Muscular and mandibular adaptation after lengthening, detachment, and reattachment of the masseter muscle

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This experimental study using adult female rhesus monkeys investigated the skeletal and muscular adaptions in the mandible after lengthening, detachment, and reattachment of the masseter muscle. Skeletal repositioning was greater in those animals in which the muscle was not detached. Surgical repositioning of the muscle after surgical detachment produced more predictable postsurgical repositioning than when the muscle was allowed to reattach spontaneously.

Orthognathic surgical procedures are designed not only to correct skeletal imbalances in the craniofacial region but also to improve the functional maxillomandibular relationship in the dentition and to provide a more harmonous soft tissue profile. These procedures can lengthen, shorten, or change the direction of function of various masticatory and facial muscles. The failure of these muscles to completely adapt to alterations in length has been cited as a major factor in the lack of postoperative stability. For example, Astrand and others[1] studied 55 patients who had undergone oblique osteotomies for correction of mandibular prognathism. Posttreatment stability was variable; relapse of the surgically altered mandibular position averaged 11% at 6 months, 15% at 18 months, and 19% at 30 months. The authors thought that this relapse was caused, at least in part, by the displacing effect of the activities of the muscles and other soft tissues attached to the mandible, and by the activity of the tongue. The possibility of relapse in the postoperative period is increased if the patient has poor occlusion or lacks posterior teeth.

Lysell and others[2] evaluated 30 patients after surgical correction of mandibular prognathism. They observed that the gonial region of the mandible was displaced superiorly and the symphyseal region was displaced posteroinferiorly, resulting in an increased mandibular plane angle. They postulated that the forces generated by the musculature, in particular by the pterygomasseteric sling, led to the changes in skeletal position during the postoperative period.

In a review article on the evolution of orthognathic surgical techniques, Kole[3] found that a significant amount of relapse of the skeletal elements occurred with many of the early surgical procedures. After clinicians had the opportunity of evaluating long-term patients, however, newer techniques were developed (for example, the inverted L osteotomy and the sagittal split osteotomy of Trauner and Obwegeser[4] and the arched osteotomy of the ramus described by Kole[3]). With these techniques, less postoperative relapse occurred. Kole has suggested that the new procedures were successful because the muscles of mastication were detached, thus minimizing the effect of muscle forces on the associated bony segments.

The results of these and other clinical studies have led many investigators to the conclusion that the musculature is an important factor in the determination of the stability or instability of orthognathic surgical correction. The present study was conducted to qualitatively and quantitatively assess the adaptation of the masseter muscle in monkeys to various experimental procedures; more specifically, to study the adaptations in the masseter after changes in its length, to study adaptations in the masseter after surgical detachment and spontaneous or surgical reattachment, to monitor any skeletal alterations that may occur after certain changes in muscle length, and to correlate these muscular and skeletal adaptations with orthognathic surgical procedures currently performed.

■ *Materials and Methods*

An experimental model was designed in which the length of the muscle was altered by using a cast occlusal splint to displace the mandible in an inferior and posterior direction.[5,6] This effectively increased the length and changed the orientation of the muscle.

EXPERIMENTAL ANIMALS—Thirty-three adult rhesus monkeys (*Macaca mulatta*) were used in this experiment. The exact ages of the 32 females and one male were unknown, but judging by previously published data on tooth eruption in rhesus monkeys,[7] these animals were at least 4½ years old at the beginning of the experiment. In all animals, the permanent teeth, with the exception of third molars, were fully erupted.

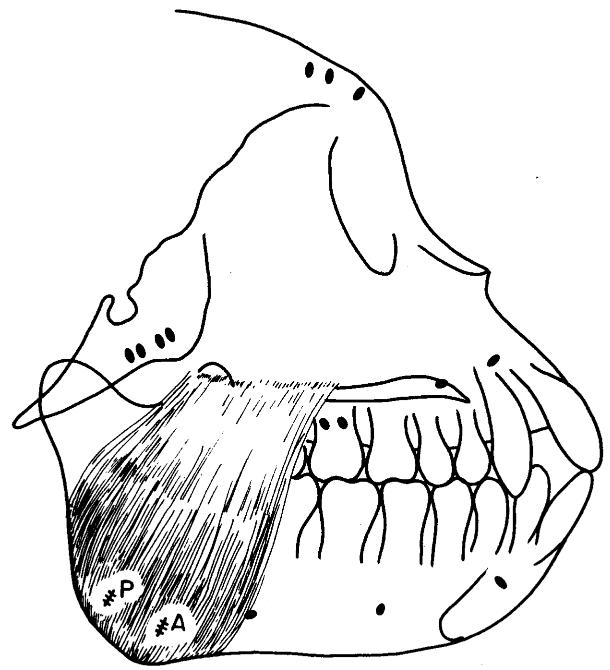

Fig 1—Position of intramuscular markers in superficial lamina of masseter. P, posterior marker; A anterior marker. These implants were placed bilaterally. Locations of osseous markers are also shown in mandible, maxilla, frontal bone, and cranial base regions.

Muscular Model—The masseter muscle of the rhesus monkey was used as the experimental model because of its similarity to that of man.[8] In both species, it is a quadrangular muscle that overlies the angle of the mandible. The larger superficial lamina (Fig 1) originates from the zygomatic process of the maxilla and from the anterior two-thirds of the lower border of the zygomatic arch. The smaller, deeper portion originates from the posterior third of the lower border and from the entire medial surface of the zygomatic arch. The fibers insert into the lateral surface of the coronoid process, the ramus, and the angle of the mandible.

