with normal skeletal proportions. When correction is indicated, treatment by means of orthodontic appliances will be effective. However, when the malocclusion is based on a severe skeletal discrepancy, treatment of the dentoalveolar component, only by means of conventional orthodontic appliances, will not have satisfactory results.

Though there is a wide variety of dentofacial deformities, in most of the developmental deformities the face is symmetrical from a frontal view. Deviations in facial height are frequently reported. However, the majority of the deformities consist of anteroposterior deviations of the maxilla and, especially, the mandible. Such an anteroposterior deviation will have consequences for the sagittal relationship of the dental arches. When, for instance, the mandible is too short (mandibular deficiency or mandibular retrognathism), the lower dental arch is relatively positioned posterior with respect to the upper dental arch, resulting in a class II molar relationship. On the opposite, in patients with a mandibular prognathism, a class III molar relationship will be found. Now, proper treatment of the malocclusion requires correction of the skeletal discrepancy. Because the Angle classification of a malocclusion is based on the position of molars and thus the relative topography of upper and lower dental arches, it is unclear to which extent an aberrant position of the maxilla or of the mandible is responsible. Therefore, it is necessary to acquire supplementary data which gives insight in the topography of the maxilla and the mandible in relation to the craniofacial skeleton. In patients without deviations in face width and without severe asymmetry, analysis is based on vertical and sagittal skeletal dimensions. The lateral cephalometric radiograph provides this information. In this two dimensional representation of the craniofacial skeleton, anatomical landmarks are defined and are used for linear and angular measurements. The values are ranged, leading to a classification which enables us to distinct malformed from normal, and helps us to define the anomalous skeletal structure.

Of the skeletal discrepancies, mandibular deficiency, resulting in a class II molar malocclusion, has the highest prevalence and affects about 12% of the U.S. population. In 5% of the population this discrepancy is severe enough to be considered for surgery. It appears to be race dependant, since it is more prevalent in blacks and Hispanics than in whites (Bailey *et al.*, 2000). The present study will be confined to this category of patients: patients with a mandibular deficiency, also known as mandibular retrognathism.

Treatment

Goals of treatment are to normalize skeletal relationships and to establish a class I molar relationship, which usually requires a combination of orthognathic surgery and orthodontics. Treatment commonly includes three phases, *i.e.* presurgical orthodontic treatment, orthognathic surgery and postsurgical orthodontic treatment.

Presurgical orthodontic treatment

In preparation for orthognathic surgery, the dentoalveolar component of the malocclusion is treated by conventional orthodontics. Regular, congruent upper and lower dental arches are formed in which the position and orientation of the teeth have a correct relationship to the maxillary and mandibular base. Since both upper and lower dental arches are parabole shaped, surgical advancement of the mandible will oppose a more dorsal, hence wider part of the mandible against its maxillar counterpart. As a consequence, the arch width of the maxilla will become relatively too small. Therefore, a transverse maxillary expansion is frequently required. Presurgical orthodontic treatment usually takes 2 to 2.5 years.

Orthognathic surgery

Thanks to traumatology (victims of war, traffic and violence) there is a wide experience in the treatment of craniofacial injuries. Standardization of surgical methods and the use of antibiotics has led to predictable and acceptable results which encouraged surgeons to apply surgical techniques in patients with developmental facial deformities.

In deformities which are diagnosed as a mandibular retrognathism, there is a deficiency of mandibular length. Therefore, when surgical correction is indicated, gain of mandibular lenght is necessary. A surgical method to lengthen the mandible was developed by Obwegeser (1955) and modified by Dal Pont (1958) and Hunsuck (1968).

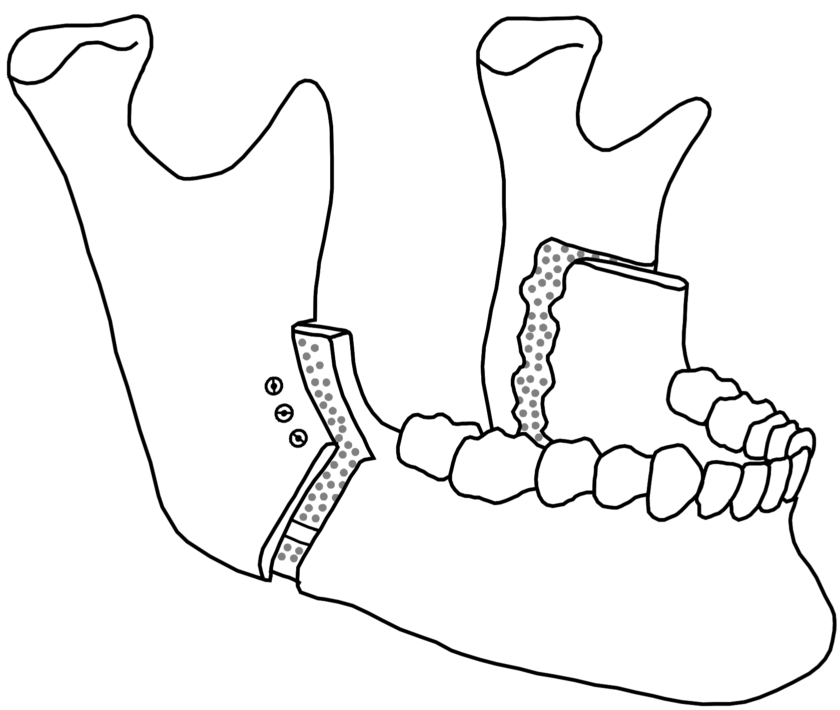

Figure 1.

By making a bilateral sagittal split in the mandibular ramus (see fig. 1), the mandible is divided into three fragments: two lateral, proximal fragments containing the condylar processes, and a medial, distal fragment which includes the dental arch and the inferior alveolar nerve. By sliding telescopically the tooth bearing fragment ventrally along the proximal fragments, the mandible is advanced. Nowadays, the fracture surfaces are immobilized by screws or plates.

Complications may occur as a consequence of mandibular advancement surgery. During surgery, sometimes the orientation of the split is unfavorable: the "bad split". Injury of the inferior alveolar nerve is a common complication, resulting in paresthesia or even anesthesia of the lower lip. The incidence of such an immediate postoperative neurosensory deficit is relatively high. Values up to 97% are found (Lupori *et al.*, 2000). Most of these deficits disappear within one year, leaving about 15% of permanent deficits (Bossuyt and Schepers, 1991). Though temporomandibular joint disorders are brought forward as an indication for surgery, TMJ dysfunction may also be introduced by surgery.

Postsurgical orthodontic treatment

The aim is to establish a good and stable occlusion, which may help to prevent relapse of the advanced mandible. Mandibular advancement often deliberately results in a terminal molar and incisal tripod occlusion. The teeth in between, that are not occluding, are guided into the correct position.

Measurements

Photographs of the face, dental models, and cephalometric radiographs that are made and analyzed by standardized methods, are used for diagnosis, evaluation of the therapy and follow up. However, the information obtained is entirely based on anatomy. Even when surgical correction of a mandibular retrognathism leads to an anatomical correct and esthetically satisfying result, consequences for oral function are still unclear. It is of great importance to know what can be actively achieved by the patients masticatory system. To quantify the function of the masticatory system, some parameters have been studied, including maximum bite force, masticatory performance, electromyographic activity (EMG) of the masticatory muscles, maximal voluntary excursions of the mandible and masticatory cycle patterns. A majority of these studies include patients with a mandibular prognathism or groups of patients with a variety of dentofacial deformities. This thesis is confined to patients with a mandibular retrognathism. An outline of previous results obtained in this category of patients is presented here.

Maximal bite force

The masticatory system can be regarded as a lever system which is subjected to the laws of mechanics. In theory, the possible influence of each category of deformities on maximum bite force can be predicted (Finn *et al.*, 1980; Throckmorton *et al.*, 1980). In patients with a mandibular retrognathism, a shorter bite force moment arm is likely to increase maximum bite force. However, in these patients a decreased maximum bite force was found (Throckmorton *et al.*, 1995; Zarrinkelk *et al.*, 1996). Surgical advancement of the mandible enlarges the bite force arm. Therefore, surgical correction of mandibular retrognathism is expected to decrease maximum bite force. However, one year after surgery decreased (Proffit *et al.*, 1989), unaltered (Proffit *et al.*, 1989) and even increased (Proffit *et al.*, 1989; Throckmorton *et al.*, 1995; Throckmorton *et al.*, 1996) maximum bite forces were found.

Masticatory performance

More than bite force, mastication is a true function of the masticatory system. However, today's methods of preparing food, makes the importance of an excellent functioning masticatory system controversial. Though mandibular retrognathism is the most common dentofacial deformity, to our knowledge, no data are available about the masticatory performance in these patients.

Electromyographic activity (EMG) of the masticatory muscles

Surface electromyography is a non invasive measurement, which reflects the degree of activity of underlying muscles (Basmajian and De Luca, 1985). Because of their accessibility, the anterior belly of the temporalis muscle and the masseter muscle are common sites to record surface EMG of the jaw adductor muscles. EMG is regularly recorded during isometric clenching at maximal and submaximal bite force levels and during chewing.

In patients with a mandibular retrognathism, EMG during maximal isometric clenching was reduced before surgery and did not increase after surgery (Harper *et al.*, 1997). Another study, with no control subjects, reported an increase one year after surgery (Raustia and Oikarinen, 1994).

EMG recorded during chewing was decreased before surgery (Youssef *et al.*, 1997), but increased after surgery (Raustia and Oikarinen, 1994) up to control values (Youssef *et al.*, 1997).

Because EMG is a reflection of muscular activity, the amplitude of the EMG and bite force are expected to be closely related. When EMG is recorded in isometric conditions at various submaximal levels of bite force, EMG can be expressed as a function of bite force, resulting in an EMG/bite force regression line. Then, the registration of EMG during chewing can be used to estimate masticatory forces since it is difficult to directly record bite force as the intra oral devices interfere with proper chewing.

The slope of the EMG/bite force regression line indicates how the muscle activity increases as a function of bite force. Therefore, the slope can also be regarded as a muscle efficiency ratio. There was no difference between muscle efficiency in patients before surgery and controls (Throckmorton *et al.*, 1995). This indicates that functional deficits that may be found before surgery, can not simply be attributed to a reduced efficiency of the jaw closing muscles. After surgery, muscle efficiency even increased (Throckmorton *et al.*, 1995).

Maximal voluntary excursions of the mandible

Maximal voluntary vertical excursion was smaller in retrognathic patients before any treatment than for controls. For lateral and protrusive excursions, no difference between patients and controls was found. These results were not influenced by presurgical orthodontics. At six weeks after surgery, there was a reduction in all measures. At two years, none of the measures was significantly different from controls (Throckmorton *et al.*, 1995). In one study, one year after surgery, presurgical values were only reached when the patient had physical therapy after surgery (Storum and Bell, 1986).

Masticatory cycle patterns

Before and after presurgical orthodontics, no differences were demonstrated in maximum excursions of the mandible during mastication in retrognathic patients when compared with controls (Throckmorton *et al.*, 1995). Six months after surgery, maximal lateral excursion was smaller in patients. Two years after surgery, no differences between patients and controls could be found.

There was no difference in duration of the chewing cycle between patients, regardless the phase of treatment, and controls (Youssef *et al.*, 1997).

Aim of the thesis

The aim of the thesis was to analyze masticatory function during the various phases of treatment in patients with a mandibular retrognathism who are undergoing mandibular advancement surgery. The following questions serve as a guideline:

1. is masticatory function in patients, who are scheduled for mandibular advancement surgery, impaired before any treatment? (chapter 2)
2. what is the influence of presurgical orthodontic treatment on masticatory function? (chapter 3)
3. what is the influence of mandibular advancement surgery and postsurgical orthodontics on masticatory function? (chapters 4 and 5)
4. what are the long-term effects (5 years after surgery) of combined orthodontic and surgical therapy on masticatory function in patients with a mandibular retrognathism? (chapter 6)

Outline of the thesis

In the first chapter, patients with a mandibular retrognathism are introduced. Some considerations about anteroposterior dental and skeletal relationships are presented. Treatment of patients with this deformity is briefly discussed. Functional aspects of the masticatory system throughout the various phases of treatment are illustrated in a concise review of studies in these patients. In chapter 2, masticatory performance is determined in patients with a mandibular retrognathism before presurgical orthodontics. The patients were offered cubes, made of a silicone rubber, and were asked to perform a fixed number of chewing cycles. The median particle size was determined with a sieving procedure (Olthoff *et al.*, 1984). The reduction of food particles can be considered as the composite result of a selection and a breakage process (Lucas and

Luke, 1983). Selection and breakage were determined in one-chew experiments using various particle sizes. Results were compared with those of controls. Chapter 3 describes masticatory performance, selection and breakage before and after presurgical orthodontics and thus reveals the influence of presurgical orthodontics. The influence of mandibular advancement surgery on these parameters is assessed in chapter 4 by comparing results in patients before and 1-1.5 years after surgery. In chapter 5, the influence of mandibular advancement surgery on masticatory function is placed in a wider perspective. Maximum bite force was measured bilaterally at the level of the first molars using a bite fork with 2 force transducers (Slagter *et al.*, 1993). Electromyographic activity (EMG) of the anterior temporal muscle and the masseter muscle were recorded bilaterally during isometric clenching at maximal and submaximal bite force levels and during the chewing experiments. EMG was expressed as a function of bite force which gives an indication of muscle efficiency. To evaluate long term effects of treatment, in chapter 6, two of the most evident functions of the masticatory system, *viz.* masticatory performance and maximum bite force, were examined at least five years after surgery.

Chapter 2

Chewing efficiency of pre-orthognathic surgery patients: selection and breakage of food particles

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Abstract

Comminution of food is the composite result of selection and breakage. Selection is characterised by the chance that a food particle will at least be damaged by the teeth during chewing. For any size, this chance equals the ratio between the weight of damaged or broken particles and that of all initial particles. The breakage process refers to fracturing of selected particles. The aim was to examine whether a reduced chewing performance of pre-orthognathic surgery patients is due to an impairment of selection, breakage or both. Eight cubes of 8.0 mm of the silicone rubber Optosil® were used as a test food to determine chewing efficiency for 12 patients (skeletal Angle Class II and dental Angle Class II, subdivision 1) and 12 controls (class I molar relation). Selection and breakage were determined in one-chew experiments using various particle sizes. Chewing efficiency was significantly lower for the patients than for the controls. The selection chance was significantly smaller for the patients, in particular for smaller (≤ 4.8 mm) particles. The degree of breakage was lower for the patients, in particular for medium-sized particles of 4.8 mm. These findings suggest that the reduced chewing performance of pre-orthognathic surgery patients is due to an impairment of both selection and breakage.

Introduction

Chewing is a major function of the masticatory system. Solid food is prepared for swallowing by crushing it into fragments to be moistened with saliva. One of the factors involved in the food comminution is occlusion. Using a variety of test foods and analysis methods, a reduced chewing performance has been reported for patients who are scheduled for orthognathic surgery (Tate *et al.*, 1994a; Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993; Zarrinkelk *et al.*, 1995a; Kikuta *et al.*, 1994). Hence, besides aesthetic considerations, improving the patient's chewing function by altering the skeletal and occlusal relationships might be an indication for orthognathic surgery.

The reduction of food particle sizes during mastication can be considered to be the composite result of a selection and a breakage process (Lucas and Luke, 1983). During chewing, every cycle starts with the selection process, in which the food particles have a chance of being placed between the teeth and being subjected to the breakage process in which they are comminuted or at least damaged by the teeth. For any particle size X, the selection chance can be defined as the weight (volume) of fragments, with respect to the total weight of damaged and non-damaged particles, originating from size X. This chance depends on the ease by which particles are transported to and captured by the teeth. The selection process will conceivably depend on factors such as the action of the tongue and cheeks, the tooth shape, the occlusal area of the postcanine teeth (and the distribution of interocclusal distances between antagonistic teeth), and the size and number of particles. An abnormal relationship between antagonistic teeth in orthognathic surgery patients might decrease the occlusal area of the postcanine teeth where small interocclusal distances occur. An abnormal occlusal relationship might therefore decrease selection chances in particular. Breakage is the process by which selected particles are fractured between the teeth into fragments of variable size and number. Breakage mainly depends on the tooth shape, the amount and coordination of the muscle activity (controlling the bite force and its direction), fracture characteristics of the food, and the particle size, shape and number. Hence, both the selection and the breakage process are subject to many anatomical and physiological variables.

The aim of this study was to examine the extent to which a decreased masticatory function in pre-orthognathic surgery patients could be attributed to an altered selection chance, breakage process or both, for different particle sizes. To that end, these functions have been compared between patients and controls.

Materials and methods

Test food

The silicone rubber Optosil ® (Version 1980; Bayer, Leverkusen, Germany), a dental impression material, was used as a standardised test food. Since Optosil appeared to be too tough for the patients, a softer version was obtained by heating the base for 5 h at 248°C. Cubes (edge size of 8.0 mm) with a yield force of 83 N instead of 120 N were prepared using a mixture of approximately 80% heated Optosil base and 20% non-heated base. The yield force of this softer test food, hereafter denoted as Optosoft, was determined using a bite simulator with a plunger cone of 120° (Slagter *et al.*, 1992).

Subjects

Two groups of subjects volunteered and gave informed consent for this study, which was approved by the Ethics Committee of the University Medical Centre Utrecht. These groups consisted of (i) 12 patients (4 males and 8 females) who belonged to a skeletal Angle Class II and a dental Angle Class II, subdivision 1, and who were scheduled for orthognathic surgery, and (ii) 12 healthy controls with a class I molar relation, matched for age and gender. The mean age of the patients was 24.9 yr (S.D. ± 5.5) and that of the controls 25.1 yr (S.D. ± 5.9). Four out of 12 patients had a slight anterior open bite. All subjects had complete dentitions and showed no signs and symptoms of temporomandibular disorders. The patients were tested before any pre-surgical orthodontic treatment was started.

Chewing experiment

Since details have been described previously (Olthoff *et al.*, 1984), only an outline is presented here. In order to determine chewing performance and efficiency, eight cubes of Optosoft with an edge size of 8.0 mm were offered as a test food. Each subject performed four chewing sequences consisting of 15, 30, 30 and 15 chewing cycles, respectively. In each test the number of chewing movements was counted by the examiner. After completion the chewed particles were expectorated and those obtained after 15 chewing cycles were pooled, as well as those from the two series of 30 cycles, to obtain enough material for sieving and to reduce data scatter. After washing and drying, the chewed Optosoft was sieved through a stack of nine sieves with apertures within a range of 0.50 - 8.0 mm and a factor of √2 between successive apertures. The cumulative particle-size distribution by volume (weight) of the comminuted Optosoft was described in terms of central tendency and variation of particle size by curve fitting the weight values obtained after sieving by the Rosin-Rammler function:

$$Q_w(X) = 1 - 2^{-(X/X_{50})^b} \qquad (1)$$

in which Q_w is the weight fraction of particles with a size smaller than X. The median particle size, X_{50}, which is the aperture of a theoretical sieve through which 50% of the weight can pass, is a measure of central tendency of the size distribution. A large value of X_{50} indicates a poor chewing performance. The value of *b* in equation 1 reflects the extent to which the particles are equally sized. A large value of *b* corresponds to a range of particle sizes that is less broad.

The decrease of the median particle size as a function of the number of chewing cycles, N, can be adequately described as a power function:

$$X_{50}(N) = c.N^{-d} \quad (2)$$

in which the variable *c* defines the notional median particle size after one chewing cycle. This value is only theoretical because relevant data for X_{50} can be obtained only from curve fitting using equation 1 after some initial cycles. The decrease of the median particle size per chewing cycle is given by variable *d*.

In order to quantify food comminution in human mastication process, two types of measures have essentially been applied in the dental literature (van der Glas, 1997). The first one is chewing performance, *i.e.* the value of X_{50} for a particular number of chewing cycles, for example 15 cycles. The second measure of comminution, chewing efficiency, has been defined as the number of chewing cycles required either to attain a particular median particle size or to reduce particles to the half of its initial size. The number of chewing cycles required to halve the initial particle size is denoted as $N_{½}$ (van der Bilt *et al.*, 1987). A large value of $N_{½}$ corresponds to a poor chewing efficiency. By fitting the two values of X_{50} determined at 15 and 30 chewing cycles by equation 2, $N_{½}$ could be calculated; the value of $N_{½}$ includes the influence of both variables *c* and *d* in equation 2.

One-chew experiment

In order to determine selection chances and breakage functions for different particle sizes, three classes of cubes with an edge size of 8.0, 4.8 and 2.4 mm, respectively, were applied in one-chew experiments (van der Glas *et al.*, 1992). In these experiments, it is important to choose a particle number which is, on the one hand, sufficiently large for facilitating a normal tongue manipulation of the particles and, on the other hand, the particle number should not be too large for preventing saturation of the breakage sites on the tooth row which would hamper the selection of particles between antagonistic teeth. The number of particles which was offered each time in the present one-chew experiments was 3, 12 and 68 for the size classes of 8.0, 4.8 and 2.4 mm, respectively. These particle numbers corresponded with the critical numbers beyond which the breakage sites on the teeth become saturated in control subjects. The number of selected particles increases approximately linearly with the number of particles offered so far as the breakage sites are not saturated. The selection chances observed with the particle numbers used will therefore be similar to those observed if a smaller particle number were used in the presence of normal tongue manipulation (van der Glas *et al.*, 1992). The number of particles used corresponded to food volumes of 1.54, 1.33 and 0.94 cm^3 for the size classes of 8.0, 4.8 and 2.4 mm, respectively. These volumes were small as they represented 13 to 21% of the mean freely chosen mouthful and 3 to 5% of the mean maximum volume of peanuts a subject could store in the mouth (Lucas and Luke, 1984).

The particles of the various sizes were randomly offered seven times. Each subject first made pseudo-chewing movements to obtain a natural dispersion of the particles in the mouth and to produce saliva. At the end of a jaw-opening phase, the subject was unexpectedly instructed to carry out a real chew. The particles were expectorated, pooled across 7 trials, washed, dried and sieved. Because all particles had initially a regular shape, the non-damaged (non-selected) particles could easily be distinguished from damaged and broken (selected) ones by visual inspection. The weight of the selected particles divided by the total weight of damaged and non-damaged particles corresponds with the selection chance of size X, S(X). Adding the weight fractions of the fragments of initial size X, from the bottom of the sieve stack to the sieves with the various apertures Y, gives the experimental values of the breakage function B(Y, X). B(Y, X), a cumulative distribution function, is defined as the weight fraction of selected particles, of size X, which break into particles smaller than sieve size Y($Y \leq X$). For any initial particle size X, the experimental breakage function B(Y, X) per chew was fitted by the function:

$$B(Y,X) = 1- (1+ r.Y/X)(1-Y/X)^r \qquad (3)$$

in which r is related to the degree of fragmentation (Austin, 1971; van der Glas *et al.*, 1987). Larger r-values correspond to a higher degree of fragmentation.

