

Treatment of Mandibular Condylar Process Fractures: Biological Considerations

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The topic of condylar injury in adults has generated more discussion and controversy than any other in the field of maxillofacial trauma. It is an important subject because such injuries are common and complications of trauma to the temporomandibular joint (TMJ) are far-reaching in their effects. Why are there so many different methods to treat this injury? How can seemingly disparate treatment options all produce satisfactory outcomes in the majority of patients? The reason lies with the biological adaptations that occur within the masticatory system that are poorly understood, not readily quantifiable, and variable from one person to the next. This discussion presents our current understanding of the adaptations that must occur to provide the patient with a satisfactory outcome. The adaptations for patients treated open are different than for those treated closed. However, it is when these adaptations fail to occur that unsatisfactory outcomes occur, regardless of how they were treated.

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The topic of mandibular condylar fracture has generated more discussion and controversy than any other in the field of maxillofacial trauma. Such injuries are common; accounting for between 25% and 35% of all mandibular fractures in reported series.¹⁻⁴ Further, complications of trauma to the temporomandibular joint (TMJ) are far-reaching in their effects and not always immediately apparent. Disturbance of occlusal function, deviation of the mandible, internal derangements of the TMJ, and ankylosis of the joint with resultant inability to move the jaw are all sequelae of this injury.

Unlike the nonsurgical approach to condylar fractures in children, for which there is a great consensus of opinion, the treatment of condylar fractures in adults is still a highly debated theme. The broad range of treatment advocated for these individuals

is best demonstrated in the statement by Malkin et al⁵: "Concerning the treatment of condylar fractures, it seems that the battle will rage forever between the extremists who urge nonoperative treatment in practically every case and the other extremists who advocate open reduction in almost every case."

The majority of surgeons seem to favor nonsurgical treatment of condylar fractures. This preference is largely the result of 3 main factors. First, nonsurgical treatment gives "satisfactory" results in the majority of cases. Second, there are no large series of patients reported in the literature who have been followed after surgical treatment because management of condylar fractures has historically been with nonsurgical means. Third, surgery of condylar fractures is difficult because of the inherent anatomical hazards (ie, VII nerve).

In recent years, open treatment of condylar fractures has become more common, probably because of the introduction of plate and screw fixation devices that allow stabilization of such injuries. Although several reports and a few series of open treatment have emerged in the world literature,⁶⁻³³ there has still been no definitive study performed that has shown the superiority of open versus closed reduction. Unfortunately, the type of study needed to clarify this question may never be possible.

Treatment of condylar fractures today seems to be based mostly on tradition and experience. If one pe-

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uses the literature on this topic, one will find that there are 3 main treatments advocated for adults with condylar process fractures: 1) a period of maxillomandibular fixation (MMF) followed by functional therapy; 2) functional therapy without a period of MMF; and, 3) open reduction with or without internal fixation. The first 2 are forms of closed treatment, meaning that a surgical procedure on the fractured segments is not undertaken.

We do not use the term “closed reduction,” which we believe is a misnomer, because reduction of the fracture does not generally occur, and instead use the term “closed treatment” or “nonsurgical treatment.” For similar reasons, we do not use the term “conservative treatment,” a term that smacks of bias as being “less invasive” and somehow more appropriate, when, in fact, enough data is not available to prove closed treatment is more appropriate (or “conservative”).

Why are there so many techniques advocated for treating the same fracture? The reason is based solely on tradition and experience. A quote from Melvin Moss³⁴ about the abundant nonscientific literature available on the TMJ is just as appropriate to the debate about treatment of condylar fractures, “I know of no other single anatomical subject concerning which so much misinformation has been printed, and then believed.” It is probable, and the literature will bear this out, that all of such treatments give satisfactory results in the *majority* of cases. The literature will also bear out the fact that not *all* fractures have satisfactory outcomes with any of the above treatments. Why is it that some fractures can be satisfactorily treated and others not? The reason lies in basic biology. As with any treatment for a given malady, one should understand that there are a complex series of structural and functional adaptations that occur to produce the satisfactory outcome we so eagerly seek. It is when the ability of the masticatory system to perform such adaptations is superseded that we have unsuccessful outcomes.

Thus it is necessary to understand how the masticatory system adapts to the structural alterations that accompany fractures of the mandibular condyle. With this knowledge in hand, it becomes possible to select a form of treatment that will have the greatest opportunity to assure a successful outcome. Before answering the question, “How should condylar fractures be treated?,” we must first ask other more basic questions to provide information about the ability of the masticatory system to adapt to such injuries. Fortunately, there is a great body of scientific information available to help us understand how the masticatory system adapts to condylar fractures.

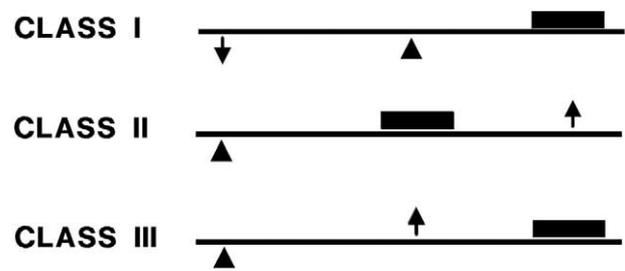


FIGURE 1. Illustration of the 3 classic lever systems. The arrow represents the muscle force; the triangle represents the axis or fulcrum; the rectangle is the load or resistance force. Class I levers are used in seesaws, catapults, and use of a crowbar. A class II lever is used in the function of a wheelbarrow.

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Is a Temporomandibular Articulation Necessary/Advantageous?

The first basic question that must be answered before making a decision about treatment is, “Is a temporomandibular articulation necessary and/or advantageous for the functioning of the masticatory system?” If the answer to this question is yes, then it might seem reasonable to perform open reduction of a fractured condyle to immediately reconstruct the temporomandibular articulation, or to maximize the development of a new articulation using nonsurgical means. Unfortunately, the question cannot be simply answered. To seek information about this question, others must be sought: 1) Is the TMJ a stress-bearing joint? 2) Does the TMJ *have* to be a stress-bearing joint? 3) Does the TMJ guide mandibular movement? 4) How does the masticatory system function when one TMJ is damaged? 5) How does the masticatory system function when both TMJs are damaged?

IS THE TMJ A STRESS-BEARING JOINT?