Implant Technique—*Osseous markers.* Tantalum implants were placed in specific regions of the craniofacial complex, using the method developed by Bjork[9-11] and further modified by McNamara[12,13] for use in rhesus monkeys. A minimum of four markers were placed in the mandible; two in the corpus, one in the ramus, and one in the simian shelf. Three markers were placed in the maxilla; two in the anterior maxillary region and one in the malar eminence. Three markers were placed in the frontal bone and four in the cranial base.[13]

Intramuscular markers. Previous studies have shown that muscle markers can be used to measure longitudinal growth of skeletal muscle in nontreated animals, as well as monitor experimentally induced changes in muscle length.[14-16]

These markers usually become stable in the muscle four to eight weeks after implantation. Three muscle markers were implanted in the masseter bilaterally. These markers were short pieces of specially prepared 14 karat gold or chromium cobalt metal (A. S. Koch and Sons, Intercourse, Pa). Markers 1.5 mm in length and 0.75 mm in diameter were implanted into the right masseter, and markers 3.0 mm in length and 1.5 mm in diameter were implanted in the left masseter. The difference in the size of the markers allowed radiographic interpretation of both sides simultaneously. For this experiment, one anterior marker and one posterior marker inserted at the gonial angle were used to monitor alteration in muscle length bilaterally (Fig 1).

Cephalometric Technique—A cephalometric head holder for primates[12] was used in this study. Cephalograms were taken with a medical X-ray unit and type-M industrial film for greater definition of structures.[12]

Before the experimental period, radiographs of all animals were taken weekly, usually over a period of four to eight weeks, until the intramuscular and osseous implants appeared stable in successive cephalograms. During the experimental period, radiographs of the animals were taken immediately preoperatively and at 1, 4, 8, 12, 24, 36, and 48 weeks postoperatively. The radiographs were enlarged to three times their original size when copied on translite film. This enlargement permitted accurate tracing and direct visualization of the changes in the position of the markers and of the changes in distance between the markers; without enlargement, these changes might have been masked by tracing error.

Appliance Construction—The appliance used in this study (Fig 2) was similar to that used in previous studies by our group.[5,6] In the current study, the appliance was further modified to provide the maximum bite opening while still permitting masticatory and other oral functions to continue. A bite opening of 15 to 18 mm incisally usually allowed functional activity to continue and produced an increase in the length of the masseter, temporalis, and medial pterygoid muscles and a corresponding decrease in the suprahyoid muscle group. The changes in the length and the orientation of the masseter varied slightly from animal to animal because of variation in the skeletal configurations of each monkey.

Fig 2—Bite-opening appliance cemented on maxillary arch. Vertical dimension was increased 15 to 18 mm incisally.

EXPERIMENTAL GROUPS—The 33 animals in this study were divided into four experimental groups and one control group (Table). To examine other physiological parameters of muscular and skeletal adaptation (for example, histochemical and biochemical properties), the animals in the five experimental groups were killed according to a predetermined schedule.

Group A (appliance only). Bite-opening appliances were placed in six animals to increase the length and alter the direction of the masseter and its associated muscle groups. The animals were killed at 4 weeks (one), 8 weeks (one), 12 weeks (one), 24 weeks (two), and 48 weeks (one) after insertion of the appliance.

Group AD (appliance-detachment). Bite-opening appliances were placed over the maxillary dental arches of eight animals one day before surgery. Surgical detachment of the masseter was performed bilaterally, and no attempt was made to establish the original position of the pterygomasseteric sling. The animals were killed 4 weeks (one), 8 weeks (three), 12 weeks (two), 24 weeks (one), and 48 weeks (one) postoperatively.

Group DR (detachment-reattachment). The effects of surgical detachment and reattachment of the masseter with no preoperative alterations in muscle length were studied in this group of six animals. No bite-opening appliances were placed in these animals, and the masseter was surgically detached from the ramus bilaterally and surgically reattached at the gonial angle in its original position. The animals were killed 4 weeks (one), 8 weeks (one), 12 weeks (one), 24 weeks (two), and 48 weeks (one) postoperatively.

Group ADR (appliance-detachment-reattachment). To monitor the effects of muscle lengthening and surgical detachment and reattachment, bite-opening appliances were placed in six animals one day before surgery. The masseter was then surgically detached bilaterally and reattached in its original position. The animals were killed 4 weeks (one), 8 weeks (one), 12 weeks (one), 24 weeks (two), and 48 weeks (one) postoperatively.

Table • Number of monkeys radiographed at each postoperative interval.

	Postoperative intervals (in weeks)				
Experimental groups	4	8	12	24	48
A	6	5	4	3	1
AD	8	7	5	3	1
DR	6	5	4	3	1
ADR	6	5	4	3	1
C	7	6	6	3	0

Group C (control). Seven animals were used to establish baseline values for the stability of the intramuscular and osseous markers. No appliances were placed or surgical procedures performed on this group. The animals were radiographed postoperatively at 4, 8, 12, and 24 weeks but were not killed, as they were used in other experiments at the end of the control period. One animal was removed from the experiment after four weeks, three animals after 12 weeks, and three animals after 24 weeks.

SURGICAL PROCEDURES—The animals were sedated with an intramuscular injection of 1.5 mg/kg phencyclidine hydrochloride and then given an intravenous injection of 5 mg/kg of sodium pentobarbitol.