Statistical analysis

All analyses were carried out using SPSS® 9.0 (1998; SPSS, Chicago, IL, USA). Analysis of variance (ANOVA) with repeated measures was applied to values of median particle size (X_{50}), selection chance (S) and fragmentation factor (r) respectively, to test the null hypothesis of no statistical differences between the subject groups, regardless of the number of chews or the particle size (between-subjects effects). Effects of the number of chews or the particle size were revealed by examining the significance of within-subjects effects (the effect of a variable regardless of the subject group) and that of interactions between these effects and the group effect. The difference of chewing efficiency ($N_{½}$) between patients and controls was tested using a Student's *t*-test for unpaired observations.

Results

Chewing performance

Fig. 1 shows the median particle size (X_{50}) after 15 and 30 chewing cycles for the patients and the controls. Analysis of variance (ANOVA) revealed that X_{50} was larger for the patients than for the controls, regardless of the number of chewing cycles (between-subjects effect; $P<0.001$). X_{50} was significantly larger ($P<0.01$-0.05) for patients than for controls after 15 cycles as well as after 30 cycles (Student's *t*-tests, using the standard error from ANOVA). X_{50} after 30 cycles was smaller than after 15 cycles, regardless of the subject group (within-subjects effect of cycle number; $P<0.001$). This result can be expected, as the food was further comminuted. The decrease in X_{50} between 15 and 30 cycles was larger for the patients than for the controls (significant interaction of cycle number by group; $P<0.01$).

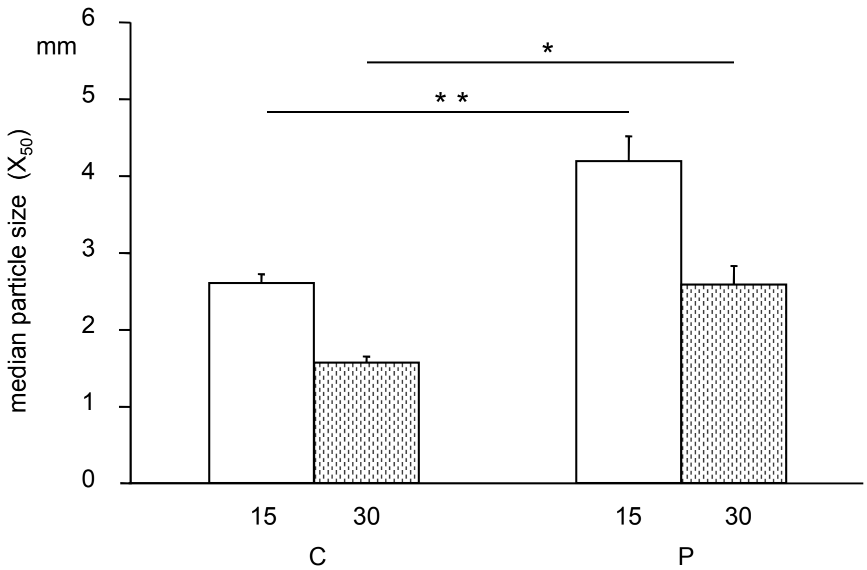

Fig. 1. The median particle size (X_{50}) (mean and standard error of the mean) as a function of number of chewing cycles (indicated below the bars) for control subjects (C) and pre-orthognathic surgery patients (P). For both groups, the initial particle size was 8.0 mm. Horizontal bars, significant differences between patients and controls ($P<0.05$; **$P<0.01$).*

Broadness of the size distribution

Fig. 2 shows the extent to which the particles were equally sized after 15 and 30 chewing cycles for the patients and the controls. The broadness value (*b*) was significantly larger ($P<0.05$) for the patients than for the controls (between-subjects effect; ANOVA). This finding indicates that the particles were more equally sized for the patients. The broadness difference between the patients and the controls was significant ($P<0.05$) for 15 cycles (Student's *t*-test using the standard error from ANOVA). Averaged over the two subject groups, the broadness depended on the number of chewing cycles (within-subject effect of cycle number; $P<0.01$), *viz*. the *b*-value was, on average, larger after 15 cycles than after 30 cycles. Such a result can be expected, as chewing was started on equally sized particles (8.0 mm). However, whereas *b* decreased between 15 and 30 cycles for the patients, it remained nearly constant for the controls. The different change of the variable *b* between patients and controls was reflected as a significant interaction of cycle number by group ($P<0.05$).

The decrease was significant for the patients ($P<0.05$; Student's t-test for paired observations).

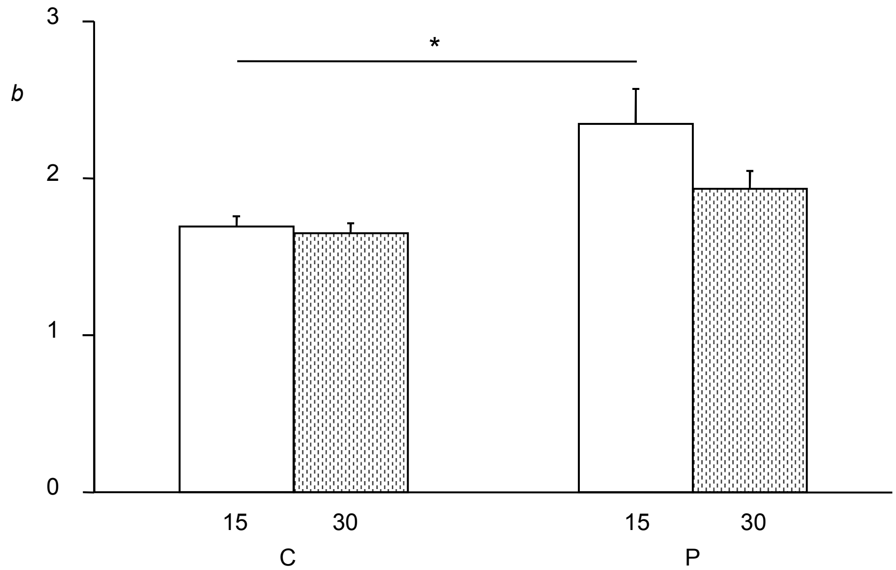

*Fig. 2. The broadness (b) (mean and standard error of the mean) of the particle size distribution, for two numbers of chewing cycles (indicated below the bars), for control subjects (C) and pre-orthognathic surgery patients (P). Horizontal bar, significant difference between patients and controls (*P<0.05).*

Chewing efficiency

The number of chewing cycles needed to halve the initial median particle size ($N_{½}$) was, on average, 17.7 (S.E.M. ± 3.0) for the patients and 8.1 (S.E.M. ± 0.6) for the controls. The chewing efficiency of the patients was lower than that of the controls, as $N_{½}$ was significantly larger for the patients ($P< 0.05$, Student's t-test for unpaired observations).

Selection chances from one-chew experiments

For both subject groups, Fig. 3 shows selection chances for the three particle sizes. Overall, the selection chance was significantly smaller for the patients than for the controls (between-subjects effect; $P<0.001$; ANOVA). Within the entire group of subjects, significant differences in selection chances occurred for various particle sizes (within-subjects effect of particle size; $P<0.001$). The selection chance increased with particle size in both subject groups. The increase of the selection chance with particle size depended on the subject group (within-subject effect regarding the interaction particle size by group; *P*<0.01; ANOVA). For particle sizes of 2.4 as well as 4.8 mm, the selection chances were smaller for the patients than for the controls (*P*<0.001-0.01; Student's *t*-tests using the standard error from ANOVA). Since the selection chance always approached the maximally possible value of one for a particle size of 8.0 mm, the increase in selection chance with particle size, which occurred between 2.4 and 8.0 mm, was more pronounced for the patients than for the controls.

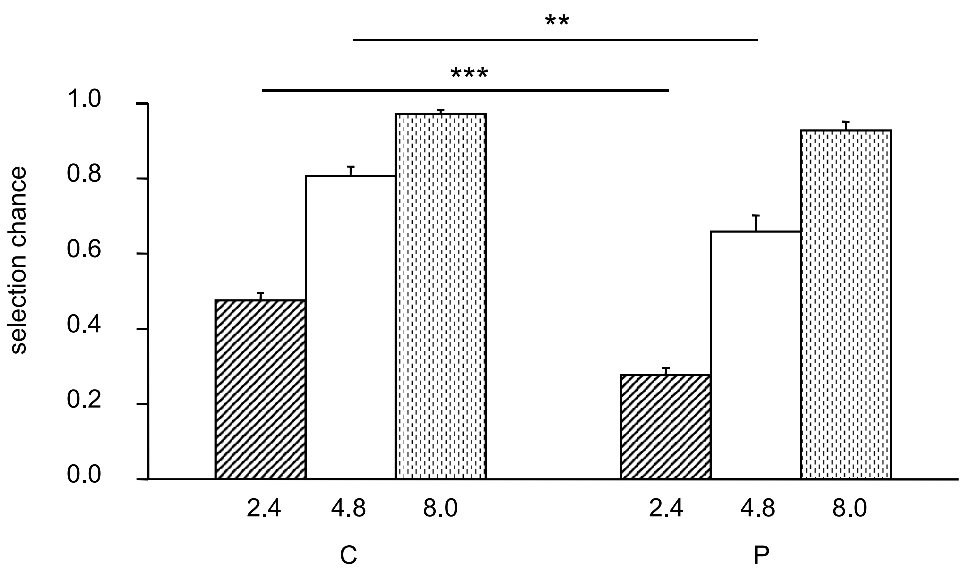

*Fig. 3. The selection chance (mean and standard error of the mean) for three particle sizes (indicated below the bars in mm) for control subjects (C) and pre-orthognathic surgery patients (P). Horizontal bars, significant differences between patients and controls (**P<0.01; ***P<.0.001).*

Breakage functions from one-chew experiments

For each of the subject groups, Fig. 4 shows the degree of fragmentation (r) for the different particle sizes. Regardless of particle size, the fragmentation factor was smaller for the patients than for the controls (between subjects effect, *P*<0.01; ANOVA). For particle sizes of 4.8 mm, the fragmentation factor was significantly larger for the controls than for the patients (*P*<0.05; Student's *t*-test using the standard error from ANOVA). The fragmentation factor depended on particle size regardless of the subject group (within-subject effect of particle size; *P*<0.01). Changes in this factor as a function of particle size were similar for both subject groups (no significant within-subject effect for the interaction fragmentation by group). For both groups, the fragmentation factor tended to increase with particle size (Fig. 4).

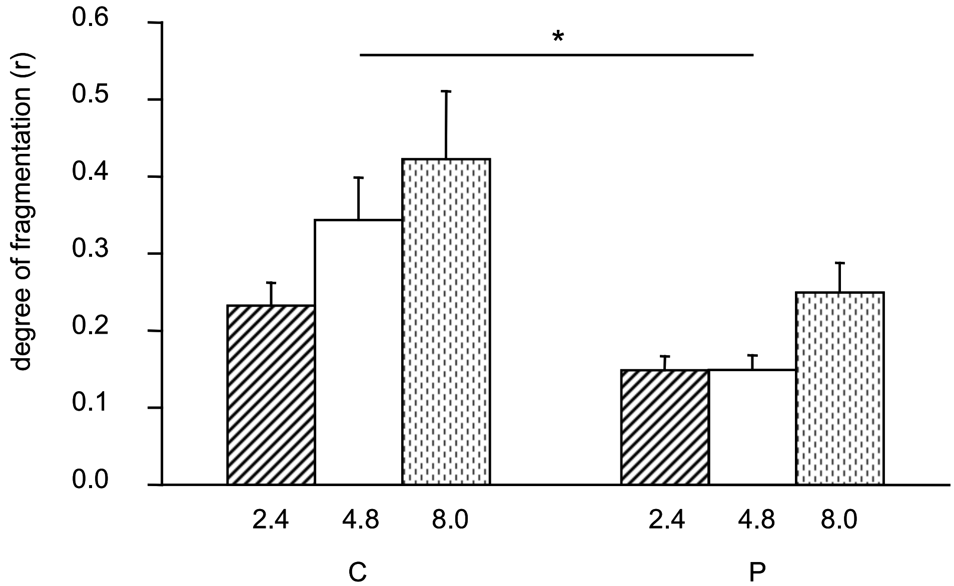

*Fig. 4. The degree of fragmentation (r) (mean and standard error of the mean) for three particle sizes (indicated below the bars in mm) for control subjects (C) and pre-orthognathic surgery patients (P). Horizontal bar, significant difference between patients and controls (*P<0.05).*

Discussion

The function of the masticatory system includes size reduction of food particles in preparation for swallowing. In order to study the masticatory process, the initial particle size should be substantially larger than the particle size that is swallowed. The size at swallowing is, in general, a few millimetres (Prinz and Lucas, 1995). Another reason for choosing an initial particle size which is not too small is that particles which become small with respect to the dimensions of the cusps of a molar tooth will be squeezed at most and not broken. Therefore, if chewing would be started on small particles, the rate of food comminution will be low. An initial particle size of 8.0 mm, used in the present study as well as in our previous studies (Olthoff *et al.*, 1984; van der Bilt *et al.*, 1987;

van der Glas *et al.*, 1987) allowed us to study a range of chewing cycles in which a high rate of comminution occurs.

Artificial test foods may be preferred to natural foods for measurements of masticatory performance and efficiency because of a larger reproducibility of their physical properties. Furthermore, the food particles can easily be given the distinct shape of a cube, thus allowing a determination of selection chances. The values for the selection chances and breakage functions determined for carrots as a test tood (Lucas and Luke, 1983) showed a large overlap with those determined for Optosil in normal subjects (van der Glas *et al.*, 1987). Furthermore, mastication of peanut did not yield particle size distributions that were fundamentally different from those of the artificial test food Optosil, except that a certain degree of comminution was reached after fewer chewing cycles (Olthoff *et al.*, 1984). The results on variables describing the chewing process obtained by using an artificial test food like Optosil or Optosoft are therefore representative for those of natural foods.

The yield force of the Optosoft test food was lowered to such a degree that despite an impaired bite force, the patients were able to comminute it well. However, the hardness of the test food was still sufficiently large to differentiate between the comminution ability of the various patients and controls.

Consistent with previous studies (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993; Kikuta *et al.*, 1994; Tate *et al.*, 1994a; Zarrinkelk *et al.*, 1995a), the chewing performance of patients was impaired with respect to that of control subjects. The median particle size X_{50} for the patients was 1.66 times larger after both 15 and 30 chewing cycles. This ratio is similar to the values of 1.39 and 1.35, which can be derived from previous studies using carrot as a test food (Tate *et al.*, 1994a; Zarrinkelk *et al.*, 1995a). Because of a smaller comminution rate, X_{50} after the first 15 cycles was larger for the patients than for the controls. This allowed a larger decrease of X_{50} for the patients during the subsequent 15 cycles. However, the decrease in X_{50} was very similar in a relative sense between patients and controls, *viz.* 39%. The finding of distributions with more equally sized particles (larger values of the broadness variable *b*) for the patients, in particular after 15 cycles, reflects their reduced ability to produce small particles within the range of chewing cycles studied. Overall chewing performance is reflected in the variable chewing efficiency ($N_{½}$) which is smaller for the patients, *i.e.* the patients needed about twice as many chewing cycles than controls to halve, on average, the initial particle size.

Differences in chewing performance and efficiency between control subjects and patients might be explained by differences in selection chances and/or breakage functions. Regarding selection, optimally fitting antagonistic premolars and molars normally contribute largely to the food platform area during chewing. In normal subjects, *viz.* with a class I occlusion, chewing predominantly takes place in this region (Wictorin *et al.*, 1971). Even in normal subjects, the selection chance of smaller particles is smaller than that of larger ones (Lucas and Luke, 1983; van der Bilt *et al.*, 1987; van der Glas *et al.*, 1987) because of a less efficient particle manipulation of the tongue and a lesser extent to which the antagonistic teeth are able by their morphology to capture transported small particles. Assuming that the tongue manipulation is similar between the patients and the controls, the larger differences in selection chance between smaller and larger particles for the patients must be due to less optimal occlusal relationships. In patients with a clearly marked class III occlusion, the most distal upper elements might miss their antagonists. Furthermore, the relative ventral shift of the lower dental arch will oppose the first lower molars against the upper first premolars. Hence a more anterior part of the upper dental arch might be involved in chewing. This expectation has been confirmed in a cineradiographic study (Lundberg *et al.*, 1974). In terms of missing antagonists of distal elements and the involvement of an anterior part of a dental arch, a pronounced class II occlusion can be considered as a mirrored situation of a class III occlusion. In class II patients, a more anterior part of the lower dental arch instead of the upper one will be used in chewing. More anteriorly positioned elements are less suitable for selection of particles for two reasons. First, because their occlusal area is smaller, the area of possible breakage sites is reduced. Second, the occlusal fit of antagonistic pairs in which more anterior elements are involved will be less than optimal. It can be expected that in the distribution of interocclusal distances between antagonistic teeth, larger distances will occur more frequently in subjects with malocclusions than in controls. Apart from the influence of missing distal antagonists and more involvement of anterior teeth in chewing, anomalies in location and orientation of individual elements will interfere with an optimal occlusion. When relatively large spaces are present between poorly fitting antagonistic teeth during maximum intercuspation, small particles might escape from selection, whereas large ones might still easily be trapped and damaged. Such a mechanism is consistent with the findings from the present study, *viz.* that the selection chance of a particle of 8.0 mm was similarly large (nearly one) for the controls and the patients whereas this chance was smaller in the patients, in particular for a size of 2.4 mm.

Some factors which influence selection are, at least in part, also involved in fragmentation, *e.g.* tooth morphology. When particles are not too small with respect to the dimensions of the cusps they will be cut, not just squeezed. When particles are sufficiently large, they will undergo multiple breakage as they will be processed by more than one cusp of molar teeth. Moreover, fragments from these larger particles which are locked up between antagonistic postcanine teeth, might be broken further in the same chewing cycle as jaw closing continues. Impairments of occlusal relations might diminish the contribution of multiple breakage, resulting in smaller r-values for the patients.

In agreement with previous studies, the present one has shown that chewing efficiency is reduced in pre-orthognathic surgery patients. This study has further shown that this impairment is due to smaller selection chances of small (≤ 4.8 mm) food particles as well as a lower degree of breakage for a variety of particle sizes between 2.4 and 8.0 mm. Before it can be concluded that orthognathic surgery might improve selection as well as breakage of a patient's chewing function by altering the skeletal and occlusal relationships, a longitudinal study is required, using the same methodology and preferably the same patients. Previous studies (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993; Kikuta *et al.*, 1994; Zarrinkelk *et al.*, 1995a) have shown that chewing performance did not significantly improve 1-3 yr after surgery. However, small grains have been used as a test food in two of these studies (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993), diminishing the chance of finding a difference in chewing performance before and after surgery because of a low rate of food comminution. Furthermore, the period between surgery and re-testing was, in general, short (1-2 yr) and Angle class III patients have been studied (Shiratsuchi *et al.*, 1991; Kobayashi *et* *al.*, 1993; Kikuta *et al.*, 1994). The patients' occlusal relationship will not have been definitely stabilized so shortly after surgery. Moreover, the change in chewing performance might be different for patients whose mandible is surgically shortened (class III patients) than for patients whose mandible is lengthened (class II patients, examined in the present study). In the only study in which chewing performance was determined by using a large initial particle size of the test food, and three years after surgery, the patient group was heterogeneous, *viz.* both class II and class III patients participated (Zarrinkelk *et al.*, 1995a). A longitudinal study might only be successful in detecting a significant change in chewing efficiency and its underlying mechanisms when the same class of patients will be studied for a post-surgical period that exceeds 3 yr.

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Chapter 3

The influence of orthodontics on selection and breakage underlying food comminution in pre-orthognathic surgery patients

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Abstract

Comminution of food is the composite result of selection and breakage. Selection is characterized by the chance that a food particle will at least be damaged during a chew. For any particle size, this chance equals the ratio between the weight of damaged and broken particles and that of all initial particles. The breakage process refers to fracturing of selected particles. Since orthodontic treatment applied to patients before orthognathic surgery has an effect on the position and orientation of teeth, it may alter chewing efficiency by influencing selection and/or breakage. The effect of such orthodontic treatment on chewing efficiency was examined using eight cubes of 8.0 mm of a silicone-rubber (Optosil®) as a test food for determining the number of chews required to halve the initial particle size ($N_{½}$) in 12 patients. Three particle sizes (2.4, 4.8 and 8.0 mm) were used for determining selection and breakage in one-chew experiments. Orthodontic treatment had no effect on the chewing efficiency and the selection chances of all particle sizes whereas the degree of breakage was significantly ($P<0.05$) increased only for a particle size of 8.0 mm. These findings suggest that presurgical orthodontics has only a minor effect on food comminution.

Introduction

Chewing is a major function of the masticatory system. Solid food is prepared for swallowing by crushing it into fragments to be moistened with saliva. One of the factors involved in food comminution is occlusion. In patients with a dentofacial deformity, unfavourable skeletal relationships might be related to an impaired occlusion and thus contribute to a decreased chewing function. Hence, apart from aesthetic considerations, improving the chewing function might be an indication for treatment. Such a treatment usually includes three phases, *i.e.* presurgical orthodontic treatment, orthognathic surgery and postsurgical orthodontic treatment. Before application of presurgical orthodontic appliances, the patients have a reduced chewing performance with respect to controls (Tate *et al.*, 1994a; Zarrinkelk *et al.*, 1995a). A reduced chewing performance has also been observed in patients with mandibular prognathism after presurgical orthodontics (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994). It is difficult to assess the influence of presurgical orthodontics on chewing efficiency by inter-study comparisons as such comparisons are hampered by differences in subject groups, the diversity of methods used to quantify chewing efficiency and the variety of test foods applied. The first aim of this study was to determine chewing efficiency before as well as after presurgical orthodontics in a particular group of subjects, *viz.* class II (subdivision I) patients.