If the TMJ bears functional loads, then its immediate reconstruction would seem reasonable to allow normal function to return. Surprisingly, this question has been the harbinger of a great debate throughout modern medical/dental literature. Early studies by German anatomists^{35,36} suggested that there might be a relationship between joint form and type of bite or occlusal plane curvature, and argued for the presence of some stress at the joint. However, by the early 1920s, a divergence of opinion about this possibility dominated the literature. Gysi³⁷ was one of the first to suggest that the function of the mandible could be likened to a lever system (Fig 1). He argued that the mandible functioned as a class III lever, where the muscle force vector was between the fulcrum (TMJ) and the bite point, necessitating loads be transmitted through the TMJ (Fig 2). Wilson^{38,39} cast the most vocal dissent to this opinion, attempting to show

CLASS III LEVER

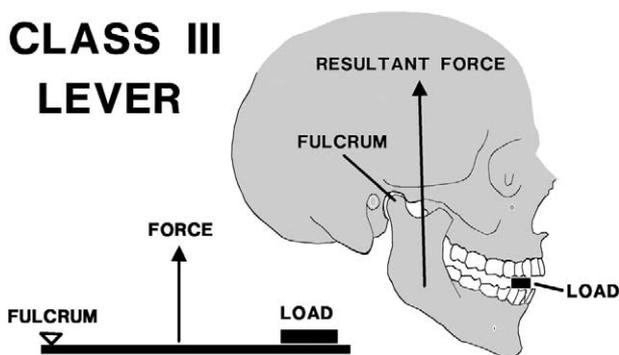


FIGURE 2. Illustration suggesting that the mandible functions as a class III lever system, where the muscle force is between the TMJ (fulcrum or axis) and the occlusal load.

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that no resultant force was necessary at the TMJ to generate a bite force at the dentition. The reasoning behind his assertion centered on a purported demonstration that the resultant muscle force vector passed through (equilibrium) or anterior to the bite point (class II lever), thus eliminating the necessity for a balancing force at the joint (Fig 3). Wilson’s major objection to the Gysi’s “lever” theory of jaw function was its inherent inefficiency that resulted in “wasted” force at the joint, an inefficiency which seemed contrary to “Nature.” Robinson⁴⁰ promoted an updated version of Wilson’s^{38,39} nonlever theory. In an article published in the *Journal of the American Dental Association*, he used force parallelograms similar to those of Wilson to indicate the likely colinearity of the resultant muscle force vector with the bite point, arguing that the force vector could pass through the bite point, obviating the necessity of forces from passing through the TMJ (Fig 4). Robinson further showed histologic specimens of the TMJ and argued

CLASS II LEVER

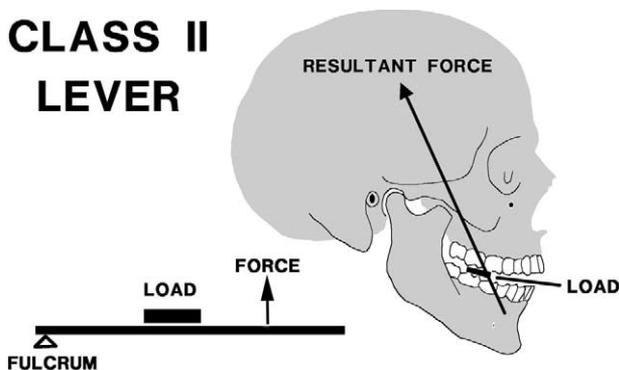


FIGURE 3. Illustration suggesting that the mandible functions as a class II lever system, where the occlusal load is between the TMJ (fulcrum or axis) and the muscle force.

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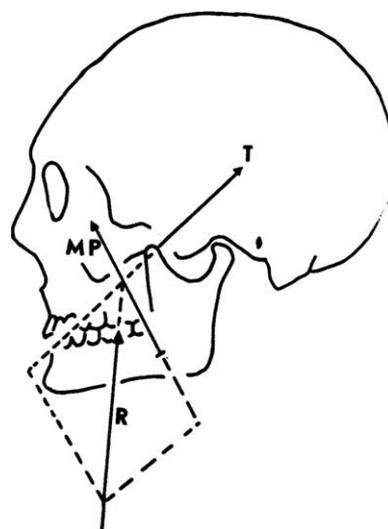


FIGURE 4. Marsh Robinson’s parallelogram of forces. R, resultant of components T and MP. T, component force of temporalis muscle. MP, component force of masseter and medial pterygoid muscles in plane of temporalis muscle. (Reprinted from Robinson M: The temporomandibular joint: Theory of reflex controlled nonlever action of the mandible. *J Am Dent Assoc* 33:1260, 1946, Copyright © 1946 American Dental Association. All rights reserved. Reprinted by permission.) Several inaccuracies in this illustration were later pointed out by many investigators. The direction of the combined force of the temporalis muscle is incorrect—it should be directed more vertically. Secondly, the direction of the combined force of the masseter and medial pterygoid muscles is also incorrectly determined. Robinson positioned this force too far anteriorly relative to the tooth row. The force of the superficial masseter might pass through the third molar in some individuals; however, when the muscle force of the deep masseter and medial pterygoid are added to it, the resultant must pass posterior to the tooth row (because the central fibers of these two muscles are positioned well posterior to the tooth row). In this diagram, the anterior root of the zygoma lies over the premolars. Normally this structure lies over the first and second molars. In addition, Robinson shows the incisors lying vertical and slightly posterior to the medial margin of the orbit, instead of vertical and anterior to the orbit. Robinson’s non-lever action theory of the mandible is therefore untenable, because the dental arcade is incorrectly positioned and the combined temporalis muscle force is incorrectly determined.

that the joint was not well-suited to bear functional stresses. The lack of hyaline cartilage, lack of vascularity to much of the joint, and paper-thin bone of the fossa roof all convinced him that the TMJ was not structurally equipped to bear compressive forces. Because of Robinson’s esteem within the dental profession and the specialty of oral surgery, and the confusion in the literature, his (and Wilson’s) concept of an unloaded TMJ was propagated for many years thereafter. Others similarly believed the position that the TMJ is a nonloaded joint.⁴¹⁻⁴⁴

Later, evidence to refute the concept of an unloaded TMJ began to emerge (see Hylander,⁴⁵ for a thorough discussion). In 1955, Roydhouse⁴⁶ showed that the contention of Wilson^{38,39} and Robinson⁴⁰ that the muscle resultant force passes through the bite point (thus obviating a reaction force at the TMJ) is misleading because this is only a special case of

numerous combinations of bite point and muscle vectors, most of which do not result in bite force and muscle resultant vectors with equal magnitudes, opposite directions, and identical lines of action necessary to avoid a balancing force at the condyles. Other inaccuracies were also revealed.⁴⁵ Not surprisingly, many investigators felt that the TMJ is a heavily loaded joint.⁴⁷⁻⁵¹ However, there was no good evidence for either position until the 1960s.