Muscle detachment. The region between the zygoma and the clavicle was shaved bilaterally, and a sterile surgical field was prepared in the usual manner. A modified Risdon approach was made at the posteroinferior border of the mandible.[17] After the platysma muscle was sharply dissected, the underlying tissues were bluntly dissected, with close attention to the dissection inferior and posterior to the buccal pouch. Facial vessels, if encountered, were clamped and tied to provide homeostasis. After the inferior border of the mandible had been exposed, the pterygomasseteric sling was incised at its most inferior attachment to the mandible. A dental periosteal elevator was then used to strip the masseter completely from the lateral and posterior surfaces of the ramus (Fig 3).

Muscle reattachment. After reflection of the masseter, it was repositioned by reapproximation of the pterygomasseteric sling with a no. 3-0 chromic suture (Fig 4).

CEPHALOMETRIC ANALYSIS—*Preparation of tracings.* Changes in the position of the intramuscular and

Fig 3—Surgical detachment of masseter from gonial region of mandible.

Fig 4—Surgical reattachment of masseter.

osseous implants were monitored by placing a piece of 0.003 acetate tracing paper over the initial cephalogram. The outlines of the cranial and cranial base implants and the inferior portion of the endocranial surface of the orbital roof were traced. This template was transferred to successive cephalograms and was used in recording changes in implant position relative to the position of the implants in the anterior portion of the cranial base.

Digitization. To quantify the amount and direction of osseous and muscular implant movement and of changes of contour, the serial tracings were digitized. A Prime 300 interactive computer and a Sumagraphics digitizing system were used; this system is accurate to 0.1 mm. The tracings were placed on a backlighted digitizer board, and the position of the implants was translated into an X, Y coordinate system. The muscular and skeletal reference points used are illustrated in Figure 5.

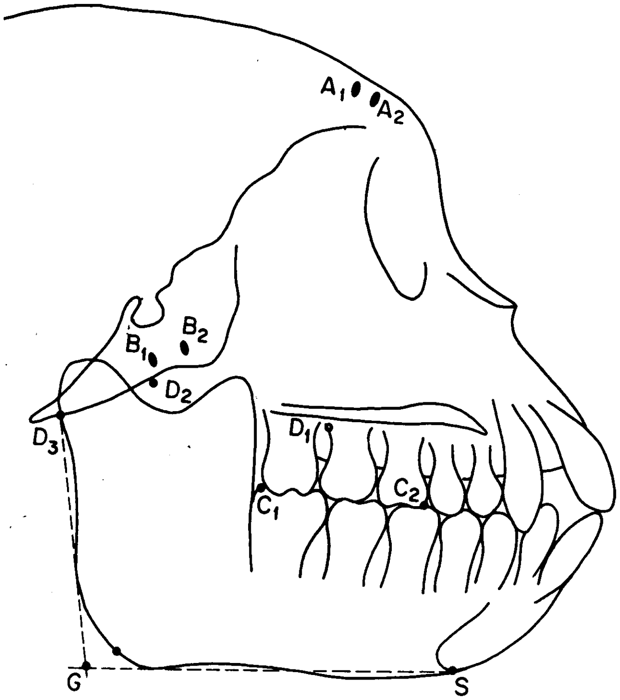

Fig 5—Location of digitized points. A_1A_2, frontal bone implants; B_1B_2, cranial base implants; C_1C_2, points used in determining occlusal reference plane; D_1, malor strut; D_2, articular eminence; D_3, articulare; G, constructed gonion (determined by intersection of lines tangent to posterior border of ramus and inferior border of mandible); S, lower border of symphysis. Digitized muscle markers P and A are not shown.

Analysis of digitized points. The movement of muscle markers on each side, A (anterior) and P (posterior), were analyzed (Fig 6). By means of the Michigan Data Analysis System (MIDAS) retrieval system, measurements of marker movements were made between each successive interval.

Mathematical analysis of the vector movement of the muscle markers was necessary to measure the changes that occurred in the masseter. The midaxis of origin of the masseter was established at the midpoint of the zygomatic arch and designated point Z. The midaxis of insertion was the digitized point G_1, which was constructed at the gonial angle (Fig 6). A reference plane or masseter axis was thus established. All measurements of muscle and bone marker movements were made perpendicular and parallel to this axis and the vector distances were calculated.

As previously mentioned, the number of animals in each group decreased as the postoperative interval increased. Thus, data represented on graphs from 0 to 4 weeks postoperatively are from all animals (all markers in all groups). However, at 48 weeks postoperatively, the data on the graphs are from one animal (four markers for each group).

■ *Results*

Adaptive changes in the length of the masseter were observed in each experimental animal. The

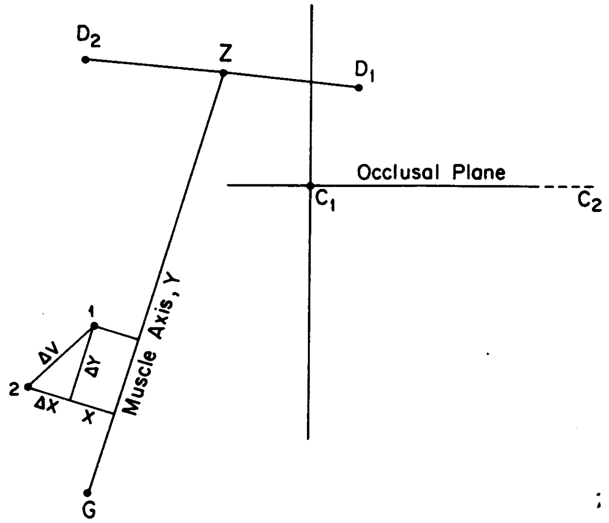

Fig 6—Determination of muscle axis. Midpoint of zygomatic arch, as indicated by midpoint between D_1 and D_2, was determined (point Z). Muscle axis was then constructed as line connecting points Z and C. Note angular relationship of occlusal plane, which was determined by line through points C_1 and C_2.