The reduction of food particle sizes during mastication can be considered to be the composite result of a selection and a breakage process (Lucas and Luke, 1983). Selection was defined as the chance that a food particle is placed between the teeth and comminuted or at least damaged during a chewing cycle. Selection depends on factors such as the total occlusal area of the post-canine teeth, tooth morphology, relationship between antagonistic teeth, movement of the jaw, the action of the tongue and cheeks and particle size and number. Breakage is the process by which selected particles are fractured between the teeth into fragments of variable number and size. Breakage may depend on tooth morphology, the amount and co-ordination of the jaw-muscle activity (controlling the bite force and its direction), fracture characteristics of the food and particle size and shape. The second aim of this study was to examine to which extent presurgical orthodontics in class II patients influences chewing efficiency in terms of selection chance, breakage process or both.

Materials and methods

The silicone rubber Optosil® (Version 1980, Bayer, Germany), a dental impression material, was used as a standardized test food. Since Optosil appeared to be too tough for the patients, a softened version was prepared by heating the base for 5 h at 248°C. Cubes (edge size of 8.0 mm) with a yield force of 83 Newton instead of 120 Newton were prepared, using a mixture of approximately 80% heated Optosil base and 20% non-heated base. The yield force of this softer test food, hereafter denoted as Optosoft, was determined using a bite simulator with a plunger cone of 120 degrees (Olthoff *et al.*, 1986).

Eighteen patients, all with an Angle Class II molar relation and scheduled for orthognathic surgery, formed three subgroups. The first subgroup consisted of 6 subjects (2 males and 4 females) who were tested on two occasions for obtaining paired observations. Testing occurred (i) before any presurgical orthodontic treatment was started, and (ii) just before orthognathic surgery was carried out, *viz.* after the presurgical orthodontic treatment had been finished. Furthermore, paired observations were obtained from two groups of matched patients (2 males and 4 females in each group), one group tested before and the other one tested after orthodontic treatment. First, these patients were matched regarding age, gender and dental status. Because orthodontic treatment mainly influences occlusal factors (cf. Discussion), other factors than occlusal ones which might influence chewing performance, were excluded as much as possible. The patients were also matched for maximal bite force as this factor is important for masticatory performance (Julien *et al.*, 1996). The value of maximal bite force was selected out of three trials which were recorded bilaterally at the level of the first molars using a bite fork with two force transducers (Slagter *et al.*, 1992). Left and right force signals were summed. The subjects who did not show signs and symptoms of TMD, gave informed consent.

Chewing experiment

Only an outline of the chewing experiment is presented here; details has been described previously (Olthoff *et al.*, 1984). In order to determine food comminution, eight cubes of Optosoft with an edge size of 8.0 mm were offered. Each subject performed four chewing sequences consisting of 15, 30, 30 and 15 chewing cycles respectively. The chewing products were pooled for 15 chewing cycles as well as for 30 ones. After a sieving procedure, the cumulative particle-size distribution by weight was described by the Rosin-Rammler function:

$$Q_w(X) = 1 - 2^{-(X/X_{50})^b} \qquad (1)$$

in which Q_w is the weight fraction of particles with a size smaller than X. The median particle size, X_{50}, which is the aperture of a theoretical sieve through which 50% of the weight can pass, has been used as a measure of central tendency of the size distribution. A large value of X_{50} indicates a poor chewing performance. The value of *b* reflects the slope of the relationship between Q_w and X which indicates the extent to which the particles are equally sized. A large value of *b* corresponds to a steep slope of this relationship and thus to a range of particle sizes that is less broad.

The decrease of the median particle size as a function of the number of chewing cycles, N, can be adequately described as a power function:

$$X_{50}(N) = c.N^{-d} \qquad (2)$$

in which the variable *c* defines the notional median particle size after one chewing cycle. This value is only theoretical because the Rosin-Rammler function (equation (1)) cannot be successfully applied for obtaining a value of X_{50} at the beginning of the chewing process, when the parent particles are of identical size. The decrease of the median particle size per chewing stroke is given by variable *d*.

In order to quantify food comminution, X_{50} was determined after 15 as well as after 30 chewing cycles. Furthermore, as a measure of chewing efficiency, the number of chewing cycles required to halve the initial particle size, $N_{½}$, could be calculated by fitting the two values of X_{50} by equation (2), thus combining information on the variables *c* and *d* in equation (2) (van der Bilt *et al.*, 1987).

One-chew experiment

In order to determine selection chances and breakage functions for different particle sizes, three classes of cubes with an edge size of 8.0, 4.8 and 2.4 mm respectively were applied in one-chew experiments (van der Glas *et al.*, 1992). In these experiments, it is important to choose a particle number which is, on the one hand, sufficiently large for facilitating a normal tongue manipulation of the particles, and on the other hand, which is not too large for preventing saturation of the breakage sites on the tooth row. This saturation would hamper the selection of particles between antagonistic teeth. The number of particles which was offered each time in our one-chew experiment was 3, 12 and 68 for the size classes of 8.0, 4.8 and 2.4 mm respectively. These particle numbers corresponded with the critical numbers beyond which the breakage sites on the teeth become saturated in healthy subjects. The critical number of a particle size is approximately given by the ratio between the number of breakage sites and the selection chance of a single particle (van der Glas *et al.*, 1992). Because both variables in this ratio will proportionally decrease in a similar way by an impaired occlusion, the critical numbers of healthy subjects could also be applied to the patients from the present study. The number of selected particles increases approximately linearly with the number of particles offered so far as the breakage sites are not saturated. The selection chances observed with the particle numbers used (being equal to the ratio between the number of damaged or broken particles and the number of particles offered) will therefore be similar to those observed if a smaller particle number were used in the presence of normal tongue manipulation (van der Glas *et al.*, 1992).

The particles of the various sizes were randomly offered seven times. Each subject first made pseudo-chewing movements to obtain a natural dispersion of the particles in the mouth and to produce normal amounts of saliva. At the end of a jaw-opening phase, the subjects were unexpectedly instructed to carry out a real chew. The particles were expectorated, pooled across 7 trials, washed, dried and sieved. Because all particles had initially a regular shape, the non-damaged (non-selected) particles could easily be distinguished from damaged and broken (selected) ones by visual inspection. The weight of the selected particles divided by the total weight of damaged and non-damaged particles corresponds with the selection chance of size X, S(X). For the damaged and broken (selected) particles, adding the weight fractions of the fragments of initial size X, from the bottom of the sieve stack to the sieves with the various apertures Y, gives the experimental values of the breakage function B(Y,X). B(Y,X), a cumulative distribution function, is defined as the weight fraction of selected particles, of size X which break into particles smaller than sieve size $Y (Y \leq X)$. For any initial particle size X, the experimental breakage function B(Y,X) per chew was fitted by the function:

$$B(Y,X) = 1 - (1 + r.Y/X)(1 - Y/X)^r \qquad (3)$$

in which r represents a fragmentation factor (van der Glas *et al.*, 1987). Larger r-values are related to a higher degree of fragmentation.

All statistical analyses were carried out using SPSS 9.0 (SPSS Inc., 1998). An analysis of variance (ANOVA) with repeated measures was applied to values of median particle size (X_{50}), selection chance (S) and fragmentation factor (r) respectively to test the null hypothesis of no statistical differences between the two phases of orthodontic treatment, regardless of the number of chews (N) or the particle size (X). Effects of the number of chews or the particle size were revealed by examining the significance of inter-treatment phase effects and that of interactions between effects of N or X and the effect of treatment phase. The difference of chewing efficiency ($N_{½}$) between the two phases of orthodontic treatment was tested using a Student's t-test for paired observations.

Results

Maximal bite force

No significant change in maximum bite force was detected for the group I patients (the six patients who were tested twice, *viz.* before and after orthodontic treatment; Table 1; Student's t-test for paired observations). However, the sample size is too small to rule out the possibility of a difference. The maximal bite force of two other patients groups, *viz.* one group before orthodontic treatment and one after such treatment (both groups matched for age, gender and maximal bite force), was similar to the one of the six patients who were studied longitudinally. The degree of correlation between the values

Table 1. Comparison of maximal bite force before and after orthodontics in preorthognathic surgery patients

	Age mean (year) ± S.D.	Maximum bite force before orthodontics mean (Newton) ± S.D.	Maximum bite force after orthodontics mean (Newton) ± S.D.	Pearsons's correlation (r)
Group I: 4 females, 2 males longitudinal data	27.4 ± 6.5	339.0 ± 84.9	306.4 ± 96.7	0.58
Group IIa: 4 females, 2 males	22.4 ± 2.8	351.2 ± 46.3		0.56
Group IIb: 4 females, 2 males (matched with group IIa)	23.5 ± 4.0		343.5 ± 57.5	

of maximal bite force obtained before and after orthodontic treatment was also similar for the longitudinally studied group and the matched patient groups (*r*=0.56-0.58; Table 1).

Chewing performance

Fig. 1 shows the median particle size (X_{50}) after 15 and 30 chewing cycles before (pre-ortho) and after (post-ortho) orthodontic treatment. Orthodontic treatment had no effect on X_{50} (ANOVA: no significant between-phase-of-treatment effect, F=0.05, df=1; $P>0.82$). X_{50} after 30 cycles was smaller than after 15 cycles, regardless of the phase of treatment (ANOVA: within-phase-of-treatment effect of cycle number, F=156.3, df=1; $P<0.001$). Of course, this result could be expected as the food was further comminuted. The decrease in X_{50} between 15 en 30 cycles was similar for both phases of treatment, *i.e.* a significant within-phase-of-treatment interaction of cycle number and treatment phase did not occur (ANOVA: F=1.0, df=1; $P>0.32$).

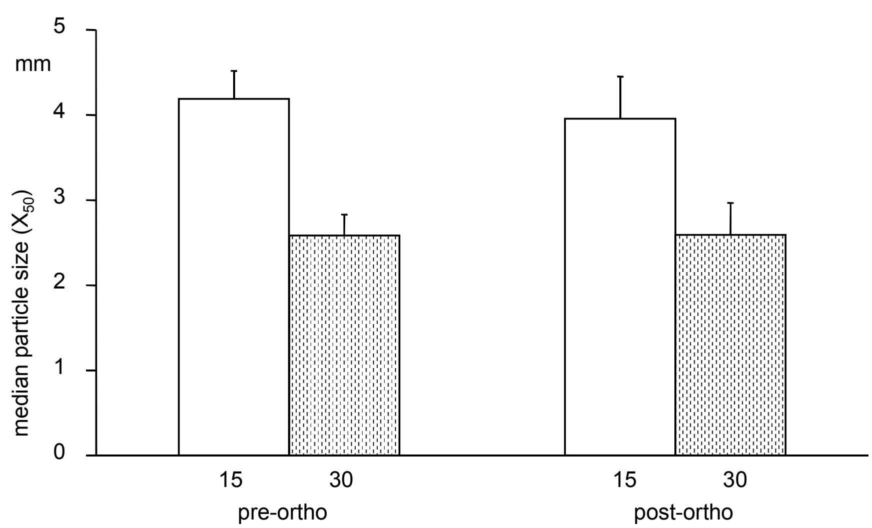

Fig. 1. The median particle size (X_{50}) (mean and standard error of the mean) after 15 (open bars) and 30 (hatched bars) chewing cycles for preorthognathic surgery patients before and after orthodontic treatment.

Broadness of the size distribution

Fig. 2 shows the extent to which the particles are equally sized after 15 and 30 chewing cycles before and after orthodontic treatment. The broadness value (b) was similar before and after treatment, after 15 cycles as well as after 30 cycles (ANOVA: no significant between-phase-of-treatment effect, F=0.15, df=1; *P*>0.70). Hence, the particles were equally sized for a particular cycle number, regardless of the phase of treatment. However, the broadness depended on the number of chewing cycles (ANOVA: within-phase-of-treatment effect of cycle number, F=18.4, df=1; *P*<0.001), *viz.*, the b value was, on average, larger after 15 cycles than after 30 ones.

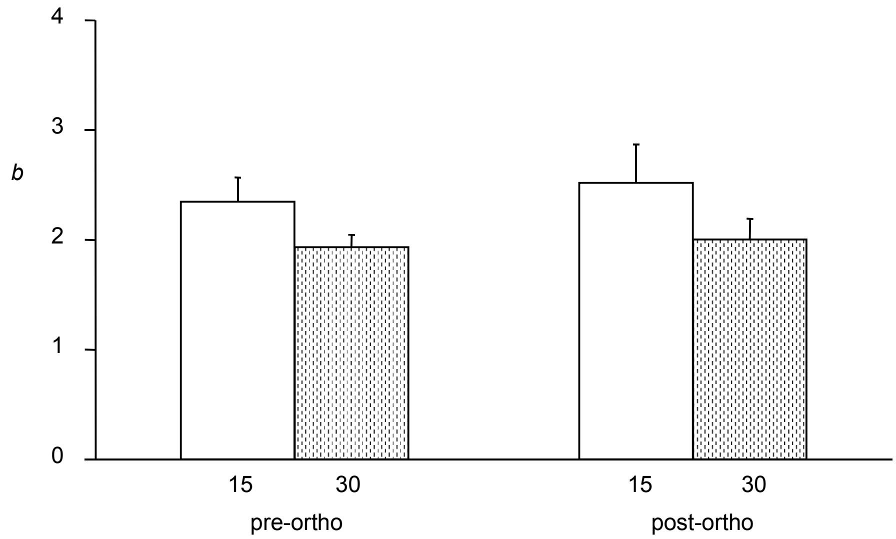

Fig. 2. The broadness (b) (mean and standard error of the mean) of the particle size distribution, for two numbers of chewing cycles (indicated below the bars), for preorthognathic surgery patients before and after orthodontic treatment.

Chewing efficiency

The number of chewing cycles needed to half the initial median particle size, $N_{½}$, was similar before and after orthodontic treatment, *viz.*, $N_{½}$ was on average 17.7 cycles (SEM=3.0, *n*=12 patients) and 18.6 cycles (SEM=4.7) respectively.

Selection chances from one-chew experiments

For both phases of treatment, Fig. 3 shows selection chances for three particle sizes. Averaged across the various particle sizes, the selection chance was similar regardless of the phase of treatment (ANOVA: no significant between-phase-of-treatment effect, F=0.14, df=1; *P*>0.71). Irrespective of the treatment phase, the selection chance increased significantly with particle size (ANOVA: within-phase-of-treatment effect of particle size, F=346.3, df=2; *P*<0.001). This increase was similar for both phases of treatment (ANOVA: no significant within-phase-of-treatment interaction of particle size by treatment phase, F=0.56, df=2; *P*>0.57). The selection chance approached the maximal possible value of 1 for a particle size of 8.0 mm.

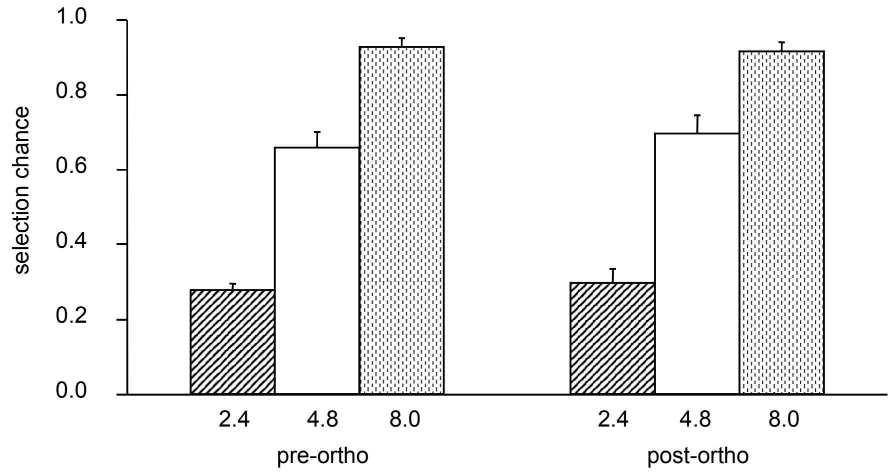

Fig. 3. The selection chance (mean and standard error of the mean) for three particle sizes (indicated below the bars in mm) for preorthognathic surgery patients before and after orthodontic treatment.

Breakage functions from one-chew experiments

For both phases of the treatment, Fig. 4 shows the degree of fragmentation (r) for the different particle sizes. Averaged over all particle sizes, the fragmentation factor was similar before and after treatment (ANOVA: no significant between-phase-of-treatment effect, F=0.79, df=1; *P*>0.38). However, the fragmentation factor depended on particle size in each phase of treatment (ANOVA: significant within-phase-of-treatment effect of particle size; F=26.9, df=2; *P*<0.001). Changes in the fragmentation factor as a function of particle size were different for both phases of treatment (ANOVA: within-phase-of-treatment interaction of particle size by treatment phase, F=3.40, df=2; *P*<0.05). In particular, the fragmentation factor for a particle size of 8 mm was significantly larger after orthodontic treatment than the one observed before treatment for this size (Student's t-test for paired observations: *t*=2.58, df=11; *P*<0.05), whereas the fragmentation factors were similar for a size of 2.4 or 4.8 mm.

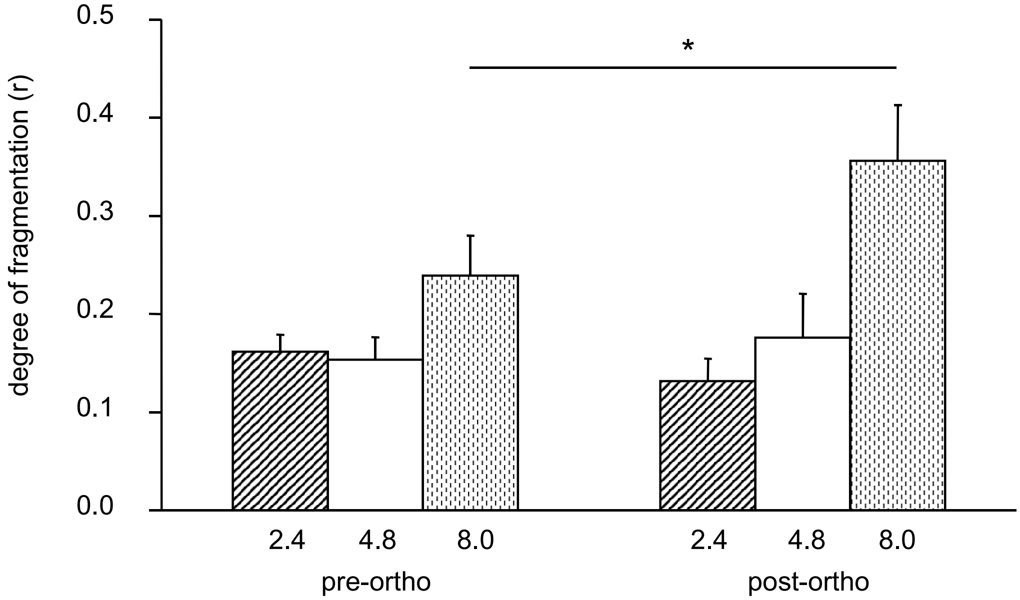

Fig. 4. The degree of fragmentation (r) (mean and standard error of the mean) for three particle sizes (indicated below the bars in mm) for preorthognathic surgery patients before and after orthodontic treatment. Horizontal bar, significant difference between the two phases of treatment (, P<0.05).*

Discussion

Pre-surgical orthodontic treatment in Class II (subdivision I) patients usually includes an elimination of crowding of the teeth and the formation of congruent upper and lower dental arches. The introduction of orthodontic appliances may temporarily cause pain and discomfort. Pain will also be present for a couple of days, each time orthodontic appliances have been activated. Furthermore, the patient may experience an altered occlusion as being unfamiliar or even inconvenient. One might therefore argue that because the generation of maximum bite force might be hampered by pain and/or discomfort, atrophic changes in the masticatory muscles might occur. However, no significant decrease of maximal bite force was found in the six patients who were examined before as well as after presurgical orthodontics at times when pain or discomfort were absent. One might argue that the difference in bite force values might have become significant if a larger sample size were used. However, the post-treatment decrease was on average so small (9.6% with respect to the pre-treatment mean) that such a change will hardly, if at all, be relevant. This finding is consistent with that reported of a previous study where only a small post-treatment decrease (10.0%) of maximal bite force occurred for the molar region, using a larger sample of 15 patients (Thomas *et al.*, 1995). No significant alterations were observed in jaw movements during chewing, EMG/bite force slopes or moment arms (Thomas *et al.*, 1995). All findings from this previous study and the present one suggest that orthodontic treatment does not cause permanent changes of jaw muscle function in preorthognatic surgery patients.

In the present study, no changes occurred in the broadness of the distribution of the chewed particles, or in the chewing efficiency ($N_{½}$) after orthodontic treatment of Class II (subdivision I) patients. However, an opposite change in the underlying mechanisms selection and breakage might still be possible as, for example, a constant chewing efficiency might occur if one of the mechanisms (*e.g.* selection) were improved by treatment while the other one (*e.g.* breakage) were hampered. For each particle size studied, the number of particles used was sufficiently large for obtaining natural values for selection chances and fragmentation factors following a normal tongue manipulation of the particles. In addition, the number of particles used was sufficiently small to achieve that the selection chance was invariant for this particle number and only depended on particle size. The number of particles used corresponded to food volumes of 1.54, 1.33 and 0.94 cm^3 for the size classes of 8.0, 4.8 and 2.4 mm respectively. These volumes were small as they represented 13 to 21% of the mean freely chosen mouthful and 3 to 5% of the mean maximum volume of peanuts a subject could store in the mouth (Lucas and Luke, 1984). By using such small volumes, selection will not be hampered due to saturation of the breakage sites on the tooth row. No significant treatment induced differences were observed in selection chances of the three particle sizes studied and in breakage for smaller particle sizes (2.4 and 4.8 mm). On the other hand, there was a significant increase in breakage for the particle size of 8.0 mm. After presurgical orthodontic treatment, Class II patients have in principle the ability to accomplish proper unilateral, or even bilateral occlusal contacts by compensatory movements of the mandible. The presence of congruent dental arches might enable the patient to manipulate 8.0 mm particles in such a way that these particles will have a larger chance of being subjected to a process of multiple breakage (Lucas and Luke, 1983). During the closing movement of the mandible, large particles will be processed by more than one cusp of molar teeth. Furthermore, fragments from these large particles which are locked up between antagonistic post-canine teeth, might be broken further in the same chewing cycle as jaw closing continues. However, when chewing is started on particles of 8.0 mm, only a few cycles are required to comminute these large particles towards particles of smaller size. The increase in fragmentation factor which occurs after orthodontic treatment for this large particle size will therefore hardly be reflected in a value of chewing efficiency which is based on size distributions which occur between 15 and 30 chews on Optosoft.