In 1966, Moffett⁵² showed that the reason the mandibular condyle was lined by fibrous tissue instead of hyaline cartilage was because of the embryologic origins of the joint: the fibrous tissue develops from the mesenchyme that intervenes between the separate blastemata that will become the condyle and temporal component. Hence, this feature in and of itself should not be construed as an indication of the functional capability of the joint.⁵³ In addition, Moss and Moss-Salentijn⁵⁴ argued that fibrous tissue and fibrocartilage are better suited to withstand shearing forces than hyaline cartilage, a useful capability in a joint in which the condyle slides along the articular eminence under load. In 1978, Hylander and Bays⁵⁵ showed appreciable levels of bone strain in the condylar neck region of monkeys during both incisal biting and molar chewing. By inference, they concluded that compressive force in the condylar neck during function must indicate loading of the mandibular condyle. Using similar methodology in the minipig, Marks et al⁵⁶ also showed strain during the occlusal phase of mastication, with higher strain on the balancing side than the working side. Using different methodology, Brehnan et al⁵⁷ implanted piezoelectric foil into the TMJ of a monkey and recorded maximum loads of 1 to 3 lb during molar chewing and 3 to 4 lb during incisal biting. A later study from that laboratory using similar but improved technology in the TMJs of monkeys showed loading of the mandibular condyle during incisal biting, chewing, and aggressive behaviors. The forces ranged as high as 17.7 kg, which far exceeded the 4-pound range reported in the previous article from this laboratory.⁵⁷

A host of biomechanical and finite element models have been designed over the past 20 years, some using electromyographic and bite force data, which suggest that the joint is loaded under certain, if not most, functional activities.^{45,57-81} A host of clinical and microscopic examinations of normal adult condyles and articular discs also suggest that the TMJ is loaded during function.⁸² Indirect evidence for loading also comes from the prevalence of articular disk perforations within the TMJ. Today, most investigators conclude that the TMJ is loaded during many functional activities. The controversy that now rages is over the magnitude of the loads.

What does this mean for treatment of condylar fractures? The most meaningful inference from the finding that the TMJ bears at least some loads is that re-establishment of a temporomandibular articulation may be advantageous. However, it is impossible to say, with the data presently available, whether it is preferable to perform open reduction (ie, immediate reconstruction), or allow adaptations within the masticatory system that will re-establish a new articulation.

DOES THE TMJ HAVE TO BE A STRESS-BEARING JOINT?

Biomechanical analysis shows that as the position of the bite force is placed further posteriorly along the dental arch, more of the muscular force producing the bite is directed to the teeth and less is directed to the joint.⁸³ During biting on the most posterior teeth it is even possible to eliminate all compressive loading of the TMJ on the biting side.^{37,72,84} However, it is impossible to eliminate compressive loading on both joints simultaneously, ie, the joint opposite the biting side always experiences a compressive load. When biting at more anterior tooth positions, both joints will experience a compressive load.³⁷

One strategy used by almost all patients with damaged or diseased TMJs is a reduction in the amount of occlusal force used.^{30,85,86} The exact magnitude of the compressive load on each joint can be further altered by changing the relative activity levels among the various jaw closing muscles,⁷² but in normal individuals the activity patterns are not altered enough to eliminate compression on the working-side joint.^{84,87} Recordings of muscle activity patterns in patients without a functional joint (whether through fracture, condylectomy, or congenital absence) indicate that these patients do alter their muscle activity enough to protect the missing or damaged joint from compressive loads.

DOES THE TMJ GUIDE MANDIBULAR MOVEMENT?

In addition to transmitting forces between the mandible and skull, the TMJ also plays a role in controlling jaw movements. Injury or joint disease does not always limit the amount of mouth opening,⁸⁸ apparently because condylar rotation can compensate for limited condylar translation during mouth opening.^{89,90} But disease and injury do limit mandibular protrusion and lateral excursions⁸⁸ because these movements are more dependent on condylar translation.⁹¹ In addition, limited condylar translation may introduce excessive lateral deviation during opening.⁹² Thus, the TMJ does help guide mandibular movements. Aberrations within the TMJ can alter mandibular movement, which usually manifest as limiting certain excursions (see below). Whether or not

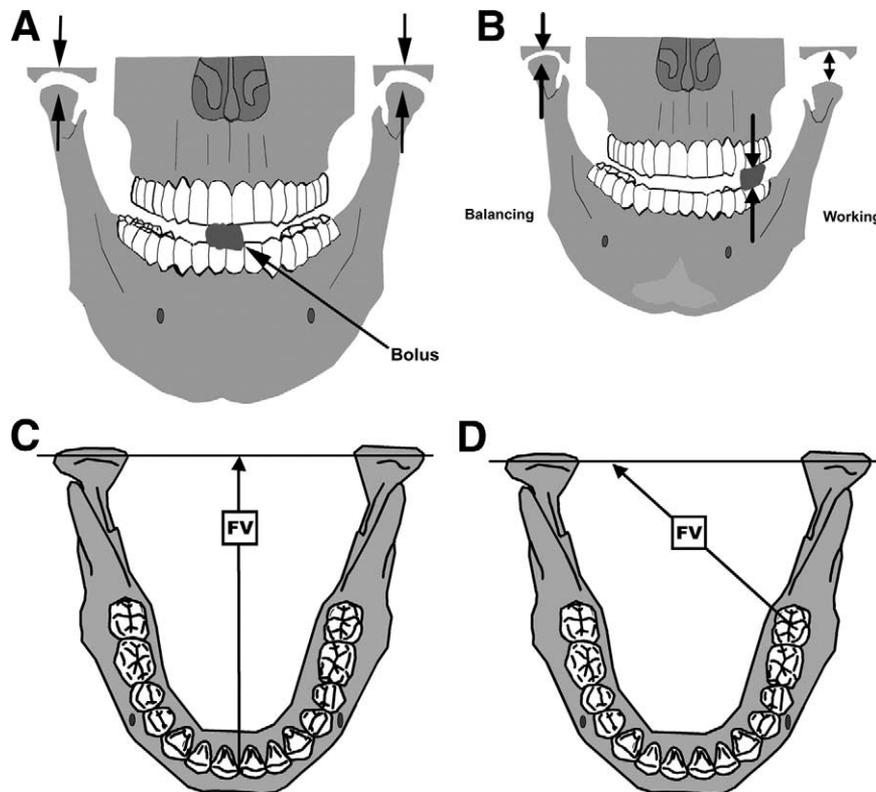


FIGURE 5. Illustrations showing relative loading of the TMJs biting at the incisors or the molar. When biting at the incisor, the joints are loaded equally (A). When biting at the molar, the opposite, balancing side joint is loaded more heavily than the working side joint (B). C and D, Illustrations demonstrating relative joint loading in axial cross-section. The relative joint loading can be determined by where a line connecting the bite point with the mean force vector (FV) of all the elevator muscles intersects with the intercondylar axis. If the elevator muscles function equally, the mean force vector (FV) is located in the midline. When biting at the incisor (C), the joints are then loaded equally. When biting at a molar (D), the opposite, balancing side joint is loaded more if the mean force vector is still located in the midline. In most individuals, the mean force vector shifts somewhat toward the working side so that the balancing side is not loaded as heavily as it otherwise would. However, it is still more heavily loaded than the working side joint.

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open treatment will normalize functional movements has not been thoroughly established.

HOW DOES ONE FUNCTION WHEN ONE TMJ IS DAMAGED?