Movement of muscle marker from position 1 to position 2 is shown. This movement is quantified relative to muscle axis. Y is movement of implant perpendicular to muscle axis. Vector distance (ΔV) is direct measurement of movement of implant from position to position 2.

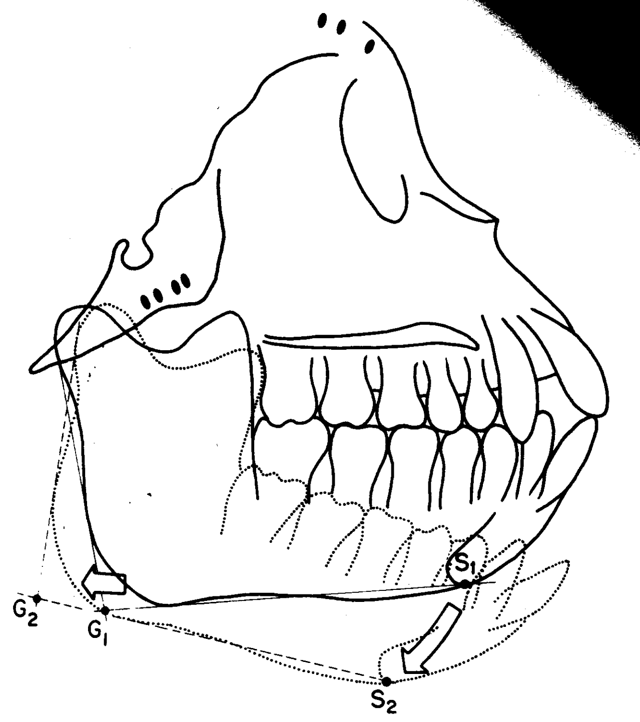

Fig 7—Schematic illustration of mandibular rotation produced by insertion of bite-opening appliance. Note posterior movement of point G and posteroinferior movement of point S.

nature of these changes depended on the experimental protocol followed.

Group A—*Analysis of skeletal adaptations.* The placement of the bite-opening appliance in the group A animals resulted in a downward and backward repositioning of the mandible. The gonial region was relocated more posteriorly (6 to 7 mm) than inferiorly (2 to 3 mm). In contrast, the symphyseal region was repositioned more inferiorly (12 to 13 mm) than posteriorly (2 to 3 mm) (Fig 7), which increased the mandibular plane angle.

During the experimental period, gradual changes in the spatial relation of the mandible were observed. This alteration in the position of the mandible was not merely a rebound along the original direction of displacement. During the first four weeks, the gonial region generally moved in an anterior direction, with an average forward displacement at point G of approxiately 2 mm. This trend continued from four to 12 weeks, with a concomitant slight inferior displacement of the gonial region. In contrast, the alteration in the position of the symphysis during the same posttreatment interval was primarily in a superior and slightly anterior direction.

Analysis of muscular adaptations. Placement of the bite-opening appliance in group A not only caused a rotation of the mandible in a posterior and inferior direction but also resulted in an increase in length and a change in the mean direction of the masseter (Fig 8). The amount and direction of implant displacement was variable within the muscle. The anterior implant (A) was displaced posteroinferiorly, whereas the posterior implant (P) was displaced more posteriorly. The average displacement of the muscle implants in group

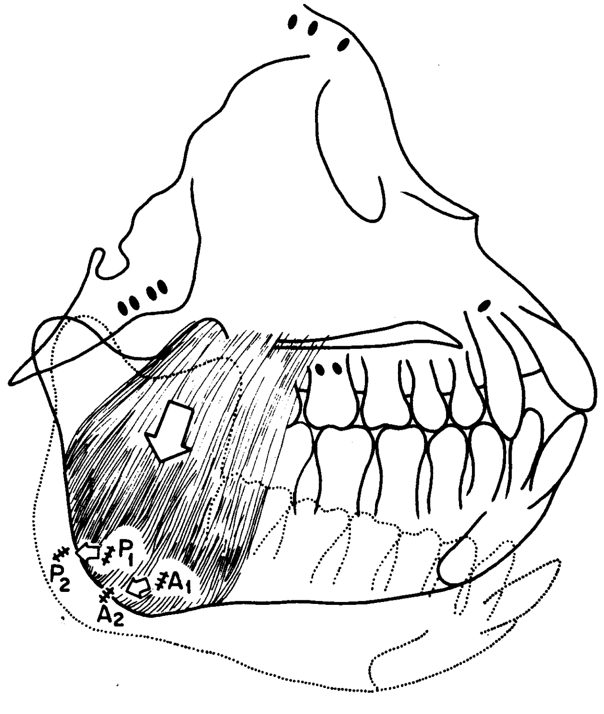

Fig 8—Schematic representation of movement of intramuscular implants after insertion of bite-opening appliance. Note posteroinferior movement of anterior implant (A) and the more posterior movement of the posterior implant (P), which indicates increase in length of masseter.