It can be concluded that despite the presence of orthodontic appliances and the alteration of occlusion, orthodontic treatment of preorthognathic surgery patients does not yield significant differences in chewing efficiency. Regarding the underlying mechanisms, this treatment does not influence the selection of particles of all sizes studied and the breakage of smaller-sized particles (≤4.8 mm). The orthodontic treatment improves breakage of large-sized particles (8.0 mm), which is, however, of little importance for the chewing efficiency during a later phase of chewing when smaller particles become abundant.

Acknowledgements - The Netherlands Institute for Dental Sciences supported this work. We are grateful to Dr. H.J. Wynne (Department of Biostatistics, Utrecht University) for advise on statistical analysis.

Chapter 4

The influence of orthognathic surgery on masticatory performance in retrognathic patients

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Summary

Surgical correction of retrognathism may influence chewing performance and its underlying mechanisms selection and breakage of food particles. In this study we examined the hypothesis that treatment of this anomaly improves chewing performance. Furthermore, we determined to what extent this change can be attributed to selection and breakage of food particles. Eleven patients were tested before and 1-1.5 years after surgery. To determine chewing performance, eight cubes of 8 mm of a silicone rubber (Optosil®) were used as a test food. Selection and breakage were determined in one-chew experiments using three particle sizes. On average, no differences were found for chewing performance, selection or breakage. However, on an individual basis, patients with a poor chewing performance before surgery tended to improve, whereas no improvement was observed for patients with a good chewing performance. The change in chewing performance was mainly due to a change in breakage of the food particles.

Introduction

Chewing is the first step of the digestive process. Food particles are broken into smaller pieces and mixed with saliva before being swallowed. A major factor involved in comminution is occlusion (Julien *et al.*, 1996). Therefore, in patients with a malocclusion, because of a dentofacial deformity, one might expect a reduced chewing performance. A reduced chewing performance has indeed been reported for patients with a variety of dentofacial deformities (Tate *et al.*, 1994a; Zarrinkelk *et al.*, 1995a) and in patients with a mandibular prognathism (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993; Kikuta *et al.*, 1994; Kobayashi *et al.*, 2001). After surgical correction, chewing performance improved significantly in some studies (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Kobayashi *et al.*, 2001), but did not reach control values. Retrognathic patients also showed a reduced chewing performance before treatment (van den Braber *et al.*, 2001). Orthodontic treatment applied to patients before orthognathic surgery had no effect on chewing performance (van den Braber *et al.*, 2002). However, no data are available about the effect of surgical correction of retrognathia on chewing performance. We therefore determined chewing performance in retrognathic patients before and after surgery.

The fragmentation of food particles can be considered as the composite result of a selection and a breakage process (Lucas and Luke, 1983). In order to damage a food particle, it has to be selected between antagonistic teeth. Selection can be regarded as the fraction of the offered food particles that is at least damaged during a chew. Once a particle is selected, the extent to which it is fractured can be expressed by a breakage factor (Austin, 1971).

The aim of the present study was to evaluate the influence of surgical correction of retrognathism on chewing performance. Furthermore, the extent to which selection and breakage might account for possible differences in chewing performance was examined.

Materials and methods

Subjects

Eleven mandibular retrognathic patients (five males and six females; mean age 24.8 years, s.d. 6.4), all with a skeletal angle class II and a dental angle class II subdivision I, were tested on two occasions. Testing occurred (i) just before orthognathic surgery, *i.e.* after pre-surgical orthodontic treatment, and (ii) 1-1.5 years after surgery (bilateral sagittal split osteotomy to advance the mandible) when orthodontic after-treatment was finished. The control group consisted of 12 subjects (four males and eight females; mean age 25.1 years, s.d. 5.9), all with a class I occlusion. All subjects had complete dentitions and were free of signs and symptoms of temporo-mandibular disorders. The Ethics Committee of the University Medical Center Utrecht approved the protocol. Written informed consent was obtained from each subject after full explanation of the experiment.

Chewing experiment

The silicone rubber Optosil® (Version 1980, Bayer, Germany), a dental impression material, was used as a standardized test food. As Optosil® frequently appeared to be too tough for the patients, a softened version was prepared by heating, which is denoted as Optosoft hereafter (van den Braber *et al.*, 2001). As details has been described in a previous study (van den Braber *et al.*, 2001), only an outline of the chewing experiment is presented here. In order to determine the chewing function, eight cubes of Optosoft with an edge size of 8 mm were offered. Each subject performed four chewing sequences consisting of 15, 30, 30 and 15 chewing cycles. The chewing products obtained after 15 chewing strokes as well as after 30 strokes were pooled. The median particle size, X_{50}, was determined for both 15 and 30 chewing cycles with a sieving method. A large value of X_{50} indicates a poor chewing performance.

One-chew experiment

A detailed description of the set-up of the one-chew experiment was given previously (van den Braber *et al.*, 2001), so only an outline will be given here. In order to determine selection chances and breakage function for different particle sizes, three classes of cubes with an edge size of 8.0, 4.8 and 2.4 mm, respectively, were used in the one-chew experiments. For the three size classes, the number of particles which was offered each time was 3, 12 and 68, respectively. The particles of the various sizes were randomly offered seven times. The particles were expectorated, pooled across seven trials, washed, dried and sieved. The non-damaged (non-selected) particles were separated from damaged and broken (selected) ones by visual inspection. The weight of the selected particles divided by the total weight of damaged and non-damaged particles yields the selection chance of size X, S(X). For the damaged and broken (selected) particles, the degree of breakage was determined (Austin, 1971; van der Bilt *et al.*, 1987; van der Glas *et al.*, 1987). Larger values are related to a higher degree of breakage.

Statistical analysis

We applied repeated measures analysis of variance (ANOVA; SPSS 9.0, SPSS Inc. Chicago, IL, USA) to test the null hypothesis that there would be no statistical difference between the results obtained for the patients before and after surgery. Subsequently, we used ANOVA with patient/control as a fixed factor to test for differences between patients and controls. Particle size (2.4, 4.8 or 8.0 mm) was used as a fixed factor for testing differences in selection and breakage. The degree of correlation between variables was determined with Pearson's correlation coefficient.

Results

Masticatory performance

Fig. 1 shows the median particle size (X_{50}) after 15 and 30 chewing cycles for patients before as well as after surgical treatment and for controls. Repeated measures analysis of variance revealed no significant differences between the median particle sizes obtained for patients before and after surgery. Furthermore, we found that controls chewed the test food significantly better than patients before (P < 0.001) and after (P < 0.001) surgery.

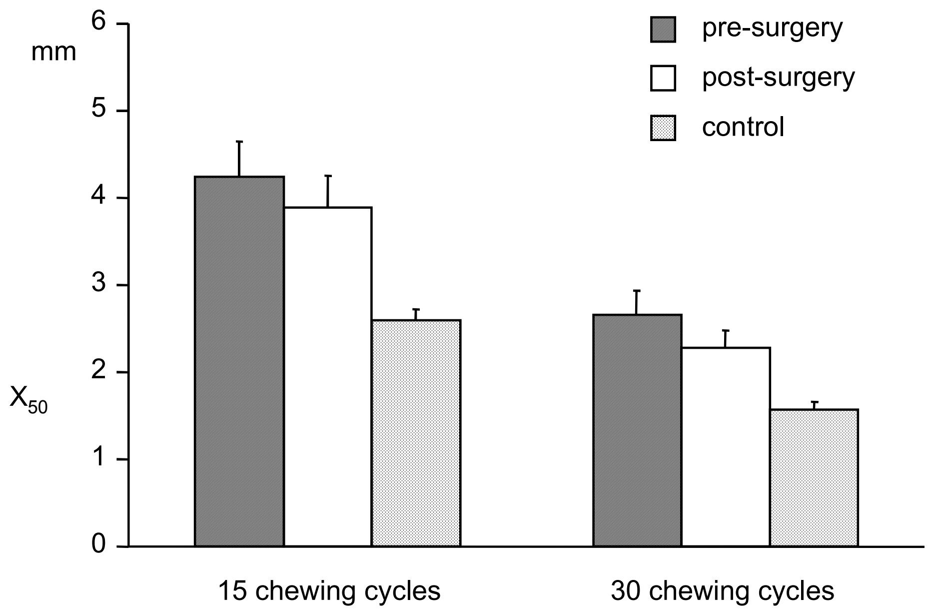

Fig. 1. The median particle size (X_{50}; mean and s.e.m. in mm) after 15 and 30 chewing cycles for orthognathic surgery patients before and after surgery and for controls.

Fig. 2 shows the change of the median particle size (post-surgical minus pre-surgical values) obtained after 15 chewing cycles for the 11 patients as a function of pre-surgical values of the median particle size. The change in the median particle size was significantly correlated (r = -0.70; P < 0.05) with the pre-surgical values. Subjects with a poor pre-surgery chewing performance had the tendency to improve in contrast to subjects with a better chewing performance. Similar findings were obtained after 30 chewing cycles (r = -0.70; P < 0.05)

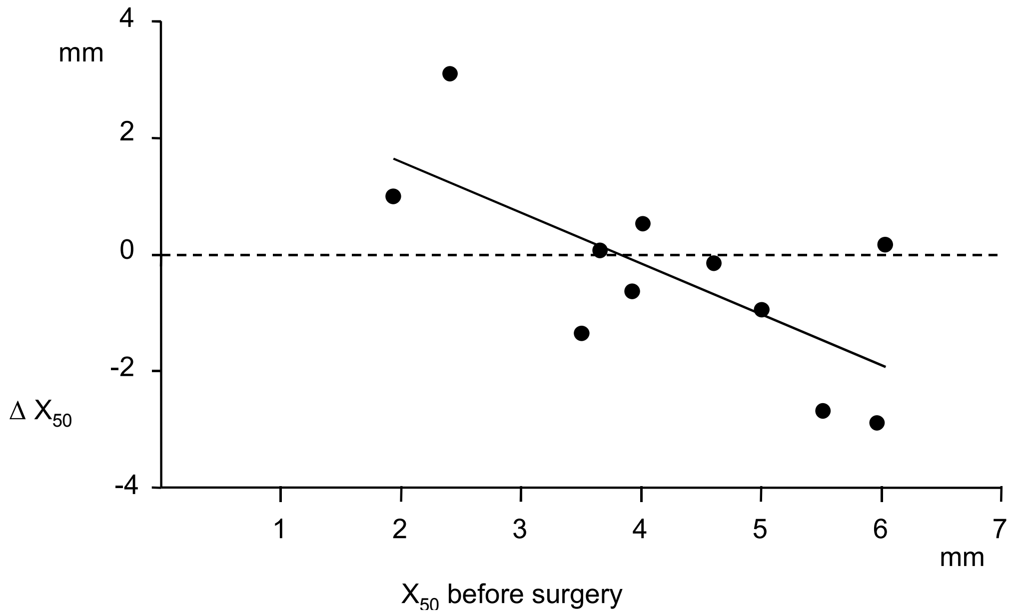

Fig. 2. The change of the median particle size (post-surgical minus pre-surgical values) as a function of the median particle size before surgery for 11 orthognathic surgery patients (r=-0.70; P<0.05). Data obtained after 15 chewing cycles.

Selection chances from one-chew experiments

For each of the three particle sizes, Fig. 3 shows selection chances for patients before and after surgery and for controls. No significant differences in selection chances were found for the patients before and after surgery. We found that controls had a better selection than patients before (P < 0.001) and after (P < 0.001) treatment. Regardless of the subject group or phase of treatment, the selection chance increased with particle size (P < 0.001). The change of selection chances for the 11 patients was significantly correlated with pre-surgical selection chances for all three particle sizes (2.4 mm: r = -0.82, P < 0.005; 4.8 mm: r = -0.64, P < 0.05 and 8.0 mm: r = -0.78, P < 0.01).

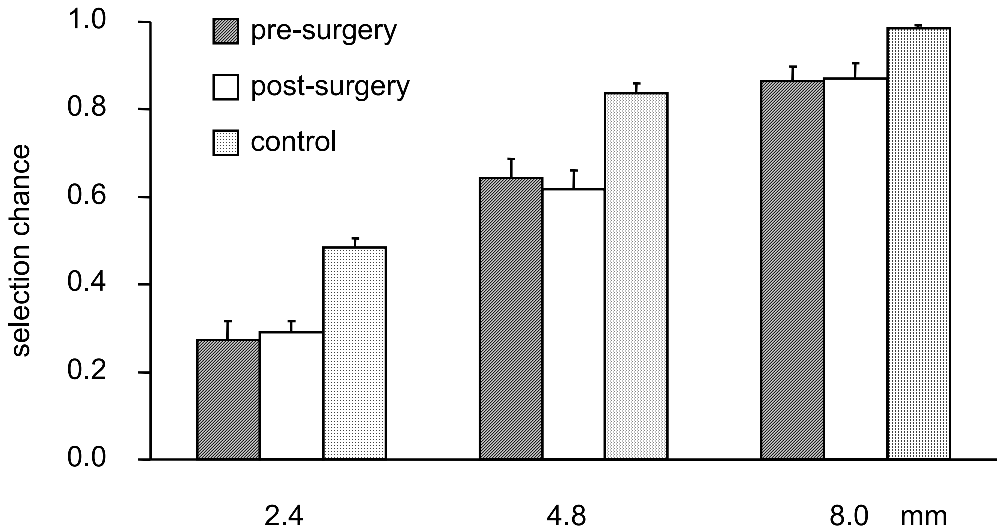

Figure 3. The selection chance (mean and s.e.m.) for three particle sizes for orthognathic surgery patients before and after surgery and for controls.

Breakage functions from one-chew experiments

For each of the three particle sizes, Fig. 4 shows the degree of breakage for patients before and after surgery and for controls. There was no difference in breakage for

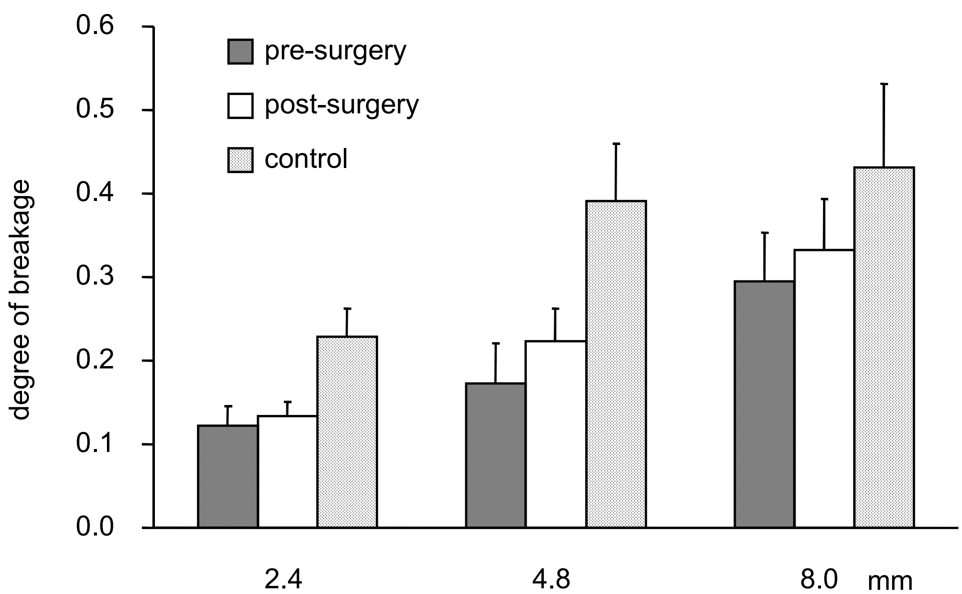

Fig. 4. The degree of breakage (mean and s.e.m.) for three particle sizes for orthognathic surgery patients before and after surgery and for controls.

patients before and after treatment. Controls did fragment the test food significantly better than patients before ($p < 0.001$) and after ($p < 0.01$) treatment. The breakage factor significantly increased with particle size ($p < 0.001$), regardless subject group or phase of treatment. The change of the breakage factor for the 11 patients was significantly correlated with pre-surgical breakage values for the particle sizes 2.4 mm and 4.8 mm (2.4 mm: $r = -0.74$, $p < 0.05$; 4.8 mm: $r = -0.67$, $p < 0.05$).

Discussion

A variety of dentofacial deformities is known in man. It is conceivable that these anomalies have consequences for function (*e.g.* maximum bite force and chewing performance) for the masticatory system. Whereas treatment of subjects with a mandibular prognathism was subject of a number of studies, little was reported about retrognathic patients. From a biomechanical point of view, surgical advancement of the mandible is expected to decrease the generation of maximum bite force (Finn *et al.*, 1980). In a previous study, advancement of the mandible did not have a consistent impact on occlusal force: both increase and decrease of bite force occurred (Proffit *et al.*, 1989). In another study, bite forces increased steadily after surgery, approaching normal values within 2 years (Throckmorton *et al.*, 1995).

In our previous study (van den Braber *et al.*, 2002) we found that presurgical orthodontics had no effect on chewing performance. In the present study, no difference was found in chewing performance before and after treatment as far as group averages are considered. However, the negative correlation in Fig. 2 shows that subjects with a poor chewing performance (large value of the median particle size) before treatment, had the tendency to improve, whereas subjects with a relatively high chewing performance did not. Especially, subjects with a poor chewing performance will have functional benefits of treatment. In patients with a chewing performance comparable to that of controls, improvement may not be expected. For these patients, other, *e.g.* aesthetic considerations should justify orthognathic surgery.

The negative correlation between the change in median particle size and the median particle size before treatment might be the result of so-called ’regression to the mean’. In that case, relatively high values obtained in the first measurement have a larger chance to be smaller in the second measurement, and vice versa. The negative correlation is then caused by chance fluctuations and not by a physiological effect. However, in an unpublished study on 81 healthy dentate subjects, where we measured the median particle size after 15 chewing cycles on two occasions with a 3-month time interval, the correlation between the change in median particle size and the median particle size at the first measurement was much weaker than the correlation observed in the present study (r = -0.19, P = 0.08 as compared to r = -0.70 P < 0.05). Thus, the negative slope of the regression line in Fig. 2 is most likely a consequence of treatment.

In comminution of food particles, two subprocesses can be distinguished: selection and breakage. Change in the chewing performance, as a result of surgical correction of a dentofacial deformity, may be due to a change in selection, breakage or both. On average, treatment did not have an effect on either selection or breakage. However, subjects with a poor selection or breakage before treatment did select and break the food better after treatment.

The change in median particle size after chewing 15 or 30 cycles, following treatment, was significantly correlated with the change in breakage, whereas such a correlation was not found for the change in selection. Apparently, the alteration of the chewing performance is mainly due to a change in the breakage of food particles. Therefore, the improvement of chewing performance in some patients may be attributed to a better breakage of food particles. It has been suggested that breakage might depend on factors like cusp form and maximum bite force (Lucas and Luke, 1983). Though surgery did not significantly influence cusp form, the occlusion was changed which may have led to a change in breakage of the food particles.

For patients selection and breakage did not reach control values. With a decrease of particle size of the one-chew experiments (8.0, 4.8 and 2.4 mm), the differences in selection between patients before as well as after surgery and controls became more pronounced (Fig. 3). Apparently, patients with a dentofacial deformity, have more difficulties to select small particles than controls. Selection of larger particles is less affected (Fig. 3).

In patients with mandibular retrognathia a reduced chewing performance was found. This is due to an impairment of both selection and breakage of food particles. On average, surgical correction did not improve these functions. However, on an individual basis, patients with a poor function before treatment tended to improve. This improvement was mainly related to a better breakage of food particles.

Acknowledgements

This work was supported by the University Medical Center Utrecht, and the Netherlands Institute for Dental Sciences. We are grateful to Dr. M. Schipper (Department of Biostatistics, Utrecht University) for advice on the statistical analysis.

Chapter 5

Masticatory function in retrognathic patients, before and after mandibular advancement surgery

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Purpose: Mandibular retrognathia is a dentofacial deformity that can be surgically corrected. The purpose of this study was to evaluate the influence of orthognathic surgery on masticatory function in a sample of retrognathic patients and to compare these findings with those of controls.

Patients and methods: Eleven retrognathic patients were tested before and 1 to 1.5 years after mandibular advancement surgery and compared with 12 controls. The median particle size after chewing a silicon rubber test food, the maximum bite force, and the electromyographic activity (EMG) of the anterior temporalis and the masseter muscles during isometric clenching and during chewing were determined. Patients, before and after treatment, and controls were statistically compared by analysis of variance.

Results: Surgical correction of mandibular retrognathia did not change chewing efficiency, maximum bite force, EMG during maximal clenching, EMG during chewing, or the EMG/bite-force relationship. Compared with controls, the chewing efficiency, maximum bite force, EMG during maximal clenching, and EMG during chewing values were lower. No difference for the EMG/bite force ratio at maximal clenching was found, indicating similar muscle efficiency for patients and controls. However, in the range of 10% to 40% of the maximum bite force, the slope of the EMG/bite-force regression line was steeper for the patients than for the controls, indicating decreased muscle efficiency for patients.

Conclusions: The results of this study suggest that in retrognathic patients, function of the masticatory system is impaired. Oral function was not influenced by mandibular advancement surgery.