The fractured mandibular condylar process provides a unique look into how the masticatory system functions with a damaged TMJ. Under normal circumstances, when one bites on the left molar, the right (contralateral or balancing side) TMJ bears more load than the left (ipsilateral or working side) TMJ (Fig 5).^{72,84,87} If the right TMJ were injured, one way to reduce loading it when biting on the left molar would be to selectively increase left masseter activity and selectively decrease right masseter activity.^{72,87} Doing so produces greater loading of the left, uninjured TMJ (Fig 6A). In contrast, when biting on the right (ipsilateral or working side) molar, alteration of the muscle activity ratio is not necessary because the normal left-side joint carries the greater load (Fig 6B).

It has been shown in patients treated for unilateral condylar process fractures that the maximum bite forces

that can be generated are much less than control samples can generate.³⁰ It has also been shown that when biting on the fracture-side molar, masseter electromyogram (EMG) ratios were essentially normal, with equal amounts of electrical activity in both masseter muscles.³⁰ When biting on the nonfracture-side molar, the working side masseter muscle was 1.5 times more active than the masseter on the balancing side. This finding occurred irrespective of whether the patients were treated open or closed and is consistent with the concept that a variety of muscle activity patterns can be used to generate a given submaximal bite force.⁹³⁻⁹⁵ Although these patients were asked to generate a maximal bite force, discomfort probably inhibited maximum exertion of their jaw muscles. Therefore, at submaximal muscular effort these patients could modify muscle recruitment to limit loading of the fracture site. One can postulate that changing the working/balancing EMG ratios is the physiologic response to prevent loading of a damaged part of the skeleton, in this case the condylar process.

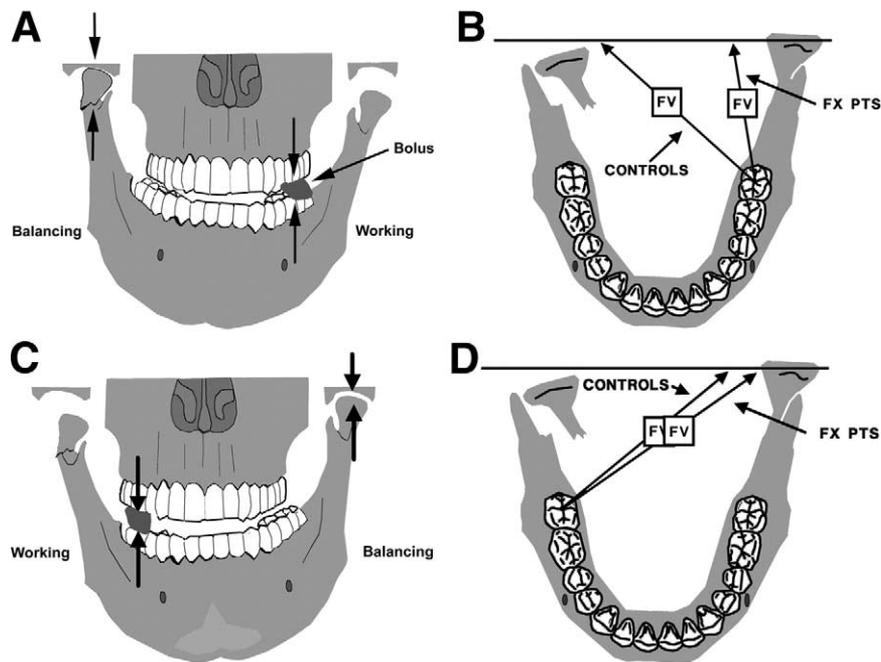


FIGURE 6. Illustrations showing what happens with unilateral condylar process fracture. When biting on the side opposite the fracture, the fractured joint would be expected to be loaded more than the nonfractured side joint (A). However, it has been demonstrated that in patients with such injuries, the mean force vector moves toward the uninjured side so that the relative loading of the damaged joint is reduced (B). This occurs by selective increase in the muscles on the nonfractured side and a selective decrease in activity of muscles on the fractured side. When biting on the fractured side (C), one would normally expect that the uninjured joint would have most of the loads. There is less need for neuromuscular compensations to occur in this instance because the major loads would occur to the uninjured joint, not the fractured joint (D).

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Open reduction and internal fixation of the condylar process fracture might be expected to allow normal loading of the fracture site when biting on the side opposite the fracture; avoiding the neuromuscular adaptations discussed above. Indeed, it was found that patients treated open did tend to have a lower working/balancing ratios than patients treated closed, suggesting less neuromuscular adaptation to protect the fracture site.³⁰

Another functional component of the masticatory system that could be hindered by a condylar process fracture is mandibular mobility and asymmetrical motion. With fracture, the normal translation and rotation of the mandibular component of the TMJ can be upset. Further, the action of the lateral pterygoid muscle may no longer exert its action on the distal portion of the mandible, resulting in deviation toward the site of fracture when the mouth is opened. Several studies have shown dramatic differences in the amount of lateral deviation on opening and protrusive excursion after patients were treated closed for condylar process fractures.^{9,10,92,96-102} For example, Silvennoinen et al¹⁰¹ found 30% of their condylar process fractures treated closed had persistent deviation on opening.

However, most studies that have noted deviation on opening after closed treatment of condylar process

fractures have used a period of MMF as part of the treatment. A study by Palmieri et al²² found that patients treated closed, on the average, deviated toward the side of fracture, but the average amount of deviation was less than 2 mm at most time periods. Patients treated open had less deviation on opening and the average deviation was usually toward the nonfractured side. A statistically significant difference was found at 3 of 5 time periods for deviation on opening, but the actual magnitudes of the deviations were, on the average, small. No statistically significant difference was found between the 2 treatment groups for deviation on protrusive excursions. A possible reason why there was not more lateral deviation on opening for patients treated closed is that no postsurgical MMF was used. The combination of a damaged condylar process and immobilization may cause a cicatricial reduction in condylar translation, resulting in deviation toward the side of fracture on opening or in protrusion. The orthopedic literature is replete with studies demonstrating if there is injury to intra-articular structures, the optimum condition for articular repair is by active or passive motion of the joint.^{103,104} Conversely, immobilization of a damaged joint leads to degeneration of the articular surfaces and development of fibrous adhesions, limiting mobility.¹⁰³⁻¹⁰⁷

What are the consequences of a condylar process fracture for the patient? Lindahl's studies show persistent symptoms of dysfunction of the masticatory system (eg, clicking, pain, deviation on opening) to occur frequently in adults but rarely in children with condylar fractures.¹⁰⁸ It has been shown that closed treatment of condylar fractures results in centric relation-centric occlusion discrepancies,^{92,97,108,109} but it is unclear if this ever becomes a clinical problem.