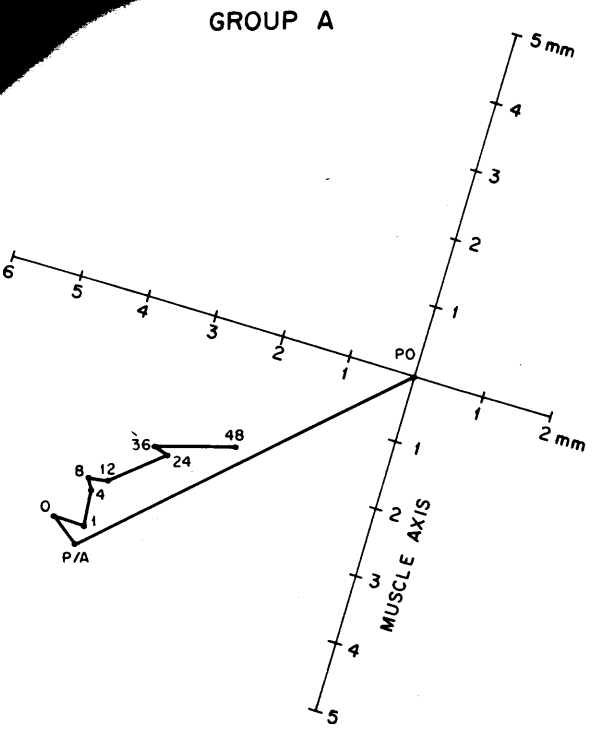

Fig 9—Graphic representation of mean movement of intramuscular implants in group A. This graph shows average movement of anterior and posterior implants bilaterally.

In this figure and in Figure 10-13, following radiographic intervals are considered: preoperative (PO); preoperative with appliance (P/A); immediate postoperative (O); 1 week postoperative; 4 weeks postoperative; 8 weeks postoperative; 12 weeks postoperative; 24 weeks postoperative; 36 weeks postoperative; 48 weeks postoperative.

A animals was 5.4 mm in a posteroinferior direction.

Muscular adaptation in the group A animals during the experimental period was characterized by a gradual movement of the muscle implants to their original spatial location. At the end of the first four weeks, there was a mean return of approximately 10% toward the original position; and at the end of 12 weeks there was a mean rebound of approximately 20% (Fig 9). By the end of 24 weeks, the muscle markers had returned about 40% of the distance created by the appliance, and more than 50% by the end of 48 weeks. The muscle markers were now approximately 2.2 mm posterior and 1.8 mm inferior to the original position.

GROUP AD—*Analysis of skeletal adaptations.* The posterior and inferior rotation of the mandible produced by the placement of the appliance in this group of animals was similar to that in group A animals. The gonial region was also relocated in an anterior and superior direction in the postoperative period. This movement more closely approximated the direction of the elongation that occurred immediately postoperatively than did the movement of the same region in group A. However, the movement was still more anterior than would be expected if a mere rebound phenomenon was being seen.

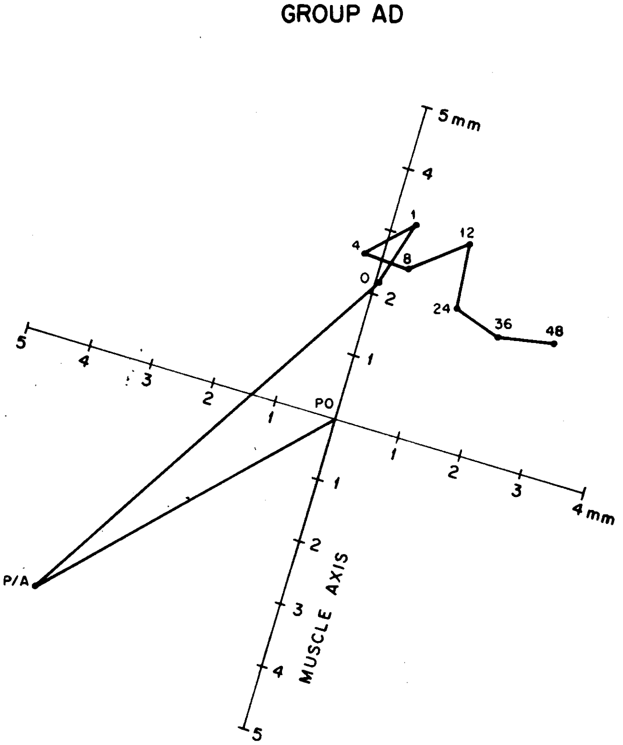

Fig 10—Graphic representation of mean movement of intramuscular implants in group AD (see Figure 9 for explanation of radiographic intervals).

Analysis of muscular adaptations. The displacement of the intramuscular implants that resulted from the placement of the bite-opening appliance in group AD was similar to that which occurred in group A. The implants were displaced an average of 4 mm posteriorly and 4 mm inferiorly, with a resultant posteroinferior displacement of 5.2 mm (Fig 10). The immediate postoperative change observed in group AD, however, was an extreme shortening of the masseter (approximately 6.6 mm) in an anterosuperior direction. The masseter tended to shorten and elongate at random during the first four weeks postoperatively. In the four- to 12-week postoperative period, the masseter shortened in an anterosuperior direction along the original muscle axis (Fig 10). From 12 through 48 weeks postoperatively, the muscle continued to shorten in an anterior direction, but also elongated again inferiorly, to some extent. The final length of the masseter was shorter than its original length. At the end of the 48-week experimental period, the muscle markers were an average of 3 mm anterior and 3 mm superior to their original position.