Introduction

A variety of dentofacial deformities are known to humans. Such a deformity might hamper the function of the masticatory system. Hence, besides esthetic considerations, presumed functional deficits are frequently used as a motive to carry out surgical corrections in these patients. To quantify the function of the masticatory system, a number of parameters have been studied, including chewing efficiency, maximum bite force, electromyographic activity (EMG) of the masticatory muscles and maximum range of mandibular motion. As a measure of efficiency of the musculoskeletal system, the electromyographic activity can be expressed as a function of bite force (Hagberg *et al.*, 1985; Lindauer *et al.*, 1991). Pre-orthognathic surgery patients with a variety of dentofacial deformities showed lower masticatory performances (Tate *et al.*, 1994a; Ästrand, 1974; Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993; Zarrinkelk *et al.*, 1995; Kobayashi *et al.*, 2001), reduced maximum bite forces (Tate *et al.*, 1994a; Dean *et al.*, 1992; Throckmorton *et al.*, 1996), reduced maximum EMG (Harper *et al.*, 1997), and reduced EMG during mastication (Tate *et al.*, 1994b; Kobayashi *et al.*, 2001). A lower efficiency of the jaw-closing muscles can not always be found for pre-orthognathic surgery patients (Tate *et al.*, 1994a; Tate *et al.*, 1994b). Hence an impaired function of the masticatory system cannot be attributed to a lower efficiency of the masticatory muscles. In some studies, chewing efficiency improved after surgical correction but did not reach control values (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 2001). In other studies, improvement could not be shown (Ästrand, 1974; Kobayashi *et al.*, 1993; Zarrinkelk *et al.*, 1995). After surgery, maximum bite force often improved (Shiratsuchi *et al.*, 1991; Iwase *et al.*, 1998; Kim and Oh, 1997; Throckmorton *et al.*, 1996) and some times even approached control values (Throckmorton *et al.*, 1995; Zarrinkelk *et al.*, 1996). However, increase in maximum bite force could not always be found (Proffit *et al.*, 1989). Surgery did not increase EMG during maximum clenching in retrognathic patients (Harper *et al.*, 1997). The efficiency of jaw-closing muscles did not change (Zarrinkelk *et al.*, 1996) or increased (Throckmorton *et al.*, 1995). The duration of the chewing cycle was the same for patients and controls, and surgery did not change this finding (Youssef *et al.*, 1997). Most of the studies refer to groups of patients with a variety of dentofacial deformities or patients with mandibular prognathism. From these studies, it is difficult to assess the influence of orthognathic surgery on oral function in patients with mandibular retrognathia. The aim of this study was to determine the influence of mandibular advancement surgery on masticatory performance, bite force, EMG during mastication and isometric clenching in retrognathic patients.

Patients and methods

Subjects

Eleven subjects (5 males and 6 females; mean age 24.8 years, S.D. 6.4) all with mandibular retrognathia and a dental Angle Class II, subdivision I, were tested on two occasions. Testing occurred 1) just before orthognathic surgery (*i.e.* after pre-surgical orthodontic treatment) and 2) 1 to 1.5 years after surgery (bilateral sagittal split osteotomy to advance the mandible) and orthodontic posttreatment. The control group consisted of 12 subjects (4 males and 8 females; mean age 25.1 years, S.D. 5.9). The Ethics Committee of the University Medical Center Utrecht approved the protocol. Written informed consent was obtained from each subject after full explanation of the experiment.

Chewing experiment

The silicone rubber Optosil (Version 1980; Bayer, Leverkusen, Germany), a dental impression material, was used as a standardized test food. Because Optosil frequently appeared to be too tough for the patients, a softened version was prepared by heating, which is denoted as “Optosoft” hereafter (van den Braber *et al.*, 2001).

Because details has been described in a previous study (van den Braber *et al.*, 2001), only an outline of the chewing experiment is presented here. To determine the chewing function, 8 cubes of Optosoft with an edge size of 8 mm were offered. Each subject performed 2 chewing sequences consisting of 30 chewing cycles. Both chewing products obtained after 30 strokes were pooled. The median particle size (X_{50}) was determined with a sieving method. A large value of X_{50} indicates a poor chewing performance.

Maximum bite force

Maximum bite force was measured bilaterally at the level of the first molars using a bite fork with 2 force transducers. The bite-force transducer has been described previously in detail (Slagter *et al.*, 1993). Subjects were encouraged to bite as hard as possible on the transducer for a few seconds. The measurement was performed 3 times. The highest bite force of the 3 efforts was selected. Left and right force signals were summed.

Surface electromyography

The electrical activity of the masseter and anterior temporalis muscles was recorded bilaterally, using bipolar surface electrodes (Blue Sensor; Medicotest, Ølstykke, Denmark; diameter, 6 mm; interelectrode distance, 18 mm). For an optimal location of the electrodes, the maximum bulk of the muscle bellies was determined by palpation while the subjects intermittently clenched their teeth. An electrode on the forehead served as a ground reference. The EMG signals were amplified, sampled at 1500 Hz, full wave-rectified, and smoothed (low pass, 1.9 Hz). The 4 signals of the 2 masseter muscles and the 2 temporales muscles were summed. EMG was recorded during the measurements of the maximum bite force. After determination of the maximum bite force, EMG was obtained at 10%, 20%, 30% and 40% of the maximum bite force. Visual feedback was provided. EMG was also recorded during maximal clenching with the teeth in maximal occlusion. This measurement was also performed 3 times and the highest value was selected. Furthermore, EMG was recorded during the chewing experiment. For each of the 30 chewing cycles of the chewing experiment, the peak of the EMG burst was determined. Cycle numbers 1 and 30 were omitted because of their usually nonspecific qualities. For the remaining 28 cycles, the peak values were averaged.

Chewing cycle time

Peaks of the EMG bursts were detected from the EMG registration of the chewing experiment. Peak-to-peak intervals were used to calculate chewing cycle times.

The onset of the EMG bursts was determined by an EMG threshold function, based on the amplitude distribution. The onset of a burst was located where EMG amplitudes started to exceed the mean plus 3 times the standard deviation of the background EMG (*i.e.* the amplitudes between bursts) (Abbink *et al.*, 1998). The interval from the onset of the burst till the peak was used to calculate the closing phase time. The values for cycle 2 to 29 were averaged.

Statistical analysis

Repeated measures analysis of variance (ANOVA) (SPSS 9.0, SPSS Inc., Chicago, IL) was applied to test the null hypothesis that there would be no statistical difference between the results obtained for the patients before and after surgery. Subsequently, we used ANOVA with patient/control as a fixed factor to test for differences between patients and controls. A Pearson correlation was calculated between median particle size and maximum bite force.

Results

Table 1. Variables describing oral function for patients, before and after surgery and for controls

	pre-surgical	post-surgical	control	pre-control	post-control
Median particle size (X_{50})	2.66 ± 0.93	2.27 ± 0.70	1.57 ± 0.31	‡	*
Maximum bite force (N)	336 ± 88	282 ± 119	569 ± 166	§	§
Maximum EMG (μV)					
In maximal occlusion	1254 ± 572	1211 ± 402	1959 ± 650	†	‡
Bite-force transducer in situ	1324 ± 512	1168 ± 419	2138 ± 586	‡	§
EMG peak chewing (μV)	607 ± 288	663 ± 221	969 ± 293	‡	*
Chewing cycle time (sec)					
Total	0.79 ± 0.07	0.75 ± 0.14	0.70 ± 0.09	*	
Closing phase	0.46 ± 0.06	0.43 ± 0.07	0.38 ± 0.06	*	

NOTE. Values are given as the mean ± SD. Degree of significance given for differences in values between controls and patients before surgery (pre-control) and after surgery (post-control). *$P < 0.05$, †$P < 0.01$, ‡$P < 0.005$, §$P < 0.001$.
Abbreviation: EMG, electromyographic activity

Chewing performance

ANOVA revealed no significant change in median particle sizes (X_{50}) obtained after 30 chewing cycles for patients before and after surgery (Table 1). Furthermore, we found that controls chewed the test food significantly better than patients before ($P < 0.005$) and after ($P < 0.05$) surgery.

Maximum bite force

There was no change in maximum bite force for patients before and after surgery (Table 1). For controls, the values were significantly higher than for patients before as well as after surgery ($P < 0.001$).

Median particle size as a function of the maximum bite force

The median particle size (X_{50}) was significantly correlated with the maximum bite force for patients before ($r = 0.71$; $P < 0.05$) and after ($r = 0.67$; $P < 0.05$) surgery (Fig. 1). For controls, no correlation was found.

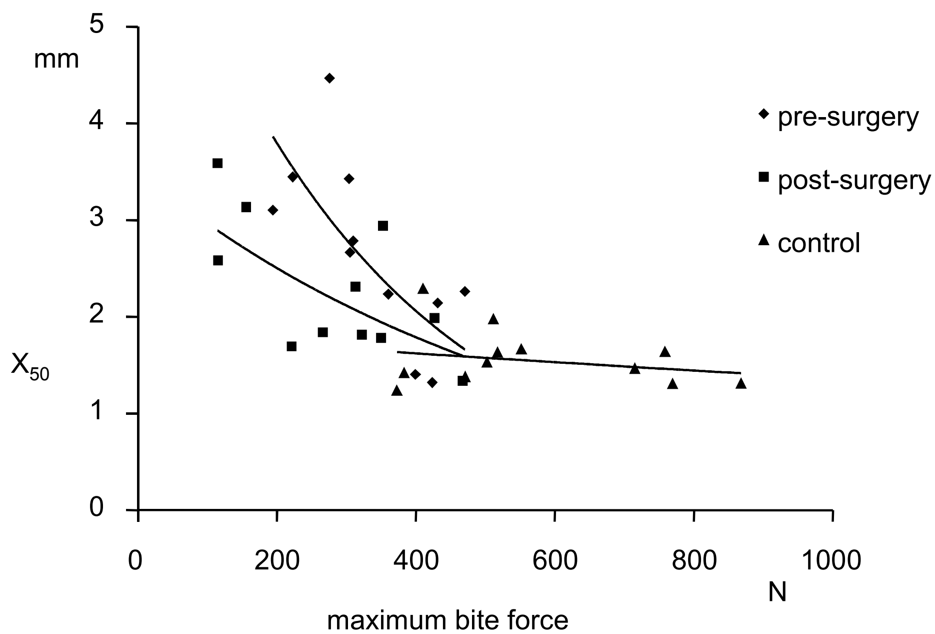

Figure 1. The median particle size as a function of the maximum bite force for patients before and after surgery and for controls. The curves indicate exponential regression of the median particle size as a function of maximum bite force.

Maximum EMG

For measurements in maximal occlusion, no changes were found in maximum EMGs for patients before and after surgery (Table 1). For controls, the values were significantly higher than for patients before ($P < 0.01$) as well as after ($P < 0.005$) surgery.

The results with the bite-force transducer in situ were similar. There were no changes in patients before and after surgery, and larger values were found for controls than for patients before ($P < 0.005$) and after ($P < 0.001$) surgery.

No differences in muscle activity were found between the measurements in maximal occlusion and those with the bite transducer in situ.

EMG during chewing

For the averaged values of the peak EMG during 30 chewing cycles, no change was found in patients before and after surgery (Table 1). For controls, the values were significantly higher than for patients before ($P < 0.005$) as well as after ($P < 0.05$) surgery. During a chewing sequence, the EMG peak values of the chewing cycle remained constant.

Chewing cycle time

There was no change in chewing cycle time in patients before and after surgery (Table 1). Chewing cycle time was less for controls than for patients before surgery ($P < 0.05$). No difference between controls and patients after surgery could be demonstrated. The results for the time needed for closing the jaw were similar.

Ratio of muscle activity and bite force

The EMG, obtained from the measurement of the maximum bite force, divided by the maximum bite force did not show differences between patients before and after surgery and controls (Table 2).

The slope of the regression line of the EMG as a function of the bite force at 10%, 20%, 30%, and 40% of the maximum bite force did not differ between patients before and after surgery. However, the slope was smaller for controls than for patients before ($P < 0.05$) and after ($P < 0.005$) surgery, indicating a greater muscle efficiency for controls.

The EMG/bite-force ratio, derived from the measurement during maximum clenching, was larger than the one derived from regression at 10% to 40% of the maximum bite force ($P < 0.001$).

Table 2. Ratio of muscle activity and bite force during clenching and relative muscle activity during chewing

	pre-surgical	post-surgical	control	pre-control	post-control
EMG/bite force (μV/N)					
Maximum clenching ‡	3.90 ± 1.08	4.44 ± 1.24	3.89 ± 0.94		
Submaximum clenching §	3.36 ± 0.75	3.94 ± 1.06	2.66 ± 0.60	*	†
Relative EMG (μV/μV)					
Peak chewing/maximum clenching ¶	0.48 ± 0.16	0.60 ± 0.20	0.47 ± 0.14		
Peak chewing/maximum clenching ||	0.55 ± 0.26	0.57 ± 0.18	0.54 ± 0.24		

NOTE. Values are given as the mean ± SD. Degree of significance given for differences in values between controls and patients before surgery (pre-control) and after surgery (post-control). *$P < 0.05$, †$P < 0.005$.
‡ Ratio of maximum EMG and maximum bite force
§ Slope of the regression line through 10, 20, 30 & 40% of maximum
¶ With bite transducer in situ
|| In maximal occlusion
Abbreviation: EMG, electromyographic activity.

Relative muscle activity EMG during chewing

The peak EMG during chewing as a percentage of the maximum EMG did not show differences between patients before and after surgery and controls, regardless of the method of determining the maximum EMG (Table 2).

Discussion

In patients with mandibular retrognathia, chewing performance was not influenced by orthodontics before surgery (van den Braber *et al.*, 2002). In these patients, we observed that before surgery, the chewing performance was impaired with respect to that of control subjects. This finding was consistent with results obtained from groups of patients with a variety of dentofacial deformities (Tate *et al.*, 1994a; Ästrand, 1974; Zarrinkelk *et al.*, 1995) and in patients with mandibular prognathism (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993; Kobayashi *et al.*, 2001). At least 1 year after mandibular advancement surgery, chewing performance was not improved in the present study. This is in accordance with findings in some previous studies (Ästrand, 1974; Kobayashi *et al.*, 1993; Zarrinkelk *et al.*, 1995). However, in other studies, containing mandibular setback patients, improvement was shown (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Kobayashi *et al.*, 2001).

We determined maximum bite force, because this is an important factor for masticatory performance (Julien *et al.*, 1996). Theoretically, one might expect higher bite forces in retrognathic patients than in controls, because of shorter bite force arms (Finn *et al.*, 1980). However, the maximum bite force before surgery was smaller than in controls. Similar results were observed in patients with mandibular prognathism (Shiratsuchi *et al.*, 1991; Iwase *et al.*, 1998; Zarrinkelk *et al.*, 1996) and in patients with a variety of dentofacial deformities (Tate *et al.*, 1994a; Dean *et al.*, 1992; Thomas *et al.*, 1995). Apparently, the anteroposterior position of the mandible did not influence maximum bite force. Advancement of the mandible enlarges the bite-force arm and thus might lead to a decrease of the maximum bite force (Finn *et al.*, 1980; Throckmorton *et al.*, 1980). Such a decrease in bite force has indeed been shown in Rhesus monkeys (Dechow and Carlson, 1986). However, 1 year after surgery, we did not find a decrease of maximum bite force in our retrognathic patients. In previous studies, advancement of the mandible did not have a consistent impact on bite force. In 1 study, 1 year after surgery, increase as well as decrease of maximum bite force was reported (Proffit *et al.*, 1989). An increase of bite force, approaching normal values within 2 years, was also reported (Throckmorton *et al.*, 1995). In this study, 1 year after surgery, the values of bite force were still increasing. A longer follow-up in our patient group might also show improvement. In a study where the mandibular advancement was combined with a maxillary intrusion (which is biomechanically advantageous), control values were reached (Zarrinkelk *et al.*, 1996). In patients who were treated with an also advantageous mandibular setback, an increase in force was found (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Iwase *et al.*, 1998; Kim and Oh, 1997) up to control values (Throckmorton *et al.*, 1995).

For patients, before as well as after surgery, the median particle size was significantly correlated with the maximum bite force. For controls, no correlation was found, probably due to the fact that when the maximum bite force exceeded a certain value, it did not further contribute to a decrease in median particle size. Similar findings were reported previously (Fontijn-Tekamp *et al.*, 2000).

EMG during maximal clenching was determined in maximal occlusion and during the measurement of the maximum bite force when the force transducer was in situ. In both conditions, maximum EMG of the patients before surgery was lower than that of controls. After advancement of the mandible, EMG did not increase. These findings are supported by a previous study in which maximum EMG was determined in maximal occlusion (Harper *et al.*, 1997). However, increased EMG was also reported 1 year after surgery, with only a slight further increase at the 2-year follow-up (Raustia and Oikarinen, 1994).

In many studies, EMG is expressed as a function of bite force, resulting in an EMG/bite-force ratio or slope of a regression line. The higher this ratio, or the steeper the slope, the more EMG activity is measured, while generating a given level of bite force, thus indicating a lower efficiency of the musculoskeletal system. The EMG/bite-force relationship for the muscles of mastication was found to be nonlinear. At higher bite-force levels, the slope of the EMG/bite-force curve becomes steeper (Hagberg *et al.*, 1985; Pruim *et al.*, 1978). Therefore, we determined the regression line also for levels at 10%, 20%, 30% and 40% of the maximum bite force. The EMG/bite-force slope, determined at these force levels, was smaller than the ratio at the maximum bite force. This confirms the nonlinear EMG/bite-force relationship over the entire force range. Before treatment, there was no difference in EMG/bite-force ratio between patients and controls, confirming results of some previous studies (Tate *et al.*, 1994a; Tate *et al.*, 1994b). In 1 study, the efficiency even tended to be higher in retrognathic patients than in controls (Throckmorton *et al.*, 1995). This increased efficiency may be explained from the biomechanical advantage in these patients, based on a smaller bite-force arm.

At lower bite forces (10% to 40% of the maximum bite force), our patients had steeper slopes than controls, suggesting that patients do have a less efficient masticatory system when they apply less than half of their maximum bite force. This finding is of importance, as muscle activities up to about 50% of the maximum EMG are used during chewing (Table 2). Surgery had no influence on the slope of the regression line; thus also after surgery, patients had lowered efficiency of the masticatory muscles. In previous studies, after surgery both an unaltered (Zarrinkelk *et al.*, 1996) and an increased (Throckmorton *et al.*, 1995) efficiency of the masticatory system have been reported.

Before surgery, patients produced less EMG activity than controls during chewing on the test food, confirming the results found in retrognathic patients (Youssef *et al.*, 1997) and in prognathic patients (Kobayashi *et al.*, 2001) and in patients with a variety of dentofacial deformities (Tate *et al.*, 1994a; Tate *et al.*, 1994b). This result suggests that patients apply less bite force than do controls during chewing on the test food. Furthermore, the muscle efficiency determined at submaximal levels was lower in patients, resulting in an even lower chewing force. After surgery, EMG during chewing did not increase and was still less than that of controls. In previous studies an increase was shown (Kobayashi *et al.*, 2001; Youssef *et al.*, 1997). We calculated the relative EMG by dividing the mean peak value of the EMG during chewing by the EMG at maximal clenching. It appeared that patients, before as well as after treatment, used the same percentage of the maximum EMG as controls. Apparently, a constant percentage of the muscle capacity is used during chewing by the patients as well as by the controls. Similar results were obtained in a study comparing the muscle activity of neuromuscular patients and controls (van der Bilt *et al.*, 2001).

The chewing cycle time of patients before surgery was larger than that of controls. There was no significant change after surgery, but the difference with controls disappeared. This is in accordance with a previous study in which a larger cycle time was observed after the preoperative orthodontic treatment just before surgery. After surgery, the chewing cycle time subsequently decreased to control values (Kobayashi *et al.*, 2001).

The present study shows that orthognathic surgery did not improve the decreased chewing efficiency in retrognathic patients. No change was found in the chewing-related factors maximum bite force, EMG values during maximal clenching or during chewing, and chewing cycle time.

Chapter 6

The influence of mandibular advancement surgery on oral function in retrognathic patients: a long term study

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Abstract

Previous studies have demonstrated that patients with mandibular retrognathism who were scheduled for orthognathic surgery have a lower maximum bite force and an impaired chewing performance. Surgical correction of this deformity is supposed to lead to an improvement of these oral functions. One year after surgery no signifcant changes could be demonstrated in these patients. However, a longer follow up might demonstrate an improvement after all. Therefore, the maximum bite force and the chewing performance were determined in 12 patients with a mandibular retrognathism before mandibular advancement surgery and at least 5 years after surgery. Chewing performance (median particle size) was determined with a sieving method after chewing 15 strokes on an artificial test food. Maximum bite force was recorded bilaterally at the level of the first molars. Five years after surgery, chewing performance was improved, especially in patients with a poor performance before treatment. An increase of the maximum bite force could not be demonstrated. Thus, surgical correction does not necessarily lead to an improvement of oral function.

Introduction

There is a wide variety of dentofacial deformities. Such a deformity might interfere with the function of the masticatory system. Indeed, reduced maximum bite forces have been reported in groups of patients with mixed dentofacial deformities (Tate *et al.*, 1994; Dean *et al.*, 1992; Throckmorton *et al.*, 1996), in patients with a mandibular prognathism (Shiratsuchi *et al.*, 1991; Ellis III *et al.*, 1996; Iwase *et al.*, 1998; Kim and Oh, 1997) and in patients with a mandibular retrognathism (Throckmorton *et al.*, 1995; Zarrinkelk *et al.*, 1996; van den Braber *et al.*, 2004). Also a lower masticatory performance was demonstrated in patients with various dentofacial deformitities (Tate *et al.*, 1994; Ästrand, 1974; Zarrinkelk *et al.*, 1995; van den Braber *et al.*, 2001), in patients with a mandibular prognathism (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993; Kobayashi *et al.*, 2001) and in patients with a mandibular retrognathism (van den Braber *et al.*, 2001). Surgical correction of a dentofacial deformity often leads to an increase of the maximum bite force in studies in mixed patient groups (Throckmorton *et al.*, 1996), in patients with a mandibular prognathism (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Ellis III *et al.*, 1996; Iwase *et al.*, 1998; Kim and Oh, 1997) and in patients with a mandibular retrognathism (Throckmorton *et al.*, 1995; Zarrinkelk *et al.*, 1996). However, the consequences of a surgical correction for masticatory performance are inconsistent. In a group of patients with mixed dentofacial deformities, three years after surgery the masticatory performance was not increased (Zarrinkelk *et al.*, 1995). Surgical correction of mandibular prognathism often leads to an increase of masticatory performance (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Kobayashi *et al.*, 2001), but control values are not reached. In our group of patients with mandibular retrognathism, one year after surgical advancement of the mandible, we found no significant change in masticatory performance (van den Braber *et al.*, 2004). The fact that masticatory performance after treatment does not meet the expectations, might be due to a follow up which was too short to establish a state of equilibrium. The aim of the present study is to evaluate maximum bite force and masticatory performance in patients with a mandibular retrognathism at least 5 years after surgical correction.

Materials and methods

Subjects

Twelve subjects (8 males and 4 females; mean age 24.2 years, S.D. 5.1) all with an Angle Class II skeletal relation and a dental Angle Class II, subdivision I, were tested on two occasions. Testing occurred (i) just before orthognathic surgery, i.e. after pre-surgical orthodontic treatment , and (ii) at least 5 (mean 5.7 years, S.D. 0.8) years after surgery (bilateral sagittal split osteotomy to advance the mandible). Skeletal relapse was not observed. The control group consisted of 12 subjects (4 males and 8 females; mean age 25.1 years, S.D. 5.9). The Ethics Committee of the University Medical Center Utrecht approved the protocol. Written informed consent was obtained from each subject after full explanation of the experiment.