Depending on what one considers "dysfunction," the rates vary widely in the literature, from "none" to 85% for dislocations.^{1,92,96,110-132} Intracapsular fractures seem to produce the highest incidence of dysfunction (when treated closed).¹³² Hlawitschka and Eckelt¹³² found moderate to serious limitations in all directions of excursion and nonphysiologic condylar paths compared with the nonfractured contralateral side. The reduced range of condylar excursions was not surprisingly because of a reduction in translation of the condyle and an increase in rotation. Some have shown that patients with unilateral condylar fractures will chew on one side.^{114,115,133,134} This has been thought to cause the development of TMJ dysfunction on the contralateral, nonfractured joint.^{114,115,120,121,124,130}

Mastication is a more natural function than maximum bite force or excursive ranges, and therefore, changes in daily mastication might be of greater concern to fracture patients. Because normal mastication involves both open-close and lateral movements, it might be substantially altered by disruption of the condyle and lateral pterygoid muscles.

Our recent study of 81 male patients with condylar process fractures revealed a number of important postfracture changes in the chewing cycle.¹³⁵ First, patients chewed more slowly following the fracture. The increased duration occurred during both opening and closing, regardless of chewing on the fracture or nonfracture side, and persisted for at least 2 years after the fracture. The method of treatment (open or closed) had very little effect on this slowing of the chewing cycle.¹³⁶

The amount of opening during mastication was initially reduced in the fracture patients, but returned to near-normal values within 6 months. Lateral excursion during chewing showed the biggest changes. While the chewing on the right or left side resulted in nearly identical cycle shape in controls, the fracture patients' cycles were quite different between fracture-side and nonfracture-side chewing.¹³⁵ After the fracture, patients had significantly more excursion toward the balancing side during opening and significantly less excursion toward the working side during closing, especially when chewing on the side opposite the fracture (Figs 7, 8).¹³⁵ In general, these changes were greater and more persistent in patients treated closed.¹³⁶ Even 2 years after treatment, the

patients had a chewing cycle that was centered more over the midline than normal when chewing on the side opposite the fracture, suggesting limited anterior translation of the fractured condyle. Similar changes in chewing patterns have been reported in patients with unilateral internal derangements.¹³⁷⁻¹⁴⁰

Movement during opening may be affected more than closing because opening is controlled by the temporomandibular ligaments¹⁴¹ and lateral pterygoid muscles,^{141a} which are more likely to be disrupted by the fracture. In contrast, jaw closing is primarily controlled by the jaw closing muscles, and these are less likely to be damaged by a condylar process fracture. Interestingly, surgically restoring the condyle to its initial position does little to alter these changes in chewing patterns.¹³⁶ Perhaps more attention needs to be made to restoring the integrity of the TMJ ligaments and function of the lateral pterygoid muscles.

HOW DOES ONE FUNCTION WHEN BOTH TMJs ARE DAMAGED?

Bilateral fractures of the mandibular condylar processes create a major aberration for the masticatory system. For normal function to be restored in patients with bilateral condylar process fractures, what type of changes, if any, can one expect to find in mandibular range of motion, bite force, and muscle activity? The results of a study in 22 patients treated either open or closed for bilateral condylar process fractures showed similar adaptations to those found in patients with unilateral condylar process fractures insofar as there is a reduction in the amount of condylar movement^{22,102} and muscle activity^{30,109} during the first few months after fracture.¹⁴² That study also showed that bite force for bilateral fracture patients is reduced during this same interval.¹⁴²

An analysis of masticatory patterns in this same sample of patients showed that the opening cycle was achieved with reduction of anterior translation of the condyles when compared with controls.¹⁴³ Patients also had narrower chewing cycles, with significantly lower adductor muscle activity during the closing phases of mastication. By 1 year, however, masticatory patterns normalized.

In summary, is a temporomandibular articulation necessary/advantageous? Yes! For the masticatory system to function efficiently and maximally, a cranio-mandibular articulation is necessary. Whether or not this must be in the form of a ginglymoarthrodial joint or whether a simple hinge joint is adequate is unclear. It is also unclear whether open treatment would provide a more effective temporomandibular articulation than closed treatment.

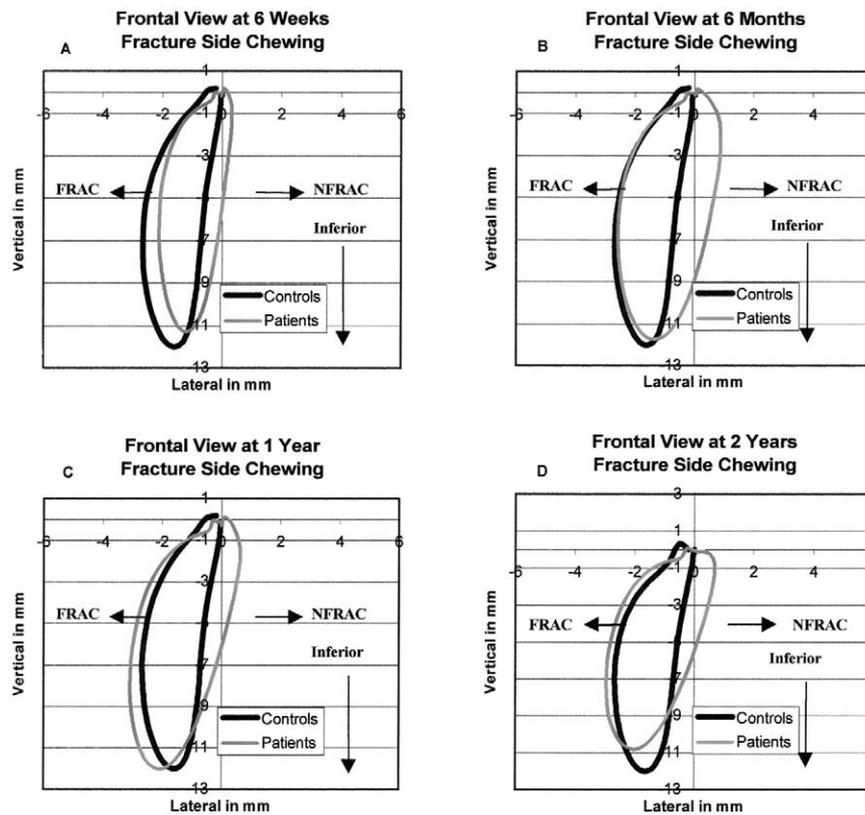


FIGURE 7. Frontal pathways of incisor movement when chewing on the same side as the condylar process fracture by controls and patients at 4 time intervals after treatment. A, 6 weeks; B, 6 months; C, 1 year; D, 2 years. (Reprinted from Throckmorton et al.: Jaw kinematics during mastication following unilateral fractures of the mandibular condylar process. *Am J Orthod* 124:695, 2003. © 2003 with permission from The American Association of Orthodontists.)¹³⁶

With Nonsurgical Treatment, Does Re-Establishment of a Temporomandibular Articulation Occur? How?

There is no doubt that with fracture of the condylar process comes a complex series of adaptations that attempt to restore an articulation to facilitate masticatory function. These adaptations begin immediately after injury, but differ somewhat in their timing and importance. There are 3 main types of adaptations that occur: 1) neuromuscular adaptations; 2) skeletal adaptations; and 3) dental adaptations.