GROUP DR—*Analysis of skeletal adaptations.* The movement of the gonial and symphyseal regions in this group was random and consistent with that observed in the control animals.

Analysis of muscular adaptations. Immediately postoperatively, there was a slight posterosuperior short-

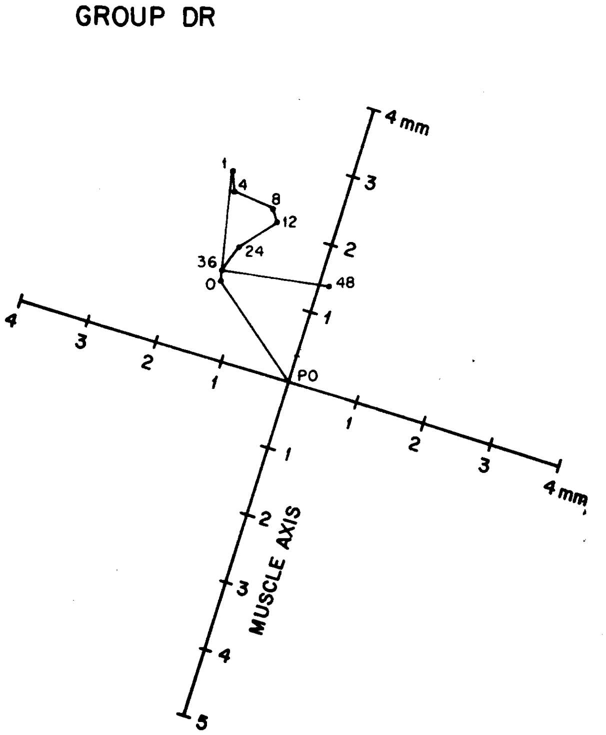

Fig 11—Graphic representation of mean movement of intramuscular implants in group DR (see Figure 9 for explanation of radiographic intervals).

ening of the masseter. The mean vector of movement of the muscle implants in this group was 2.0 mm (Fig 11). The masseter continued to shorten in a posterior and superior direction through the first four postoperative weeks. In the four- to 12-week postoperative period, the markers moved in an anterior direction. In the 12- to 48-week postoperative period, they moved in an inferior and anterior direction, back toward their original positions. The muscle did not return to its original length, however, and the final position of the muscle implants indicated that the masseter was at least 1 mm shorter than its original resting length. Significant intraside variation was observed.

Group ADR—*Analysis of skeletal adaptations.* Posterior and inferior displacement of the mandible, similar to that observed in groups A and AD, occurred in this group after placement of the bite-opening appliance. In the first four weeks postoperatively, there was an initial superior movement of both the gonial and symphyseal regions. In the next 44 weeks, however, the gonial region moved in an anterior and slightly inferior direction. Similarly, the symphyseal region moved in an anterior and superior direction.

Analysis of muscular adaptations. The mean displacement of the intramuscular markers immediately after placement of the bite-opening appliance was 5.2 mm in a posteroinferior direction. After surgical detachment and reattachment of the masseter, the alteration in the length of the masseter caused by the appliance placement was shortened by approximately 50%. The mean vector movement of the muscle implants from the preoperative position to that immediately postoperative was from 5.2 mm to 3.5 mm (Fig 12). The shortening seen in this group was less extreme than that observed in group AD, where surgical reattachment of the pterygomasseteric sling was not performed. It may be postulated that the surgical reattachment did not allow the masseter to return immediately to its original length. However, the muscle did shorten in a direction consistent with that of group AD.

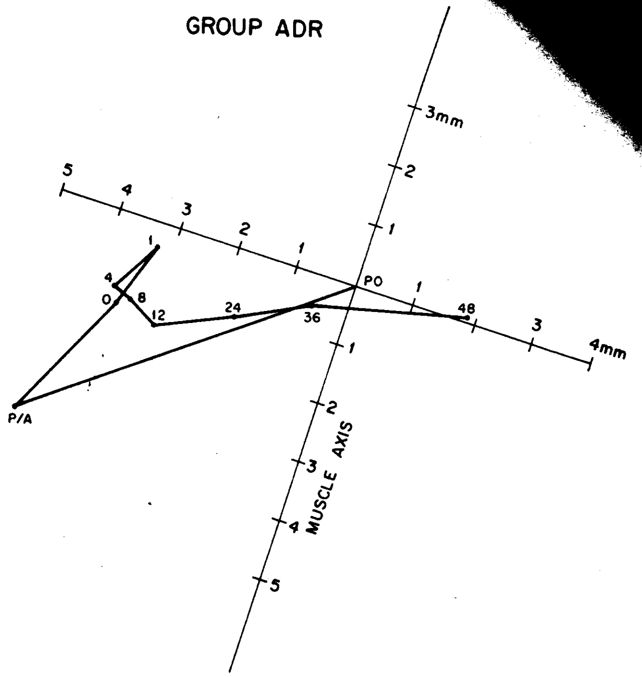

Fig 12—Graphic representation of mean movement of intramuscular implants in group ADR (see Figure 9 for explanation of radiographic intervals).