Maximum bite force

Maximum bite force was measured bilaterally at the level of the first molars using a bite fork with two force transducers. The bite force transducer has been described previously in detail (Slagter *et al.*, 1993). Subjects were encouraged to bite as hard as possible on the transducer for a few seconds. The measurement was performed 3 times. The highest bite force of the 3 efforts was selected. Left and right force signals were summed.

Chewing experiment

The silicone rubber Optosil ® (Version 1980, Bayer, Germany), a dental impression material, was used as a standardized test food. Since Optosil frequently appeared to be too tough for the patients, a softened version was prepared by heating which is denoted as Optosoft hereafter (van den Braber *et al.*, 2001).

Since details has been described in a previous study (van den Braber *et al.*, 2001), only an outline of the chewing experiment is presented here. In order to determine the chewing function, eight cubes of Optosoft with an edge size of 8 mm were offered. Each subject performed two chewing sequences consisting of 15 chewing cycles. Both chewing products obtained after 15 strokes were pooled. The median particle size, X_{50}, was determined with a sieving method. A large value of X_{50} indicates a poor chewing performance.

Statistical analysis

Repeated measures analysis of variance (ANOVA; SPSS 9.0, SPSS Inc., Chicago, IL) was applied to test the null hypothesis that there would be no statistical difference between the results obtained for the patients before and after surgery. Subsequently, we used ANOVA with patient/control as a fixed factor to test for differences between patients and controls. This test has been applied for patient results before as well as after surgery. The degree of correlation was determined with Pearson's correlation coefficient.

Results

Maximum bite force

There appeared to be no difference in maximum bite force between patients before and after surgery. Controls had a significantly higher bite force than patients before ($P < 0.01$) as well as after ($P < 0.01$) surgery (Table 1). The change of the maximum bite force (post-surgical minus pre-surgical values) was not correlated with the pre-surgical values of the maximum bite force.

Table 1. Variables describing oral function for patients, before and after surgery, and for controls

	pre-surgical	post-surgical	control	pre-post[1]	pre-control[2]	post-control[3]
maximum bite force (Newton)	381 ± 140	380 ± 142	569 ± 167		**	**
median particle size (X_{50} in mm)	4.3 ± 1.4	3.5 ± 1.1	2.6 ± 0.4	*	***	*

Values: Mean ± SD.
[1] : Degree of significance for differences in values between patients before and after surgery.
[2] and [3] : Degree of significance for differences in values between controls and patients [2] before surgery and [3] after surgery.
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.005$

Chewing performance

Analysis of variance (ANOVA) demonstrated a significant decrease of the median particle sizes for patients 5 years after surgery as compared to pre-surgery levels (Table 1; $P < 0.05$), indicating an improvement of the chewing performance. Controls chewed the test food significantly better than patients before ($P < 0.005$) and after ($P < 0.05$) surgery.

Fig. 1 shows the change of the median particle size (post-surgical minus pre-surgical values) for the patients as a function of pre-surgical values of the median particle size. The change in the median particle size was significantly correlated (r=- .69; $P < 0.05$) with the presurgical values. Subjects with a poor pre-surgery chewing performance had the tendency to improve in contrast to subjects with a better chewing performance.

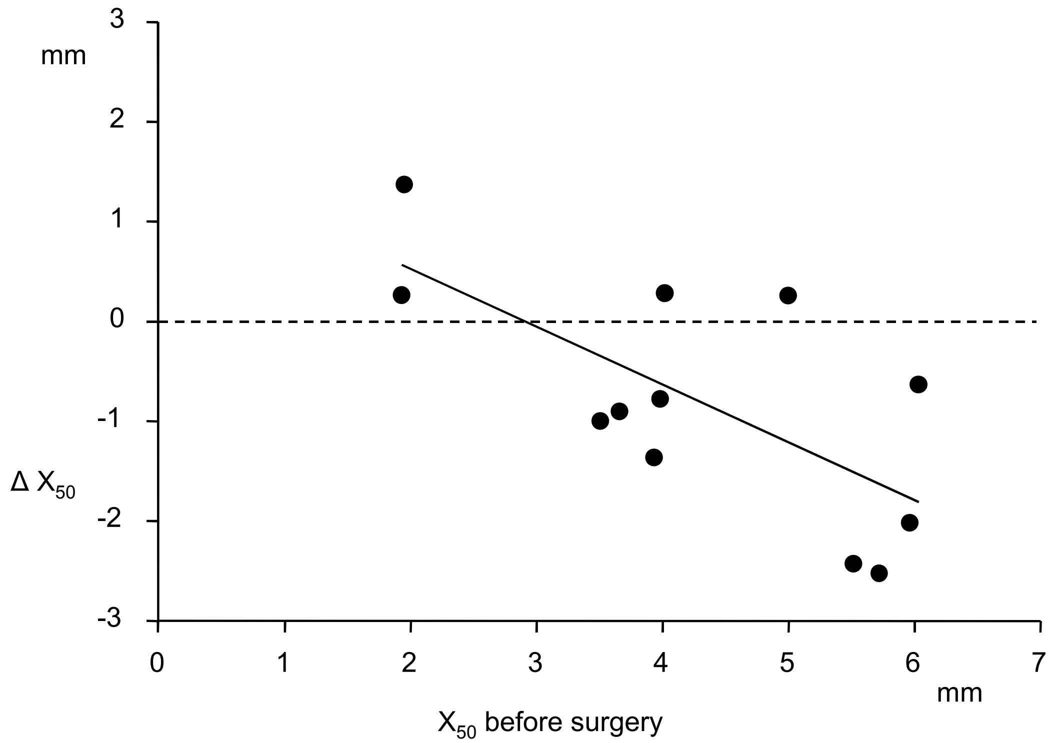

Figure 1. The change of the median particle size (post-surgical minus pre-surgical values) as a function of the median particle size before surgery for 12 orthognathic surgery patients. Data obtained after 15 chewing cycles. Dashed line: linear regression with $r = -0.69$ and $P < 0.05$.

Discussion

Groups of patients, who are scheduled for orthognathic surgery for a variety of dentofacial deformities, have lower maximum bite forces than control subjects (Tate *et al.*, 1994; Dean *et al.*, 1992; Throckmorton *et al.*, 1996). As maximum bite force is an important factor for chewing performance (Julien *et al.*, 1996), it is not surprising that these two parameters show similar tendencies. Indeed, in pre-orthognathic surgery patients also chewing performance was impaired with respect to that of controls (Tate *et al.*, 1994; Ästrand, 1974; Zarrinkelk *et al.*, 1995).

In studies on exclusively patients with a mandibular prognathism, a reduced maximum bite force was also demonstrated (Shiratsuchi *et al.*, 1991; Ellis III *et al.*, 1996; Iwase *et al.*, 1998; Kim and Oh, 1997). This can be expected because of larger bite force arms (Finn *et al.*, 1980; Throckmorton *et al.*, 1980). Corresponding with this finding, an impaired chewing performance was found in these patients (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993; Kobayashi *et al.*, 2001). Surgical correction (setback of the mandible) decreases bite force arms. Theoretically, this might lead to an increase of the maximum bite force. Actually, after surgery an increase of the maximum bite force was found (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Iwase *et al.*, 1998; Kim and Oh, 1997). In one study, maximum bite force even reached control values (Ellis III *et al.*, 1996). Two years after surgical correction, patients with mandibular prognathism showed an improvement of chewing performance (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 2001). However, control values were not reached.

The present study includes pre-orthognathic surgery patients with a mandibular retrognathism. In these patients one might expect higher maximum bite forces than in controls, because of shorter bite force arms, and subsequently a better chewing performance. However, in our patients a reduced maximum bite force was found before surgical correction (van den Braber *et al.*, 2004), which is in line with other studies (Throckmorton *et al.*, 1995; Zarrinkelk *et al.*, 1996). This suggests that factors related to jaw closing muscles may be responsible. Growth and development of the muscles might have been hindered, probably due to an impaired occlusion, leading to reduced muscle sizes. Alternatively, the orientation of the closing muscles might be unbeneficial. The chewing performance before surgery was also reduced (van den Braber *et al.*, 2001), which corresponds with the lower maximum bite force. Surgical correction (advancement of the mandible) leads to larger bite force arms. Therefore, a decrease of maximum bite force may be expected in these patients. In our patients, one year after surgery no significant change was observed (van den Braber *et al.*, 2004), confirming results of a previous study (Proffit *et al.*, 1989). One year after surgery, there was also no significant change in chewing performance in our patients with a mandibular retrognathism (van den Braber *et al.*, 2004). However, an increase of bite force, approaching normal values within 2 years after surgery, was also reported (Throckmorton *et al.*, 1995). In the same study, the bite force in the premolar and molar region, the region which is involved in the breakdown of food particles, was still increasing between two and three years after surgery. Therefore, the follow-up time of one year might have been too short to detect changes in our patients. In the present study we have chosen for a follow-up time of 5 years. After such a period of time, one can assume that an equilibrium in oral function has been established. Five years after surgery we still did not find significant changes in maximum bite force. However, chewing performance was increased. The change of median particle size was negatively correlated with presurgical values (Fig. 1). This indicates that patients with a poor pre-surgical chewing performance (large median particle size) tended to improve (decrease of the median particle size). Patients with a better chewing performance before treatment did not show this tendency. This suggests that the improvement in our patient group has to be attributed mainly to the improvement in patients with a poor chewing performance before surgery. Especially subjects with a poor chewing performance before surgery will have functional benefits of treatment. In patients with a chewing performance comparable to that of controls, improvement may not be expected. For these patients, other considerations should justify orthognathic surgery.

By surgical correction of a mandibular retrognathism, skeletal and occlusal relationships are brought back to more normal proportions. However, this does not necessarily lead to an increase of the maximum bite force. Yet, after years, improvement of the chewing performance may occur, mainly in patients with a poor chewing performance before treatment.

Acknowledgements

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Chapter 7

Discussion and Conclusions

Introduction

Mandibular retrognathism with a class II molar relationship is a frequently occurring dentofacial deformity. The masticatory system, including the jaws, the teeth and the muscles of mastication, is regarded as a functional unit. Mandibular retrognathism is expected to have some effect on the function of this unit. The skeletal discrepancy can be corrected by mandibular advancement surgery. The dentoalveolar component is orthodontically treated before as well as after orthognathic surgery. Treatment of mandibular retrognathism is also assumed to have some influence on masticatory function. A major function of the masticatory system is size reduction of food particles. However, to our knowledge, no data are available about masticatory performance in patients with a mandibular retrognathism. Therefore, we assessed masticatory performance before and after the various phases of the class II treatment. Furthermore, treatment-induced changes in masticatory performance related factors, *e.g.* occlusion and bite force, will be discussed for each phase of treatment. During the first phase, *i.e.* presurgical orthodontics, occlusion will change. In the second phase, consisting of mandibular advancement surgery, both biomechanics and occlusion are influenced. In the third phase, postsurgical orthodontic treatment will have an effect on occlusion. Hereafter, further adaptation may take place. Final measurements were performed after a period of at least 5 years after surgery which was considered long enough to establish a morphologic as well as a functional equilibrium.

The aim of the thesis was to analyze masticatory function in patients with a mandibular retrognathism during various phases of treatment.

General considerations

Masticatory performance

Masticatory performance is measured by determining the subjects capacity to reduce food particles. To that end, the median particle sizes are determined (Olthoff *et al.*, 1984) after chewing 15 as well as 30 cycles on 8 cubes of a silicone rubber, with an edge size of 8 mm. A large value of the median particle size indicates a poor masticatory performance. Masticatory performance is positively correlated with the number of postcanine functional tooth units (Helkimo *et al.*, 1978; Omar *et al.*, 1987; Akeel *et al.*, 1992; Hatch *et al.*, 2001) or occlusal contact area (Julien *et al.*, 1996) and with bite force (Julien *et al.*, 1996; Hatch *et al.*, 2001).

Selection and breakage

The breakdown of food particles can be considered as the composite result of selection and breakage (Lucas and Luke, 1983). Selection is the chance that a food particle will at least be damaged during a chew. Selection can be calculated by dividing the weight of the damaged food particles by the total weight of the offered (*i.e.* damaged and non-damaged) particles. Breakage refers to the extent to which a particle, once selected, is fragmented. Although a particle is selected only when it is broken and breakage only takes place when a particle is selected, either of both parameters is more or less specifically influenced by certain aspects of the masticatory system. Selection is supposed to be influenced by the particle collecting and arranging action of the tongue, cheeks and lips, by features of the occlusal surfaces, by the surface area of the post-canine teeth and by the size and number of the particles. Breakage is supposed to depend on factors connected to actual contact of teeth and food particles like tooth shape, the amount and coordination of the muscle activity which controls the bite force and its direction, particle size, shape and number, and physical characteristics of the food (Lucas and Luke, 1983; Lucas *et al.*, 1986; van der Glas *et al.*, 1987; van der Bilt *et al.*, 1987).

Maximum bite force

One of the features that is related to masticatory performance, is maximum bite force (Julien *et al.*, 1996; Hatch *et al.*, 2001). From a biomechanical point of view, the capacity to generate bite force depends on the morphology of the craniofacial skeleton (Ingervall and Helkimo, 1978) and the cross-sectional size (van Spronsen *et al.*, 1989; Sasaki *et al.*, 1989), topography and orientation of the jaw adductor muscles. The extent to which this capacity is used, in turn, depends on the subjects willingness to generate force and on negative sensory feedback from *e.g.* the teeth, the periodontium, the muscles of mastication and the temporomandibular joint.

The variation in bite force magnitude appeared to depend more on muscle size than on morphology of the craniofacial skeleton (Sasaki *et al.*, 1989; Raadsheer *et al.*, 1999). However, morphology of the craniofacial skeleton forms the foundation for establishing the diagnosis “mandibular retrognathism”, and it is also the factor that is directly altered by surgical correction.

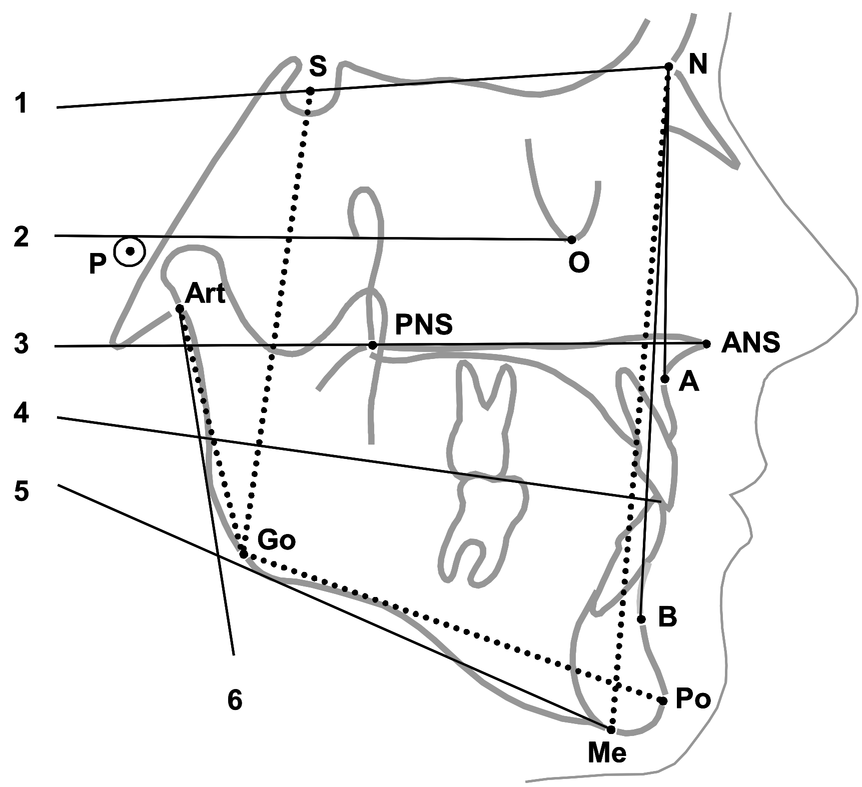

Figure 1.

Planes: 1. anterior cranial base (S – N); 2. Frankfort horizontal plane; 3. spinal plane; 4. occlusal plane; 5. mandibular plane; 6. tangent from Art to back of mandible
Linear measurements: mandibular corpus length: Go – Po; mandibular ramus height: Art – Go; anterior face height: N – Me; posterior face height: S - Go
Angular measurements between planes: mandibular plane angle: 1 – 5 / 2 – 5; occlusal plane angle: 3 – 4; gonion angle: 5 – 6

In normal subjects, bite force has been related to measures of craniofacial morphology, obtained from lateral cephalometric radiography (see fig. 1) (Ringqvist, 1973; Ingervall and Helkimo, 1978). Generally, high values of maximum bite force are associated with a large mandibular corpus length and ramus height, a small anterior and a large posterior face height, a small gonion angle and a small inclination of the mandible in relation to the anterior cranial base. This craniofacial type can be characterized as large in size and convergent (Raadsheer *et al.*, 1999).

When retrognathic patients just before surgery are compared with controls, lateral cephalograms reveal differences in mandibular size, position and orientation (for explanation see fig. 1). These differences confirm that in patients the mandible is situated more backward (smaller SNB angle, larger ANB angle and larger incisor overjet), that its length is smaller, and indicate that its angle with respect to the cranium is more obtuse (larger occlusal and mandibular plane angles) (Throckmorton *et al.*, 1995).

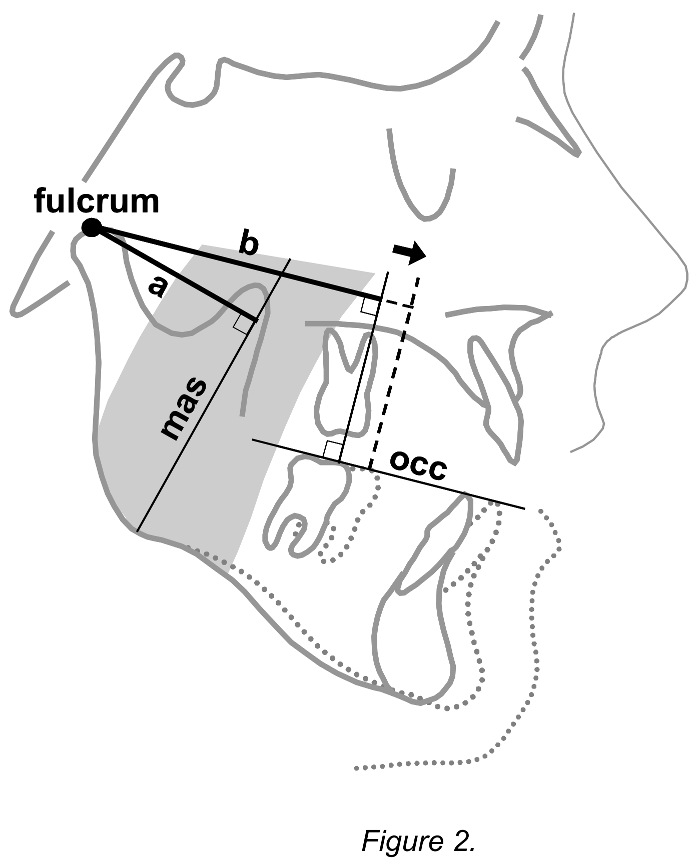

Figure 2.

The mandible can be regarded as a lever (see fig. 2). The condylar summit represents the fulcrum (fulcrum in fig. 2). The muscle force moment arm (a in fig. 2) is represented by the perpendicular distance from the condylar summit to the line of action of the muscle (mas in fig. 2). For the sake of simplicity, only for the superficial masseter muscle the muscle force arm is presented in figure 2. The bite force moment arm (b in fig. 2) corresponds to the perpendicular distance from the condylar summit to a line passing through an occlusal reference point and perpendicular to the functional occlusal plane. Because bite force was registered between the first molars, the mesial cusp of the lower first molar was chosen as an arbitrary reference point.

How efficiently a jaw adductor muscle produces occlusal force, depends on the ratio of the length of the muscle force moment arm (a in fig. 2) divided by the length of the bite force moment arm (b in fig. 2) and is termed mechanical advantage (Finn *et al.*, 1980; Throckmorton *et al.*, 1980).

Mandibular retrognathism is mainly an anteroposterior deviation. Therefore, from a mechanical point of view, anteroposterior considerations of the mandible are of particular interest in these patients. Surgical advancement of the mandible will move the teeth bearing part of the mandible forward (dotted lines in fig. 2). This will be reflected in altered cephalometric measures. The length of the bite force moment arm (b in fig. 2) will increase (arrow in fig. 2). Although the masseter and the medial pterygoid muscles are partly detached from the mandible during surgery, the attachment sites of the jaw adductor muscles are essentially left unchanged. Consequently, the length of the muscle force arm (a in fig. 2) will basically not change. The arm of the jaw adductor muscles that are not displayed in figure 2 will not change either. Hence, mechanical advantage will decrease as a result of advancement surgery.

Electromyographic activity

The quantity of surface electromyographic activity (EMG) reflects the level of activity of the underlying muscles. Under static, isometric conditions, surface EMG of the anterior temporalis and superficial masseter muscles increases with bite force. Generally, this EMG/bite-force relationship appears to be linear (Bakke *et al.*, 1989). However, at levels larger than approximately 60 % of the maximal bite force, for the superficial masseter muscle the slope of the EMG/bite-force curve becomes steeper (Pruim *et al.*, 1978;

Hagberg *et al.*, 1985). This indicates that at higher bite-force levels, the increase of maximum bite force is relatively smaller than the increase of masseter-muscle effort. To assess the linear part of the EMG/bite-force relationship, we also determined EMG for the submaximal levels at 10%, 20%, 30% and 40% of the maximum bite force.

The EMG/bite-force ratio, or the slope of the regression line, reflects the amount of muscle activity that is needed to deliver a given level of bite force. Therefore, it is considered as a measure of muscle efficiency. A high value of this ratio, or slope, suggests a low efficiency of the musculoskeletal system. It can be expected that the efficiency of a muscle depends on its orientation with respect to the skeletal parts to which it is attached. Hence, it is plausible that variations in craniofacial morphology will be reflected in the slope of the EMG/bite-force regression line. However, in normal subjects, the slope was not correlated with facial morphology during biting with the incisors (Fogle and Glaros, 1995) and even calculated mechanical advantage of the jaw adductor muscles appeared to be an incomplete predictor (Throckmorton and Dean, 1994). Nevertheless, in patients with dentofacial deformities the variations in craniofacial morphology may be sufficiently large to reveal significant differences in the EMG/bite-force relationship.