NEUROMUSCULAR ADAPTATIONS

Bilateral fractures of the mandibular condylar processes, especially those that are displaced, pose the greatest challenge to the clinician and to the masticatory system. Clinical investigations in patients treated closed show that many such injuries result in unsatisfactory occlusal results.^{99,132,144,145} Anterior open-bite malocclusion is the malocclusion that results when treatment is either not instituted or is unsuccessful.

How can one ever achieve normal occlusion with bilateral displaced condylar process fractures? If the

mandible functions as a class III lever system, as demonstrated for at least the power stroke of mastication, then loss of the fulcrum (ie, TMJ) should cause posterior collapse and premature contact of the terminal molars, creating an anterior open bite (Fig 9). While this happens in many and perhaps most patients, it does not occur in all. Some patients have the remarkable ability to bring their teeth into the proper occlusal relationship soon after injury, even without any treatment. How is this possible?

Perhaps the most fascinating adaptation that occurs within the masticatory system follows bilateral fractures of the mandibular condylar processes. For individuals with this injury to be able to obtain a normal occlusal relationship, neuromuscular adaptations are called into play to position the mandible early after injury. At this time, there is no articulation with the temporal bone to provide vertical skeletal support for the posterior ramus. Thus, the only mechanism whereby the mandible can be positioned into a normal occlusal relationship early after injury is by complex neuromuscular adaptations in the muscles of mastication. It has been shown that individuals with bilateral condylar process fractures selectively in-

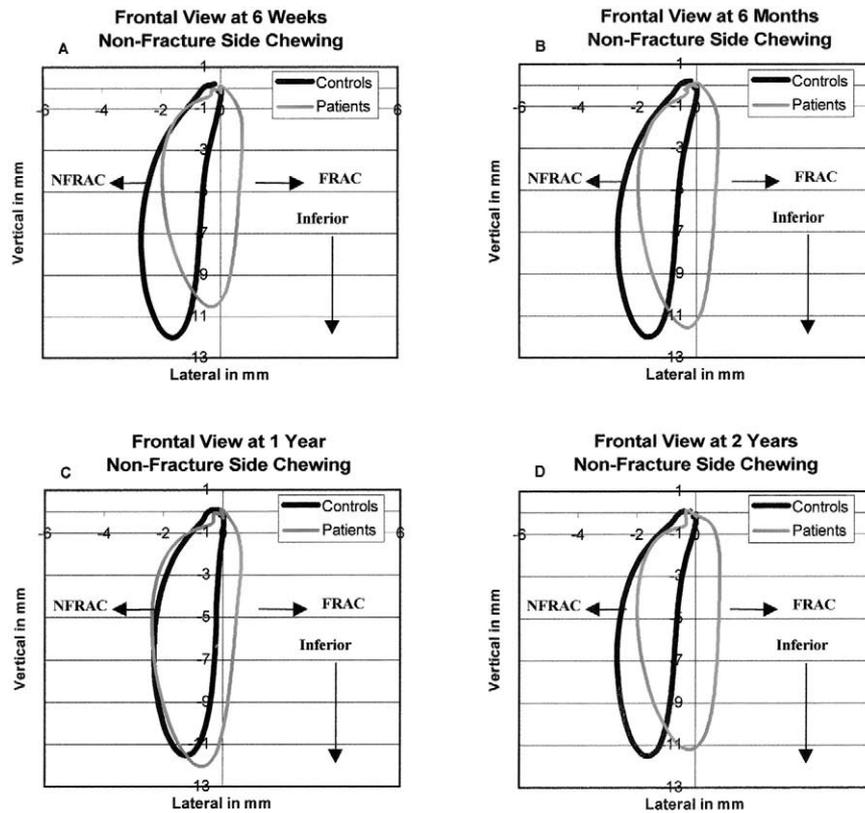


FIGURE 8. Frontal pathways of incisor movement when chewing on the side opposite the condylar process fracture by controls and patients at 4 time intervals after treatment. A, 6 weeks; B, 6 months; C, 1 year, D, 2 years. (Reprinted from Throckmorton et al: Jaw kinematics during mastication following unilateral fractures of the mandibular condylar process. *Am J Orthod* 124:695, 2003. © 2003 with permission from The American Association of Orthodontists.)¹³⁶

crease the EMG output in the posterior temporalis fibers.¹⁴² The effect of this increased activity is to provide a posteriorly directed vector onto the coronoid process, which, all other things being equal, can rotate the anterior portion of the mandible superiorly, bringing the incisors into contact (Fig 10).

While such neuromuscular adaptations are variable in magnitude and effectiveness among patients, it is expected that even when neuromuscular adaptations are optimal, they will not allow generation of much biting force at the incisors because of the extreme inefficiency of a system when the posterior skeletal articulation is

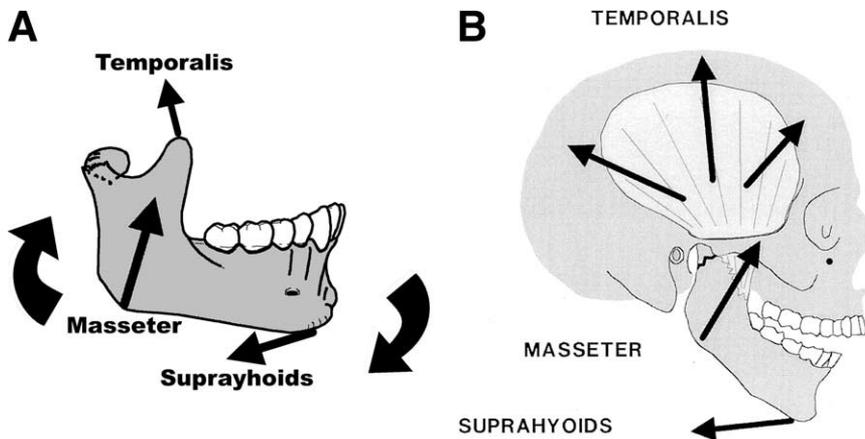


FIGURE 9. Free-body (A) and lateral skull (B) diagrams showing that the mandibular elevators combined with the suprahyoid muscles will usually cause loss of posterior vertical dimension when a fracture of the condylar process occurs.