The muscle fibers of group ADR animals continued to shorten toward their original position in the first four postoperative weeks. However, this initial shortening was in a direction more superior than anterior (Fig 12). A variable degree of migration occurred between four and 12 weeks postoperatively. From 12 to 48 weeks postoperatively, the movement occurred more along the muscle axis. In most animals, the final length of the muscles was slightly shorter than the original length. On the average, movement of the muscle produced a final shortening of almost 2 mm in an anterior direction (Fig 12).

Group C—*Analysis of skeletal adaptations.* Evaluation of the gonial angle and the symphyseal region showed a small amount of change that was similar to that of group DR. The average amount of displacement in the experimental period was less than 1 mm in any direction, and the mandibular plane angle remained constant.

Analysis of muscular adaptations. The amount of movement of the muscle markers in the control group was minimal. During the experimental period, intra-

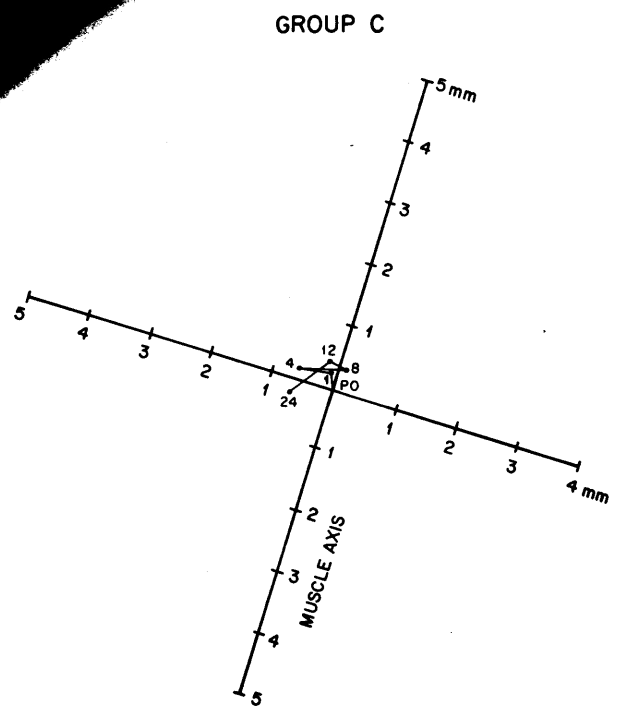

Fig 13—Graphic representation of mean movement of intramuscular implants in group C (see Figure 9 for explanation of radiographic intervals).

muscular implant movement was limited to 1 mm or less (Fig 13) and was random.

■ *Discussion*

The results of this study indicate that significant muscular and skeletal adaptation occurs in the craniofacial complex after alterations in the length of the masticatory musculature, detachment of certain muscles in that region, or both. Specifically, this study addresses the following questions: what are the short-term and long-term effects of surgical detachment of the masseter; what are the effects of surgical detachment and surgical reattachment vs spontaneous reattachment of the masseter; what is the effect on the mandible when there is an alteration in the length of the associated musculature; and how are these muscular and skeletal adaptations related to orthognathic surgical procedures currently being performed for craniofacial disharmonies?

The Effect of Muscle Detachment—If the length of a muscle has been increased, its detachment (group AD) results in immediate shortening of that muscle, often to a point shorter than its original length. Indeed, this phenomenon was not limited to muscles that had been lengthened preoperatively, but also occurred to a lesser extent in muscles that were not lengthened before surgery (group DR). When such a muscle was detached, even if it was surgically reattached at its original point of insertion, its final length was slightly shorter than its original length.

The shortening of the muscle after detachment can be explained by at least two factors. First, McNamara[18] has shown that the masseter in the rhesus monkey is intermittently active when the mandibular postural position is maintained. Therefore, some slight contraction of this muscle can be anticipated if it is detached from its original point of insertion. Second, muscles not only have the ability to contract but also have some inherent elastic properties.[19] These properties are especially important when a muscle is elongated. If a muscle is elongated beyond its physiological limits, the passive elastic properties of the muscle can be more important than the active contractile properties of that muscle in generating a retracting force. Thus, the immediate shortening of a muscle after detachment, regardless of whether the muscle has been previously elongated, is probably caused by a combination of actively and passively generated forces.

Spontaneous Reattachment vs Surgical Reattachment—The most obvious difference between those muscles that were reattached surgically (groups DR and ADR) and those that were allowed to reattach spontaneously after surgical detachment (group AD) was observed in the cephalogram taken immediately after the surgery was completed. In the muscles that were allowed to reattach spontaneously, the amount of postsurgical shortening was great. In one animal in particular, a dramatic shortening of the muscle was found; the muscle had been elongated 5 mm by the appliance, but it shortened 20 mm immediately postoperatively. Although great variation occurred in the postoperative position of the muscles, in all cases the immediate postoperative length was less than the original unaltered length.

Surgical reattachment of the muscle resulted in much more controlled postsurgical positioning, although some shortening occurred after reattachment, regardless of whether the muscle had been initially lengthened. However, the extreme shortening of the masseter that occurred with spontaneous reattachment was not seen. It can be postulated that surgical reattachment of a muscle that has been elongated allows for both the reduction of the forces produced by that elongation on the adjacent osseous structures and provides some moderating force on the muscle that prevents overshortening.