Furthermore, the EMG/bite-force relationship can be used to estimate masticatory forces from the registration of the EMG during chewing. However, chewing is a dynamic event in which bite force varies in magnitude, speed and direction under concentric, isometric and excentric conditions. Therefore, the simple linear EMG/bite-force relationship, which is determined during isometric clenching, is inadequate to completely explain the EMG during the dynamic phases in chewing (Devlin and Wastell, 1985). Nevertheless, the peak amplitude which occurs just before maximal intercuspation may still give an indication of the maximal force that is exerted during chewing (Ahlgren and Öwall, 1970; Slagter *et al.*, 1993).

Before treatment

In patients with a mandibular retrognathism the relative dorsal shift of the lower dental arch may decrease the amount of which upper and lower post-canine teeth overlap, resulting in a reduced quantity of occlusal surface area that is available for mastication.

Furthermore, the quality of the available occlusal surface may be decreased. In a severe class II malocclusion, first upper molars might be opposed against lower premolars during chewing, with consequently a decrease of functional occlusal area and an impaired occlusal fit. In addition, dentofacial deformities are often accompanied by deviations in location and orientation of individual teeth.

Masticatory performance

In patients with a skeletal discrepancy which leads to a malocclusion, it is reasonable to assume that masticatory performance is impaired. In patients before presurgical orthodontics, we found median particle sizes which were 70% larger than in controls (chapter 2), indicating a poorer masticatory performance for patients. This finding was in agreement with pretreatment results obtained in patients with a variety of dentofacial deformities (Tate *et al.*, 1994a; Zarrinkelk *et al.*, 1995a) and in patients with a mandibular prognathism (Kobayashi *et al.*, 2001). In these prognathic patients, a lower number of occlusal contacts and a decreased area of occlusal contacts were observed before any treatment (Kobayashi *et al.*, 2001).

Selection and breakage

The poorer masticatory performance in patients may be the result of an impaired selection and breakage of food particles. If a particle is sufficiently large, it will always be selected, regardless the state of occlusion. Therefore, it was not surprising that the selection chance of 8 mm particles was similar for patients and controls, and thus approached the maximal possible value of one. In normal subjects, the selection chance proved to be a power function of particle size (Lucas and Luke, 1983; van der Bilt *et al.*, 1987). In accordance with this function, selection chance decreased with a decrease of particle size for both our patients and controls. However, in the patients this decrease was more pronounced, resulting in a decreased selection in patients for, in particular, the smaller particles sizes (*viz.* 2.4 mm). These findings can be well explained by an occlusion which is characterized by a decreased surface area and larger interocclusal distances.

Overall, breakage for patients before any treatment, was smaller than for controls. Nevertheless, only for medium sized particles (*i.e.* 4.8 mm) the difference was significant. Although a decreased bite force in our patients may be held responsible for impaired breakage (Lucas and Luke, 1983), it does not explain the impaired breakage of 4.8 mm particles in particular. Possibly, fragments of these particles are broken further in the same chewing cycle as jaw closing continues. Another factor which may influence breakage, is the shape of the working surface of post-canine teeth (Lucas and Luke, 1983). In a machine with tooth-like plungers, it was demonstrated that a more pronounced cusp form leads to better breakage (Olthoff *et al.*, 1986). However, differences in cusp form between patients and controls are most unlikely. Furthermore, in both patients and controls extensive dental restorations were absent. A factor that is probably involved in both selection and breakage processes is the movement of the mandible during chewing (Lucas *et al.*, 1986). However, before any treatment no differences were demonstrated in maximum excursions of the mandible during mastication in retrognathic patients when compared with controls. Although the maximal voluntary vertical excursion was slightly smaller in patients, the trajectory of the mandible during chewing fell amply within the boundaries of maximal voluntary excursions (Throckmorton *et al.*, 1995).

Cineradiographic studies revealed that in prognathic patients the upper incisal region participated more and the premolar and molar regions less frequently during chewing (Lundberg *et al.*, 1974) than in controls (Wictorin *et al.*, 1971). Although not confirmed, it is possible that a comparable mechanism occurs in retrognathic patients. By using more anterior regions of the lower dental arch, both selection and breakage may be hampered.

Maximum bite force

One of the factors that influences bite force, is the mechanical advantage of the mandible closing muscles. In patients with a mandibular retrognathism, the bite force moment arm length is decreased, which theoretically leads to an increase of mechanical advantage. However, lateral cephalometry revealed that muscle moment arms of patients were proportionately shorter than those of controls. Hence, no significant differences in the mechanical advantages of the temporalis and masseter muscles between retrognathic patients and controls were found (Throckmorton *et al.*, 1995).

Nevertheless, in our patients maximum bite forces were approximately 60% of those in controls (chapters 3 and 5). This confirms the results found in a subgroup of preorthodontic patients in a study on retrognathic patients (Thomas *et al.*, 1995). A decreased maximum bite force was also found in patients with a variety of dentofacial deformities (Tate *et al.*, 1994a; Throckmorton *et al.*, 1996) and in prognathic patients (Ellis III *et al.*, 1996). Malocclusion may have hindered the generation of large bite forces, which inhibits proper development of the masticatory system with subsequently an impaired masticatory performance.

In normal dentate adults, the indirect effect of number of functional tooth units on maximum bite force with, in turn, its effect on masticatory performance, appeared to be lower than the direct effect of number of functional tooth units on masticatory performance (Hatch *et al.*, 2001). This suggests that maximum bite force and masticatory performance are both related to occlusal factors, but that bite force itself is not the main source for masticatory performance.

Influence of presurgical orthodontics

Presurgical orthodontics will change the position and orientation of teeth, with respect to the maxillary and mandibular base, in order to form congruent upper and lower dental arches and to eliminate crowding. It is evident that such a treatment has influence on occlusion and, subsequently, on articulation. In spite of an anomalous occlusion before any treatment, retrognathic patients must have become accustomed to the situation. By abrasion and attrition, occlusal adjustments must have been taken place. Orthodontics may disturb this substitute equilibrium. Furthermore, the presence of orthodontic appliances may be experienced as unfamiliar. For these reasons, one might expect at least some effect on masticatory function.

Masticatory performance

However, there was no difference in median particle size between patients before presurgical orthodontics and just before surgery (chapter 3). This suggests that the masticatory performance, which was impaired before any treatment, was not influenced by presurgical orthodontics. Nevertheless, in patients with a mandibular prognathism, an additional reduction of masticatory efficiency was demonstrated as a result of the preoperative orthodontic treatment. In these patients the number and the area of occlusal contacts were also further reduced (Kobayashi *et al.*, 2001).

In studies without preorthodontic measurements, before surgery prognathic patients demonstrate a decreased number of occluding pairs (Ästrand, 1974), occluding contacts (Athanasiou, 1992; Kobayashi *et al.*, 1993; Iwase *et al.*, 1998) and occlusal contact area (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993). An impaired masticatory performance was found in patients with mandibular prognathism (Ästrand, 1974; Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 1993; Kikuta *et al.*, 1994) and in groups of patients with a variety of dentofacial deformities (Zarrinkelk *et al.*, 1995a) when compared with controls. These results actually confirm our finding of an impaired masticatory performance in patients before orthognathic surgery, but without preorthodontic results the role of presurgical orthodontics remains unclear in the aforementioned studies.

Selection and breakage

Possible changes in masticatory function that do not find expression in a change of masticatory performance, may still be revealed by changes in selection and breakage. Selection chances for the various particle sizes were very similar before and after presurgical orthodontics. Averaged over three particle sizes, breakage did not change. However, breakage for a particle size of 8 mm was better after orthodontic treatment.

In contrast to conventional orthodontics, presurgical orthodontics has a preparing purpose, is not meant to improve the actual occlusion, and may even worsen occlusion. Therefore, it is striking that no decrease was found in masticatory performance and its underlying processes selection and breakage. Preoperative orthodontics create congruent, regular upper and lower dental arches with even teeth. This may lead to a better fitting occlusion, depending on the amount of compensating mandibular movement. Theoretically, the patients even have the ability to accomplish bilateral occlusion by protrusion of the mandible, imitating advancement surgery. However, in retrognathic patients the mandibular range of motion during mastication was not changed by presurgical orthodontics and was still similar to the range found in controls

(Throckmorton *et al.*, 1995). Yet, it is possible that within this range proper unilateral occlusal contacts are reached.

Maximum bite force

It is unlikely that the moment arm length of either jaw adductor muscles or bite force will change as a result of presurgical orthodontics. Lateral cephalometry showed that neither the moment arms for the bite forces nor those for the muscles of mastication were changed in patients with a variety of dentofacial deformities. Hence, no change in the mechanical advantage of the muscles of mastication could be demonstrated (Thomas *et al.*, 1995).

In our patients no change was found in maximum bite force (chapter 3). In another study on retrognathic patients, presurgical orthodontics tended to reduce maximum bite forces, but these changes were not significant (Throckmorton *et al.*, 1995). In patients with a variety of dentofacial deformities, a decreased maximum bite force for some bite positions was found. The greatest bite force decrease was found at the incisor position (Thomas *et al.*, 1995; Throckmorton *et al.*, 1996). Yet, for the post-canine region, the region where chewing predominantly takes place, this decrease was only significant for one of the premolar bite positions (Thomas *et al.*, 1995). This supports our finding of an unchanged maximum bite force which was measured at the level of the first molars. Altered occlusal support, and discomfort and pain caused by activation of orthodontic appliances (Goldreich *et al.*, 1994) may interfere with the generation of high bite-force levels. This may induce atrophic changes in the masticatory muscles. However, a decrease for the molar bite position which was not significant, and differences in decrease of maximum bite force for the various bite positions (Thomas *et al.*, 1995), suggest that the jaw adductor muscles are not affected. The larger decrease in the incisor region probably indicates that these teeth are more affected by orthodontic treatment than molars. Soreness in the incisor region may inhibit the patient to exert high bite-force levels. The more distal regions may still offer possibilities to generate a sufficient level of bite force to maintain muscle strength. Furthermore, soreness is induced each time the orthodontic appliances are activated, but diminishes after a few days. A relatively soreness-free period until the next activation may offer the opportunity to regain strength. In our patients, the tests after presurgical orthodontics were all performed one or two days before surgery. At that moment, orthodontic treatment was already finished for some time. Soreness was not reported during the measurement of maximum molar bite force. In addition, between final activation of the orthodontic appliances and surgery, soreness may have been absent long enough to allow unrestrained training of bite force. Hence, negative feedback by soreness may have been of limited importance.

Influence of mandibular advancement surgery and postsurgical orthodontics

Mandibular advancement surgery normalizes the position of the lower dental arch with respect to the upper dental arch, which is a prerequisite for an optimal occlusion. Postsurgical orthodontics further adjusts occlusion. During this period, the patients recover from surgery and get used to the new situation. Furthermore, occlusion is still changing. Therefore, measurements were performed when orthodontics were finished, with a postsurgery period of at least one year.

Masticatory performance

On average, one year after surgery, the median particle sizes were similar to those found before surgery (chapter 4). However, on an individual basis, patients with a poor chewing performance before surgery tended to improve whereas no improvement was observed for patients with a good chewing performance. In patients with a variety of dentofacial deformities, also no change was found (Ästrand, 1974; Zarrinkelk *et al.*, 1995a). After surgical correction of a mandibular prognathism, unaltered (Kobayashi *et al.*, 1993) as well as improved (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Kobayashi *et al.*, 2001) masticatory performance has been reported, but in these studies control values were not reached.

Selection and breakage

On average, no changes in selection and breakage were found. For patients with a poor selection or breakage before treatment, selection and breakage were improved after treatment. The change in median particle size was correlated with the change in breakage, whereas such a correlation was not found for the change in selection. This indicates that the individual change in masticatory performance was mainly due to a change in breakage. Therefore, the improvement of chewing performance in some patients may be attributed to a better breakage of food particles. It has been suggested that selection depends on occlusal surface area and breakage on quality of occlusion and maximum bite force. This implies that a presumed gain of overlap between upper and lower dental arches was of limited importance. On average, no change in maximum bite force was found. Therefore, occlusion may have been improved with better breakage as a result.

n prognathic patients, occlusion was improved after treatment which was reflected in an increased number of occluding pairs (Ästrand, 1974), number of occlusal contacts (Athanasiou, 1992; Kikuta *et al.*, 1994; Kobayashi *et al.*, 2001; Iwase *et al.*, 1998), and occlusal contact area (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Kobayashi *et al.*, 2001). In one study, control values were reached after 2 years (Shiratsuchi *et al.*, 1991). In three of these studies also masticatory performance was measured which did increase (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Kobayashi *et al.*, 2001). However, unaltered occlusal values were also found one year after surgery, corresponding with an unchanged masticatory performance (Kobayashi *et al.*, 1993).

Selection and breakage depend on mandibular movement during chewing. However, after treatment the maximum excursions of the mandible during mastication were not changed in retrognathic patients (Throckmorton *et al.*, 1995) (Youssef *et al.*, 1997), and in patients with other deformities (Youssef *et al.*, 1997; Zarrinkelk *et al.*, 1996; Zarrinkelk *et al.*, 1995b). Generally, decreased values were reported shortly after surgery, but they appeared to be only temporal.

Maximum bite force

A cephalometric study several months after mandibular advancement surgery demonstrated that most of the skeletal measures were brought back into the normal range. However, the angle of the lower mandibular border with respect to the cranium was still more obtuse than in controls, a finding that was supported by a larger gonion angle which was not significant before surgery. Surgery lengthened the bite force moment arms, so they were no longer different from those of controls. However, the mechanical advantages of the anterior temporalis and masseter muscles decreased, resulting in significant smaller values for patients than for controls (Throckmorton *et al.*, 1995). Therefore, it is not likely that treatment leads to an increase of maximum bite force.

In our retrognathic patients, maximum bite force did not change and was still smaller than in controls (chapter 5). In other studies, treatment did not have a consistent influence on bite force. In one study, one year after surgery decreased, unaltered as well as increased values were reported (Proffit *et al.*, 1989). However, an increase (Throckmorton *et al.*, 1996), approaching normal values within two years (Throckmorton *et al.*, 1995), was also found. In another study, maximum bite force only increased in patients who received postsurgical rehabilitation with the aid of a motion resistance appliance (Storum and Bell, 1986). In prognathic patients, mandibular setback theoretically leads to an increase of mechanical advantage of the jaw adductor muscles. Increased maximum bite forces have been demonstrated in these patients (Shiratsuchi *et al.*, 1991; Kikuta *et al.*, 1994; Iwase *et al.*, 1998; Kim and Oh, 1997; Hunt and Cunningham, 1997) up to control values 3 years after surgery (Ellis III *et al.*, 1996).

For our patients, before as well as after surgery, a negative correlation between the maximum bite force and the median particle size indicates that masticatory performance increases with bite force. For controls, such a correlation was not found. Maximum bite force was higher in controls and exceeded a certain value beyond which it did not further contribute to a better masticatory performance.

Maximum electromyographic activity

EMG was recorded during maximal clenching both in maximal occlusion and during the measurement of the maximum bite force when the force transducer was in situ. In both conditions, maximum EMG did not change after treatment and was still lower than that of controls. Since there is a correlation between EMG and bite force, it could be expected that these results are in line with those found for maximum bite force. In a previous study, also no change in maximum EMG was found and was still approximately 50% of that of controls (Harper *et al.*, 1997). In another study, one year after surgery increased maximum EMG was reported (Raustia and Oikarinen, 1994). In prognathic patients, results of EMG during maximum clenching parallelled the results of maximum bite force as well. In these patients, one year after surgery increased maximum EMG values were demonstrated (Raustia and Oikarinen, 1994) which approached those of controls (Ingervall *et al.*, 1979).

EMG/bite force

The EMG, obtained from the measurement of the maximum bite force, was divided by the maximum bite force, resulting in an EMG/bite-force ratio which is a measure of muscle efficiency. There were no differences in EMG/bite-force ratio between patients before surgery and controls. This finding is in agreement with results from a previous study in which the muscle efficiency in patients was not different from that in controls or even tended to be higher (Throckmorton *et al.*, 1995). For retrognathic patients before surgery and controls, also identical mechanical advantages have been determined (Throckmorton *et al.*, 1995). Summarizing, we suggest that the decreased bite force in patients before surgery may be due to a smaller force-generating capacity of the jaw adductor muscles.

Although maximum bite force did not change after treatment, it is still possible that the muscle effort required to generate a given level of bite force was changed. The reduced mechanical advantage of the jaw adductor muscles after lengthening the mandible (Throckmorton *et al.*, 1995) should increase the EMG/bite force slope.

However, in our patients, the EMG/bite-force ratio did not change after treatment. In one study the EMG/bite-force slope in retrognathic patients after treatment even decreased and was somewhat smaller than that in controls (Throckmorton *et al.*, 1995), indicating a higher muscle efficiency for patients after treatment. It is noteworthy that no significant differences in EMG/bite force relationship were found between controls and preorthognathic surgery patients with a vertical maxillary excess (Johnston *et al.*, 1984), a retrognathism combined with a vertical maxillary excess (Zarrinkelk *et al.*, 1996), a maxillary deficiency (Song *et al.*, 1997) and a variety of dentofacial deformities (Dean *et al.*, 1992; Tate *et al.*, 1994b; Tate *et al.*, 1994a), and that treatment did not influence this finding (Zarrinkelk *et al.*, 1996; Johnston *et al.*, 1984; Song *et al.*, 1997).

However, the slope of the EMG/bite force regression line, determined at the submaximal levels of 10% to 40% of the maximum bite force, was steeper for our patients before surgery than for controls, suggesting that muscle efficiency in patients is impaired when less than half of the maximum bite force is applied. This finding is of significance, since the levels of EMG during chewing the test food were in the range of the EMG obtained during submaximal clenching. After treatment, the slope did not change, implying that muscle efficiency was still impaired.

EMG during chewing

The EMG peak amplitude during chewing was smaller in patients before surgery than in controls, indicating that patients apply less bite force during chewing. This finding becomes more evident when the decreased slope of the EMG/bite force regression line, determined at submaximal levels, is taken into account. Before surgery, decreased EMG during chewing was also found in retrognathic patients (Youssef *et al.*, 1997), in prognathic patients (Kobayashi *et al.*, 2001), and in patients with a variety of dentofacial deformities (Tate *et al.*, 1994b; Youssef *et al.*, 1997).

In our patients, EMG during chewing did not change after treatment. This indicates that in patients after treatment, bite force during chewing did not change and was still less than in controls, since the EMG/bite force slope, determined at submaximal levels, did not change either. However, after treatment increased EMG during chewing was demonstrated in retrognathic patients (Youssef *et al.*, 1997), prognathic patients (Kobayashi *et al.*, 2001) and in a mixed retrognathic and prognathic patient group (Raustia and Oikarinen, 1994).

In patients, before as well as after treatment, the peak EMG during chewing was approximately 50% of the EMG registered during maximal clenching. The same percentage was found for controls.

Long term results

In patients with various dentofacial deformities, beyond 1 year after orthognathic surgery increasing masticatory performance (Shiratsuchi *et al.*, 1991; Kobayashi *et al.*, 2001), occlusal contact area (Kobayashi *et al.*, 2001) and EMG during chewing (Raustia and Oikarinen, 1994; Kobayashi *et al.*, 2001) have been reported. Beyond 2 years, maximum bite force (Ellis III *et al.*, 1996; Throckmorton *et al.*, 1995) and EMG during chewing (Youssef *et al.*, 1997) were still increasing. This suggests that establishing morphologic and functional equilibrium takes at least several years. Our postsurgery follow-up period of 1.5 years may have been too short to detect significant changes in masticatory function. Therefore, a brief evaluation was performed at least 5 years after surgery.

Masticatory performance

Five years after surgery, the median particle sizes as determined after chewing were smaller than before surgery (chapter 6). This indicates that masticatory performance did improve after all. The tendency to improve occurred mainly in patients with a poor masticatory performance before surgery. In spite of this improvement, masticatory performance was still impaired when compared with controls.

Maximum bite force

In contrast with masticatory performance, maximum bite force did not change and was still lower than that of controls (chapter 6). The present model to predict maximal bite force from calculated mechanical advantages of the jaw adductor muscles (Throckmorton *et al.*, 1995) appears to be incomplete. In retrognathic patients, the decreased length of the bite-force moment arm before surgery is not reflected in increased mechanical advantages of the jaw-adductor muscles. On the contrary, a decreased maximum bite force was found in all studies. Furthermore, surgical treatment, with the aim to “cure” the patient, leads to an increase of the bite-force moment arm length with, subsequently, a decrease of mechanical advantages. However, in our patients maximum bite force did not change. Even increased maximum bite forces, up to control values, have been reported (Throckmorton *et al.*, 1995). It seems that anteroposterior considerations of the mandible do not correlate with maximum bite force (Throckmorton *et al.*, 2000). This indicates that other factors, *e.g.* muscle strength, may overrule the role of skeletal relationships in generating bite force.

Résumé of the results

In retrognathic patients, scheduled for combined orthodontic treatment and mandibular advancement surgery, masticatory function is impaired before any treatment when compared with controls. In these patients, masticatory performance and its underlying processes, *i.e.* selection and breakage, are impaired and maximum bite force is lower.

Masticatory performance, selection, breakage, and maximum bite force did not change as a result of presurgical orthodontics and was still impaired when compared with controls.

After surgical advancement of the mandible and after completion of postsurgical orthodontics (1-1.5 years after surgery), masticatory performance, selection and breakage, maximum bite force, EMG during maximal clenching and peak EMG during chewing were essentially not changed and values were below those found in controls. Treatment did not change EMG/bite force relationships. The EMG/bite force ratio, determined at maximal clenching, remained similar to that of controls, suggesting equal jaw adductor muscle efficiency for patients and controls. The ratio determined at 10% - 40% of the maximum bite force was higher in patients, indicating lower efficiency for patients when less than half of the maximum bite force is applied. This finding is interesting, since muscle activities up to approximately 50% of the maximum EMG were used during chewing.

Five years after surgery, masticatory performance did improve, particularly in patients with a poor masticatory performance before surgery. However, control values were not reached. Maximum bite force did not change and was still lower than in controls.