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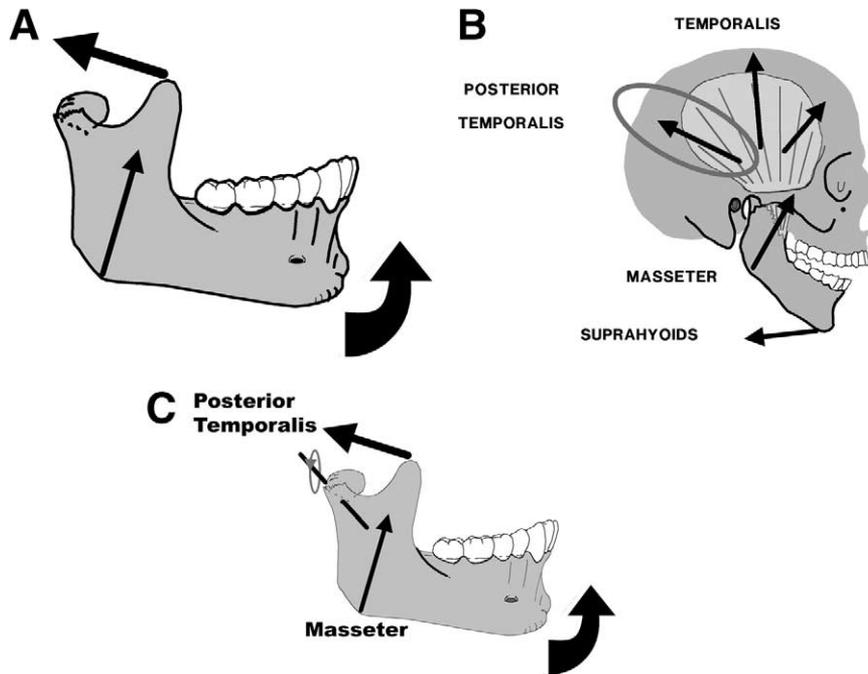


FIGURE 10. Free-body (A) and lateral skull (B) diagrams showing that with selective contraction of the posterior temporalis muscles and minimal activity within the elevators and suprahyoids, the mandible can rotate “closed.” An axis of rotation is created somewhere within the ramus to allow this to occur (C).

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compromised. However, neuromuscular adaptations can be considered early, short-term adaptations that assist in positioning the mandible until a new skeletal articulation has been re-established. Ingervall and Lindahl¹⁰⁹ have shown in several patients with condylar process fractures that after some time has passed and a new articulation has developed, EMG activity in the muscles of mastication normalizes. These patients no longer demonstrated any difference from controls, and no difference in EMG activity was found from the side of fracture to the nonfractured side. Hjorth et al¹⁴⁶ similarly showed that most of the muscles in patients treated for condylar process fractures normalized with time, although some asymmetry of the masseter muscles occurred even after up to 1 year. Ellis and Throckmorton³⁰ showed asymmetry of EMG values when biting on the side opposite the fracture that continued for at least 1 year (Fig 11), with greater asymmetry in the patients treated open (Fig 12). There was a trend toward normalization in the patients treated open. Talwar et al¹⁴² showed that patients with bilateral fractures showed abnormal (but not asymmetric) activity initially, but were significantly different from controls only at the 6-week and 6-month intervals.

SKELETAL ADAPTATIONS

A slowly developing adaptation that occurs within the masticatory system after condylar process fracture is the development of a new temporomandibular ar-

ticulation. This adaptation begins immediately after injury and continues for many months afterward. A new articulation between the temporal bone and the mandible provides a “fulcrum” so that the mandible can again function as a class III lever system during some functional activities, which increases its efficiency.

There are 3 concurrent methods by which a new temporomandibular articulation occurs: condylar re-

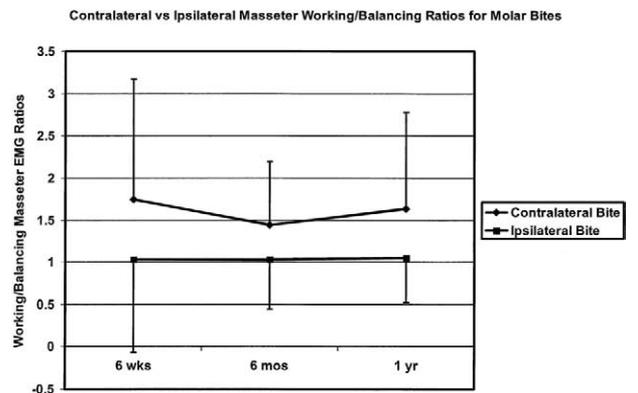


FIGURE 11. Graph showing working/balancing masseter EMG ratios for entire sample when biting on the contralateral and ipsilateral molars (in relation to side of fracture). The differences were significant at the P < .001 level at each time point. Error bars are 1 standard deviation. (Reprinted from Ellis E, Throckmorton GS: Bite forces after open or closed treatment of mandibular condylar process fractures. *J Oral Maxillofac Surg* 59:389-395, 2001. © 2001 with permission from the American Association of Oral and Maxillofacial Surgeons.)³⁰

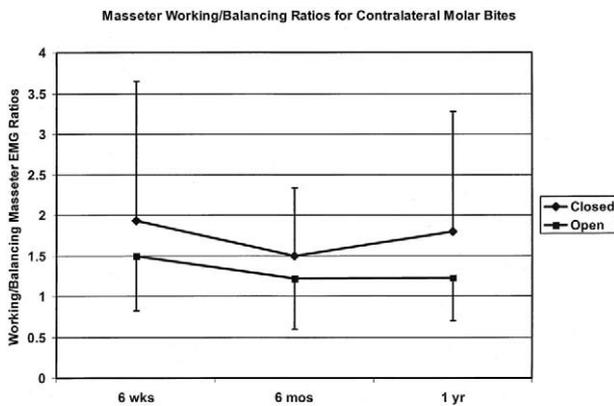


FIGURE 12. Graphs showing working/balancing masseter EMG ratios for the two treatment groups when biting on the contralateral (A) molar (in relation to side of fracture). The differences between the treatment groups were not statistically significant ($P > .05$). Error bars are 1 standard deviation. (Reprinted from Ellis E, Throckmorton GS: Bite forces after open or closed treatment of mandibular condylar process fractures. *J Oral Maxillofac Surg* 59:389-395, 2001. © 2001 with permission from the American Association of Oral and Maxillofacial Surgeons.)³⁰

generation, changes in the temporal component of the TMJ, and loss of posterior vertical dimension. Condylar regeneration is the most robust of the skeletal adaptations and is responsible for the majority of the development of a new temporomandibular articulation. The extent of condylar regeneration has been shown to be extremely variable, and seems to be age- and therapy-related.

Lindahl and Hollender¹⁴⁷ radiographically demonstrated the ability of a new condylar process to regenerate after closed treatment of condylar process fractures. They showed that individuals who were young at the time of injury could almost completely regenerate a new condylar process. They called this adaptation “restitutional” remodeling, indicating that a completely new condylar process of normal morphology was re-created. However, with advancing age at the time of injury, the condylar process had less robust remodeling ability and the regenerated condylar process has atypical morphology, even years later. They called this “functional” remodeling, indicating that the condylar process looked abnormal even though it might function very well. Others have shown the same age-related skeletal adaptations.^{1,92,96,97,99,109,115,118,123,128,129,147-176}

Biological reasons why condylar remodeling is age-related have been elucidated in several animal investigations. It has been shown that when condylar cartilage is present, growth-related adaptations to either protrusive function or to condylar fracture and dislocation is robust. Condylar cartilage is only predictably present in younger individuals. The condyles in the young have a characteristic cartilage cap with a fibrous articular tissue. The adult condyle is characterized by a bony cortical cap covered by a fibrous articular tissue. Protruding

the mandible by using a functional appliance causes hypertrophy of the posterior surface of the condylar cartilage in animals where cartilage is present (Fig 13). Similarly, when the condylar process is fractured and dislocated, the condylar cartilage becomes hypertrophic. In adult animals where little cartilage is present, the remodeling and regeneration capabilities are diminished (Fig 14).¹⁷⁷⁻¹⁸²