A comparison of groups DR and ADR shows that, even though the muscle in group DR was not previously lengthened, there was still some postoperative shortening of the muscle, despite the fact that it was surgically reattached, presumably at its original location. One must consider the fact, however, that none of these animals had maxillomandibular fixation; movement of the muscles along the ramus of the mandible would consequently be more variable.

SKELETAL ADAPTATIONS AFTER ALTERATIONS IN MUSCLE LENGTH—Significant skeletal adaptations were observed in the three groups of animals in which the length of the masseter was altered by the placement of the bite-opening appliance (groups A, AD, and ADR). Though not quantified in this study, a forward and upward displacement of the maxillary complex and a concomitant intrusion of the dentition, particularly in the mandibular arch, was readily observed. This resulted in forward and upward rotation of the mandible, thus reducing the altered vertical dimension.

Similar skeletal adaptations have been observed previously in adult and juvenile monkeys. McNamara[5,6] reported that in animals in which no muscle detachment was performed the amount of upward and forward maxillary displacement was dependent on the amount of bite opening. As in the present study, however, the immediate migration of the muscle after surgical detachment to a new orientation in relation to the associated bony surfaces probably relieved some of the forces generated by the muscle elongation. This migration provides an immediate mechanism for reducing the stresses generated in the elongated musculatures, and thus lessens the effect of these forces on the origin and insertion of the muscles.

Osseous changes in the gonial angle and the symphysis differed in amount and direction of movement for each group during the 48-week period. In group A, there was anterior and slightly inferior repositioning of the gonial region. The symphysis also migrated considerably superiorly and anteriorly past its original position. In contrast, group AD had much less anterior and superior movement of both the gonial and symphyseal regions. Group ADR had results midway between those of groups A and AD (for example, point G in group ADR migrated less than point G in group A but more than point G in group AD). This observation indicated the influence of the masseter on the movement of the mandible and its associated craniofacial elements and emphasizes the stresses present in postorthognathic surgery cases, where muscles are lengthened, whether left intact or surgically reattached.

IMPLICATIONS FOR ORTHOGNATHIC SURGERY—The findings in this study bear directly on clinical situations in which the position of the mandible and the resting length of the masticatory muscles are altered as a result of surgical intervention. The results of group A, in which the mandible was rotated posteriorly and inferiorly, show that a considerable relapse in the position of the mandible occurs after alteration in muscle length unless there is surgical detachment of the masseter. In the experimental groups in which the masseter was detached, with and without surgical reattachment, other patterns of skeletal change were apparent. These findings are consistent with relapse problems reported by Behrman,[20] Bell and Creekmore,[21] and Astrand and Ridell.[22] These and other clinical studies support our finding that repositioning of osseous elements and alteration of muscle length produces mandibular change.

Many clinicians have recommended muscle detachment in orthognathic surgical cases. Hovel,[23] who analyzed the problem of anterior open bite and skeletal relapse after surgical correction of mandibular prognathism, thought that the actions of the elevator muscles of the mandible, particularly the powerful masseter and internal pterygoid muscles, were the primary causes of the open bite. When the jaw was surgically retruded, these muscles were elongated beyond their normal resting lengths. During the postoperative period, the muscles tended to return to their original resting lengths and at the same time pulled the angle of the mandible superiorly. He concluded that one method of avoiding this postsurgical regression would be to strip the mandible of the attachments of the masseter and medial pterygoid muscles during the surgical procedures so that they might reattach in a new location.

The level of reattachment of the muscle is important in determining the skeletal configuration that evolves during the posttreatment period. Kelsey,[24] Cunat and Gargiulo,[25] and Astrand and Ridell[22] reported that the original configuration of the gonial angle of the mandible returned after gross modifications of form had been made by orthognathic surgical procedures when all normal growth was complete. Kelsey[24] suggested that the forces of the pterygomasseteric sling produced the postsurgical return of the original skeletal morphology of the mandibular angle. To avoid this relapse, various clinicians advocate that this muscle group be reattached at the new angle; others recommend that it be secured at the original level of attachment (that is, at the original resting length); and still others recommend that it be left unattached and be allowed to reattach spontaneously.

■ *Summary and Conclusions*

This investigation was undertaken to study the skeletal and muscular adaptations in the mandible after lengthening, detachment, and reattachment of the masseter. Placing the bite-opening appliance and altering the length of the masseter, with and without surgical detachment and reattachment, resulted in a number of mascular and skeletal adaptations: First, a posterior and inferior rotation of the mandible was produced. In the experimental period, forward repositioning of the gonial angle and upward repositioning of the symphyseal region occurred. The amount of skeletal repositioning was greater in those animals in which the associated musculature was not detached. Second, if the masseter muscle was lengthened and not detached from the mandible, a gradual return of the muscle to its original length was observed. After 48 weeks, a 50% return occurred. Third, if a muscle was lengthened and then surgically detached, immediate shortening of the muscle occurred in an anterior and superior direction, with ultimate reattachment often at a length shorter than the original. Fourth, if a muscle was surgically detached and then surgically reattached without placement of a bite-opening appliance, a slight shortening of the muscle occurred. Fifth, if the bite was opened and the masseter was surgically detached and then surgically reattached, the muscle returned to its approximate original length and had a more predictable postsurgical positioning.

It may be concluded that, in surgical procedures where lengthening of the masticatory muscles is mandatory, it is beneficial, if possible, to surgically detach these muscles from their insertions. In doing so, one would maintain the original orientation of the muscle and at the same time presumably impose less stress on the newly placed, surgically repositioned skeletal elements.

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