Conclusions

In this study we found that masticatory function in retrognathic patients was impaired. Treatment did not influence masticatory function. Yet, years after treatment, patients with a poor masticatory performance before surgery may benefit from therapy.

Future research

In patients with a mandibular retrognathism, functional outcomes of the masticatory system were evaluated during the various phases of treatment. Mastication is a major function of this system. Therefore, determining masticatory performance was chosen as a starting-point. We also measured bite force, a function which is indispensable in crushing and grinding food.

Masticatory performance is related to the surface area of the postcanine teeth and the relationship between occluding teeth. In retrognathic patients, occlusion is deviant and is changing throughout all the phases of treatment. It would be interesting to quantify occlusal fit by measuring the occlusal contact area and by calculating the distribution of interocclusal distances during the various phases of treatment. These data could then be correlated to function related data like masticatory performance and maximum bite force.

During the measurements of the maximum bite force, we only recorded the bite-force component perpendicular to the occlusal surface. However, the maximum forces that are exerted by the jaw adductor muscles are not always in this direction (Koolstra *et al.*, 1988; Hannam and Wood, 1989; van Eijden, 1991). In orthognathic surgery patients, skeletal relationships are abnormal before treatment and they change as a result of treatment. This may influence the orientation of the jaw adductor muscles with respect to the occlusal surfaces. In our patients, no changes were found in bite force throughout the various phases of treatment. However, anteroposterior and mediolateral components of the bite force may be subjected to differences and changes in skeletal relationships. These components may contribute to the fragmentation of the food.

The force generating capacity of the masticatory system depends on the cross-sectional size of the jaw adductor muscles. In retrognathic patients, before treatment maximum bite force is lower than in controls but the mechanical advantage of the jaw adductor muscles is not. Therefore, one may expect reduced muscle sizes in these patients. Surgical lengthening of the mandible decreases mechanical advantage of the muscles. An increase in muscle size may be required to generate the same level of maximum bite force as before surgery. On the other hand, occlusion and skeletal relationships are normalized. This may lead to a more effective system in which even less muscle size is needed. Determination of the jaw adductor muscle sizes throughout the various phases of treatment will contribute to elucidate the biomechanical concepts in these patients.

The cross-sectional size of the jaw adductor muscles has been related to craniofacial morphology (Weijs and Hillen, 1984; Weijs and Hillen, 1986). However, maximum bite force and muscle size also depend on the extent to which the system is regularly loaded. The differences in morphology between patients and controls, and the change in morphology in patients as a result of treatment, may not be exclusively responsible for differences and, respectively, possible changes in maximum bite force. Therefore, insight in the masticatory habits of the patient is required.

Combined orthodontic and surgical treatment of retrognathic patients is based on the hypothesis that a normal skeletal relationship is the foundation for an optimal occlusion, which enables proper development of the neuromuscular system with, subsequently, a good masticatory function. Future research may reveal the reasons why masticatory function in patients does not meet these expectations and is still impaired when compared with controls, although skeletal relationships and occlusion are treated. Results of this research may contribute to improve therapy.

Chapter 8

Summary - Samenvatting

Summary

There is a wide variety of developmental dentofacial deformities. Deficiency of mandibular length is frequently occurring. This deformity is also known as mandibular retrognathism. As a consequence of this deficiency, the lower dental arch is positioned posterior with respect to the upper dental arch. This anomalous type of occlusal relationship is classified as an Angle class II malocclusion.

Goals of treatment are to eliminate the skeletal discrepancy and to create normal occlusal relationships, which usually requires a combination of orthodontics and orthognathic surgery. Treatment commonly includes three phases. By presurgical orthodontic treatment, regular and congruent upper and lower dental arches are formed. Next, the mandible is surgically lengthened by means of a bilateral sagittal split osteotomy, moving the lower dental arch forward. Hereafter, occlusion is further established and stabilized by postsurgical orthodontics.

Diagnosis and treatment are entirely based on anatomy. Occlusion and skeletal relationships are abnormal before treatment and are changing as a result of the treatment. It is likely that this will be reflected in the function of the masticatory system. The aim of this thesis was to analyze masticatory function during the various phases of treatment in patients with a mandibular retrognathism who are undergoing mandibular advancement surgery.

In order to quantify masticatory function, the following parameters were measured. After a fixed number of chewing cycles on cubes of a silicone rubber, the median size of the fragmented particles was determined with a sieving procedure as a measure of masticatory performance. The breakdown of food particles can be considered as the composite result of selection and breakage. Selection is the chance that a food particle is at least damaged during a chew. Breakage refers to the extent to which a particle, once selected, is fragmented. Both parameters were determined in one-chew experiments, using cubes with edges of 2.4 mm, 4.8 mm and 8.0 mm.

Maximum bite force was measured bilaterally at the level of the first molars using a bite fork with 2 force transducers.

Electromyographic activity (EMG) of the anterior temporal muscle and the masseter muscle was recorded bilaterally during isometric clenching at maximal and

submaximal bite force levels (10-40% of the maximum bite force) and during the chewing experiments. EMG was expressed as a function of bite force which gives an indication of muscle efficiency.

In chapter 2, we compared patients before presurgical orthodontics with controls. The median particle size was 70% larger in patients than in controls, indicating that masticatory performance in patients was impaired. Selection was smaller in patients. This difference increased with a decrease in particle size. Selection of 8 mm particles was similar for patients and controls. Breakage was smaller for patients, in particular for 4.8 mm particles. Maximum bite force in patients was 60% of that in controls.

In chapter 3, we measured the influence of presurgical orthodontics on oral function. Masticatory performance did not change and was still impaired. Selection chances for the three particle sizes were similar before and after orthodontic treatment. Averaged over the three particle sizes, breakage did not change. However, for a particle size of 8 mm breakage was better after treatment. No change in maximum bite force was found.

In chapters 4 and 5, the combined influence of mandibular advancement surgery and postsurgical orthodontics was studied.

Chapter 4 reveals that, on average, masticatory performance, selection and breakage did not change. However, patients with a poor masticatory performance before surgery tended to improve. Such a tendency was also demonstrated for selection and breakage. Individual changes in masticatory performance were correlated with changes in breakage. This indicates that the improvement of chewing performance in some patients may be due to a better breakage.

Chapter 5 shows that maximum bite force did not change. EMG, determined during maximal clenching in maximal occlusion and during the recording of the maximum bite force, was lower for patients before surgery than for controls. Treatment did not change this finding. The EMG/bite force ratio, determined during maximal clenching, was similar for controls and patients before as well as after treatment. The slope of the EMG/bite force regression line, determined at submaximal levels of bite force, was steeper for the patients before surgery than for controls. After treatment, the slope did not change. The mean EMG peak amplitude, recorded during chewing, was lower in patients and did not change after treatment. The mean EMG peak amplitude during chewing, expressed as a percentage of the EMG at maximal clenching, was similar for controls and patients, regardless the phase of treatment. In patients, before as well as after surgery, masticatory performance appeared to increase with maximum bite force.

In chapter 6, patients were examined at least 5 years after surgery. On average, masticatory performance improved. The tendency to improve occurred mainly in patients with a poor masticatory performance before surgery. However, control values were not reached. In patients, maximum bite force did not change after treatment and was still lower than in controls.

In this study we found that in retrognathic patients before treatment, masticatory function was impaired. Treatment did hardly influence masticatory function. Nevertheless, years after surgery, improvement of the chewing performance may occur, mainly in patients with a poor masticatory performance before treatment.

Samenvatting

Er bestaan verschillende ontwikkelingsstoornissen van het aangezicht. Een te korte onderkaak komt regelmatig voor. Deze afwijking staat ook wel bekend als mandibulaire retrognatie. Als gevolg van een te korte onderkaak ligt de ondertandboog ten opzichte van de boventandboog te ver naar achteren. Dit afwijkende occlusie type wordt geclassificeerd als een Angle klasse II malocclusie.

Doelstellingen van de behandeling zijn het elimineren van de skeletale wanverhouding en het creëren van normale occlusale verhoudingen. Meestal is een gecombineerde orthodontische en kaakchirurgische behandeling noodzakelijk. De behandeling bestaat gewoonlijk uit drie fasen. Door middel van een orthodontische voorbehandeling worden er regelmatige, congruente boven- en ondertandbogen geformeerd. Vervolgens wordt de onderkaak chirurgisch verlengd door middel van een dubbelzijdige sagittale splijtings osteotomie. Tenslotte wordt een stabiele occlusie tot stand gebracht door middel van een orthodontische nabehandeling.

De diagnose en behandeling zijn volledig gebaseerd op anatomie. Gebitsocclusie en skeletale verhoudingen zijn afwijkend voor behandeling en veranderen door behandeling. Het ligt voor de hand dat dit tot uitdrukking komt in de functie van het kauwstelsel. Het doel van dit proefschrift is het onderzoeken van de kauwfunctie, gedurende de verschillende fasen van behandeling, bij patiënten met een mandibulaire retrognatie die in aanmerking komen voor een chirurgische kaakcorrectie.

Teneinde de kauwfunctie te kwantificeren werden de volgende parameters bepaald. Na een bepaald aantal kauwslagen op kubusjes, gemaakt van een siliconen rubber, werd door middel van een zeefprocedure de mediane deeltjesgrootte vastgesteld als maat voor kauwefficiëntie. Het verkleinen van voedsel kan worden beschouwd als het samengestelde resultaat van selectie en breken. Selectie is de kans dat een voedseldeeltje op z'n minst beschadigd wordt tijdens een kauwslag. Breken geeft aan in welke mate een geselecteerd voedseldeeltje is beschadigd. Beide parameters werden bepaald door middel van 1-beet experimenten waarbij kubusjes werden gebruikt met ribben van 2.4 mm, 4.8 mm en 8.0 mm.

De maximum bijtkracht werd dubbelzijdig gemeten ter hoogte van de eerste molaren door middel van een beetvork met twee krachttransducers.

De electromyografische activiteit (EMG) van de musculus temporalis anterior en de musculus masseter werd dubbelzijdig geregistreerd tijdens isometrisch klemmen op maximale en submaximale bijtkrachtniveaus (10-40% van de maximale bijtkracht) en tijdens de kauwproeven. EMG werd uitgedrukt als functie van de bijtkracht hetgeen een indicatie geeft van de kauwspierefficiëntie.

In hoofdstuk 2 worden patiënten voor de orthodontische voorbehandeling vergeleken met controle personen. De mediane deeltjesgrootte was 70% groter voor patiënten dan voor controle personen, wat aangeeft dat de kauwefficiëntie bij patiënten is verminderd. Selectie was slechter bij patiënten. Dit verschil neemt toe bij een afnemende deeltjesgrootte. Selectie van 8.0 mm deeltjes was hetzelfde voor patiënten en controle personen. Breken was slechter bij patiënten, vooral voor de 4.8 mm deeltjes. De maximum bijtkracht van de patiënten was 60% van die van de controle personen.

In hoofdstuk 3 wordt de invloed van de orthodontische voorbehandeling op de functie van het kauwstelsel beschreven. De kauwefficiëntie veranderde niet en bleef verminderd. Selectiekansen voor de drie deeltjegroottes waren voor orthodontie hetzelfde als na orthodontie. Gemiddeld over de drie deeltjesgroottes was er geen verandering in breken. Toch werden deeltjes van 8.0 mm beter gebroken na orthodontie. Er werd geen verschil in maximale bijtkracht gevonden.

In hoofdstukken 4 en 5 wordt de gecombineerde invloed van de chirurgische kaakcorrectie en de orthodontische nabehandeling belicht.

Hoofdstuk 4 toont aan dat de kauwefficiëntie, selectie en breken gemiddeld niet waren veranderd. Wel bestond er een tendens tot verbetering van de kauwefficiëntie bij patiënten met een slechte kauwefficiëntie voor chirurgische correctie. Een dergelijke tendens werd ook gezien voor selectie en breken. Er werd een correlatie gevonden tussen individuele veranderingen in kauwefficiëntie en veranderingen in breken. Dit betekent dat de verbetering van de kauwefficiëntie die werd gevonden bij sommige patiënten kan worden toegeschreven aan een verbetering van breken.

Hoofdstuk 5 laat zien dat de maximum bijtkracht niet was veranderd. De EMG's die werden geregistreerd tijdens maximaal klemmen in maximale occlusie en tijdens het bepalen van de maximum bijtkracht waren lager bij patiënten voor chirurgie dan bij controle personen. Behandeling had hierop geen invloed. De verhouding EMG/bijtkracht, welke betrekking heeft op maximaal klemmen, was voor controle personen hetzelfde als voor patiënten, zowel voor als na behandeling. De richtingscoëfficiënt van de EMG/bijtkracht regressielijn, welke werd bepaald aan de hand van metingen op submaximale bijtkrachtniveaus, was groter voor patiënten dan voor controle personen. De richtingscoëfficiënt veranderde niet als gevolg van de behandeling. De gemiddelde EMG piekamplitude, geregistreerd tijdens de kauwproeven, was lager bij patiënten voor behandeling en veranderde niet na behandeling. De gemiddelde EMG piekamplitude tijdens kauwen, uitgedrukt als percentage van het EMG tijdens maximaal klemmen, was voor controle personen hetzelfde als voor patiënten, zowel voor als na behandeling. Bij patiënten bleek voor en na behandeling de kauwefficiëntie toe te nemen bij een toename van de maximum bijtkracht.

In hoofdstuk 6 worden de patiënten minimaal 5 jaar na de chirurgische correctie getest. Gemiddeld was de kauwefficiëntie verbeterd. De tendens tot verbetering werd hoofdzakelijk waargenomen bij patiënten met een slechte kauwefficiëntie voor chirurgie. Het niveau van controle personen werd echter niet bereikt. De maximum bijtkracht was niet gestegen en bleef geringer dan die van controle personen.

Dit onderzoek wijst uit dat bij patiënten met een mandibulaire retrognatie de kauwfunctie is verminderd. Behandeling heeft hier nauwelijks invloed op. Toch kan er jaren na chirurgische correctie een verbetering in kauwefficiëntie optreden, hoofdzakelijk bij patiënten met een slechte kauwefficiëntie voor behandeling.

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Curriculum Vitae

Willem van den Braber werd te Haarlem geboren op 27 november 1962. In 1982 behaalde hij aan het Stedelijk Gymnasium Johan van Oldenbarnevelt te Amersfoort zijn B diploma. In 1988 werd met goed gevolg het tandartsexamen afgelegd. Van 1988 tot 1999 werkte hij part-time in een algemene praktijk. In 1988 is hij tevens aangevangen met een studie geneeskunde die hij na zes jaar zonder succes heeft beëindigd. Van 1989 tot en met 1993 was hij als ziekenhuistandarts verbonden aan de polikliniek kaakchirurgie van het Academisch Ziekenhuis Rotterdam, Dijkzigt. In 1992 werd hij als wetenschappelijk medewerker aangesteld op de afdeling Mondziekten Kaakchirurgie en Bijzondere Tandheelkunde van het Academisch Ziekenhuis Utrecht. In 1994 werd dit medewerkerschap omgezet in een deeltijd AIO-schap. Vanaf 2003 volgde hij een opleiding dento-alveolaire chirurgie op dezelfde afdeling. Per november 2004 is hij verantwoordelijk voor de Hospital Dental Service in het UMC Utrecht.

Dankwoord

Een niet onaanzienlijk deel van je leven zit je, als je een baan hebt, op je werk. Op dat werk heb je in meer of mindere mate contact met collega's. Al die mensen van de afdeling die ik regelmatig van het werk heb gehouden wil ik even persoonlijk de revue laten passeren.

Bert van der Glas is in de beginfase mijn eerste begeleider geweest en ik bewonder hem om zijn inzet. Hij weet tijdens experimenten de prestaties van zijn proefpersonen tot een bovenmenselijk niveau op te drijven. Vaak zijn z'n aansporingen tot ver in het Stratenum hoorbaar. Verder draagt hij voortdurend nieuwe ideeën en inzichten aan die een bijdrage kunnen leveren aan de "discussion" in je artikelen.

Vervolgens werd Andries van der Bilt m'n eerste begeleider. Hij is een man van rust, structuur en regelmaat. Hij heeft mijn onderzoek definitief in een eindfase weten te manoeuvreren, en dan moet je van goede huize komen. Hij weet hoofd- van bijzaken te onderscheiden, is een ware meester in het convergeren en hekelt het onnodig etaleren van niet strikt ter zake doende kennis. Het zijn eigenschappen die leiden tot een bondige "discussion" in je artikelen.

Frits Bosman was gedurende lange tijd mijn promotor en heeft er voor gezorgd dat er niet al te veel van de grote lijnen werd afgeweken. Hij was een prof in het kauwen, maar ook als amateur kauwt hij er lustig op los bij zijn kookclub. Bovendien geeft hij z'n oren en ogen goed de kost in, respectievelijk, concertzalen en musea. Zo had hij, naast een leiding gevende rol, ook de nodige culturele inbreng.

Toen Frits Bosman met emeritaat ging, moest er een nieuwe promotor worden gezocht. Die werd gevonden in de persoon van Ron Koole. Hij had niet veel verstand van Rosin-Rammlers, breek- en selectiefunkties. Hij is, zoals hij zelf al zegt, een echte doener. In een minimum aantal zittingen had hij zich de materie eigen gemaakt, en door zijn inbreng is vooral de "discussion" er een stuk leesbaarder op geworden.

Om een indruk van Jan Abbink te krijgen moet u beslist eens het voorwoord van zijn proefschrift ("Muscle response to loading during rhythmic open-close movements of the jaw", 1999) lezen. Hij stond de afgelopen jaren garant voor de nodige humor en cultuur. Bovendien is hij verantwoordelijk voor de plaatjes in dit proefschrift.

Gezelligheid kent wel degelijk tijd. Het is dan ook mede de verdienste van onze secretaresse Julia Dieben dat ik iets langer over m'n onderzoek heb gedaan dan gebruikelijk is. Bedankt voor alles wat jij met mij hebt willen delen!

Gert-Jan van Rees vertelde me eens dat hij een fan is van de saxofonist Scott Hamilton. Nu had ik nog nooit van die man gehoord. Groot was m'n verbazing toen ik enige weken later in de krant een aankondiging zag staan van een optreden van "saxofoongigant Scott Hamilton" in Amersfoort. Toch maar eens "the Penguin guide to jazz on cd" geraadpleegd. Toen bleek het merendeel van zijn cd's te zijn voorzien van het maximaal haalbare aantal van 4 sterren. GJ en ik hebben het concert bezocht. Op een afstand van twee meter hebben we van de meester mogen genieten.

Mathieu Steijvers maakt als maxillo-faciaal-protheticus oren en neuzen waarop Michelangelo trots zou zijn geweest.

Ruud de Bruyn is een ware tandtechnieker. Zo heb ik wel eens racefiets-achter-tandwieltjes op zijn werkblad zien liggen. Behalve racefietsen assembleert hij ook complete MG's.

Hoe vroeg ik ook op het werk kom, Piet Rutges is er altijd al. Evenals Hans Wichman, kom ik hem regelmatig op de gang tegen. Ze zorgen altijd wel voor een vrolijke noot.

Instrumentmaker Ed Botter, inmiddels met pensioen, is een soort illusionist die geen truc nodig heeft. Een voorbeeld: ik ben in het bezit van een benzinebrander van Zwitserse makelij. In een vlaag van overmoed heb ik eens een minuscule opening in een metalen onderdeel iets opgevijld om een grotere vlam te creëren. En wederom wees de praktijk uit dat er aan Zwitserse producten meestal niet veel te verbeteren valt! Als tandarts weet je dan als geen ander dat je gaatjes makkelijker groter dan kleiner maakt. In een dergelijk uitzichtloze situatie ga je bij Ed langs. En Ed heeft het voor elkaar gekregen. Hij kan gaatjes kleiner maken. De brander doet het weer prima en ik denk nog vaak met veel warmte aan hem terug.

Nu Will Paasse met pensioen is maak ik me een beetje zorgen om de financiële positie van de afdeling. Zij verdedigde de vakgroeps-pot op strenge doch rechtvaardige wijze.

Ary van Rhijn heeft voor een ieder van de afdeling wel eens electronische apparatuur gerepareerd. Z'n atelier heeft soms iets weg van een technisch lab van een bedrijf in huishoudelijke apparaten. Voor mij heeft hij eens het volumeknopje van m'n walkman en het aan/uit-schakelaartje van m'n IKEA-lamp (ontwerp: Nils Gammelgaard … what's in a name) vervangen.

Kees de Putter wil ik bedanken voor de vele zinvolle discussies die vaak ook niet over het werk gingen.

Frits van Kampen is bijna altijd verkleed. Zo ziet hij er uit als dokter, dan weer als kolonel. Binnenkort mag hij in rok-kostuum zijn proefschrift gaan verdedigen.

Hoewel ik Marco Cune al de nodige jaren ken, ligt voor ons een gemeenschappelijk werk in het verschiet.

Uit de kamer van Michel Steenks stijgen vaak pianoklanken op. Als je zijn kamer binnen stapt, weet hij boeiend verslag te doen van recitals die hij bezoekt. Thuis heeft hij een piano en hoewel hij zegt uitsluitend passief met muziek bezig te zijn, verdenk ik hem er sterk van dat hij regelmatig zit te oefenen. Wellicht wil hij ooit nog eens quatre-mains met me spelen. Gebroederlijk met z'n tweeën op zo'n kruk.

Anton de Wijer begroet mij altijd als een verre neef die hij in geen tijden heeft gezien. Belangstellend komt hij je kamer binnen en schudt je zelfs de hand. Hij informeert naar je vorderingen en de situatie thuis.

Bert Olthoff moet het sinds enige tijd zonder de inmiddels gepensioneerde Rob Buchner stellen. Hun relativerende inbreng aan de koffietafel zou je in modern Nederlands als "cool" kunnen bestempelen.

Natasja Hück, bedankt. Jij had mij verzocht het hierbij te laten. Je verzoek wordt uiteraard gerespecteerd.

Rob van Grootel is al die tijd mijn kamergenoot geweest en ik wens hem veel succes met het afronden van zijn proefschrift.

Floor Weijnen, Anneke Fontijn en Lina Engelen verdienen ook een plaatsje in deze opsomming.

Tenslotte wil ik hierbij enkele personen, die op zich niets met het werk te maken hebben maar die de basis vormen van mijn sub-samenleving, apart bedanken: mijn vader en mijn moeder, mijn schoonouders en vooral mijn lieve levensgezellin Iris, onze Maarten en Tessa.