The ability of a new condyle to regenerate also has some relationship to the treatment provided. Open reduction of the condylar process eliminates the need for extensive remodeling, although some may occur and depends on the accuracy of reduction, stability of the fixation, and the amount of devascularization that might have occurred during the surgery. Closed treatments also affect the extent to which a new condylar process will regenerate. It has been shown that physiotherapy provides a more favorable environment for condylar regeneration than immobilization of the jaw.^{97,99,183}

The newly formed temporomandibular articulation may or may not be another synovial joint. In the most

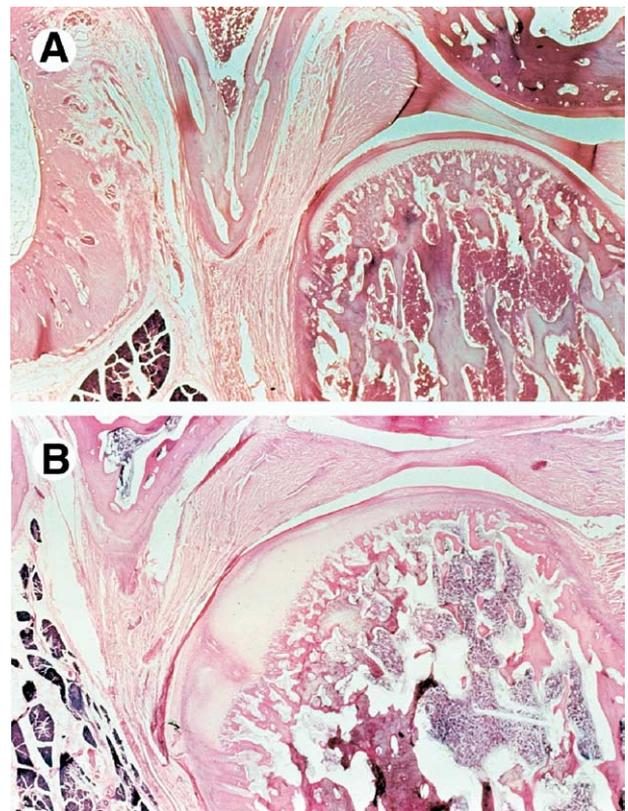


FIGURE 13. Illustrations showing the effect of anterior displacement of the condyle in young monkeys. A, right TMJ in a control (untreated) monkey. Note the uniform thickness of the condylar cartilage. B, right TMJ of a monkey 6 weeks after insertion of a mandibular protrusion appliance. Note the hypertrophy of the condylar cartilage.

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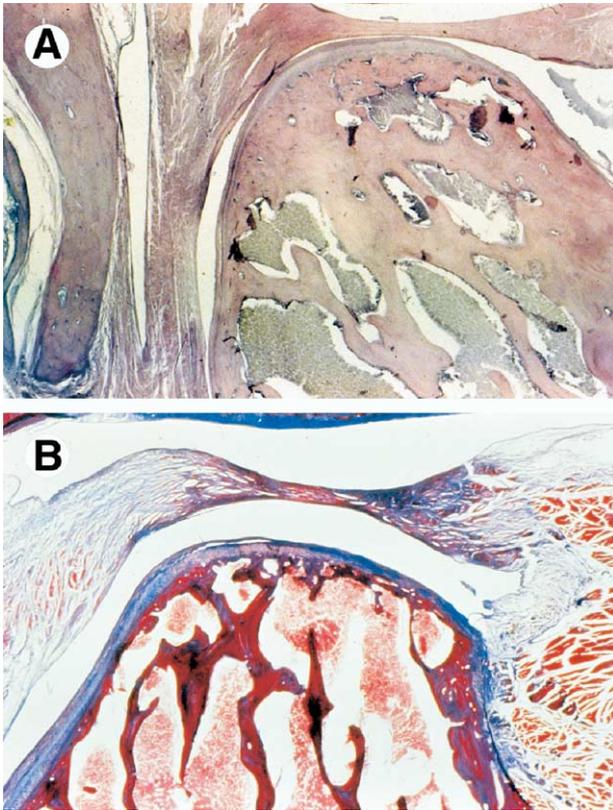


FIGURE 14. Illustrations showing the effect of anterior displacement of the condyle in adult monkeys. *A*, Right condyle in a control (untreated) monkey. Note the lack of condylar cartilage in this adult specimen. *B*, Right condyle of a monkey 8 weeks after insertion of a mandibular protrusion appliance. Note that there is no obvious change from the control *A* in this adult specimen.

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ideal circumstance, a joint with a synovial lining and the ability to both rotate and translate results. This occurs in perhaps the majority of cases, depending on the severity of the injury and the functional rehabilitation provided. However, it has been shown that some of the newly developed temporomandibular articulations function with rotation but little, if any, translation.

Another skeletal adaptation that occurs along with condylar regeneration is a change in the mandibular fossa of the temporal bone. Radiographic studies have shown that the mandibular fossa begins to fill in with osseous tissue after closed treatment of condylar process fractures.¹⁴⁷ One could consider this skeletal adaptation the creation of a temporal surface that is more inferiorly positioned so that less condylar regeneration is necessary for a new articulation to form. Often, the new temporomandibular articulation is more anteriorly located, often at the base of the articular eminence. This also results from the inability of the condylar process to totally regenerate and reach the depth of the mandibular fossa.

Another robust adaptation that occurs in concert with the above skeletal adaptations is a superior movement of the mandibular ramus. Loss of posterior vertical dimension has been demonstrated within 6 weeks after closed treatment of condylar process fractures.^{28,142} One could consider that the superior movement of the ramus an adaptation that promotes the creation of a new temporomandibular articulation by bringing the fractured condylar stump closer to the temporal bone. This would make total condylar regeneration less necessary. Although one might not desire this adaptation because of the possibility that there might be an esthetic disadvantage, it nonetheless is a very powerful skeletal adaptation in the creation of a new articulation.

DENTAL ADAPTATIONS

Adaptations that occur in concert with the skeletal adaptations just described are within the dentoalveolus. With closed treatment of condylar process fractures, extrusion of the incisors and intrusion of the molars has been demonstrated.¹⁴⁵ This should not be surprising because as the ramus moves superiorly to assist in the re-establishment of a new temporomandibular articulation, the only way this can happen without a malocclusion developing is for the molars to intrude and the incisors to extrude. This is especially common in patients treated closed with bilateral fractures of the mandibular condylar processes. In these patients, there is a strong tendency for an anterior open bite occlusal relationship to develop. The ramus moves superiorly and the chin moves inferiorly with premature contact of the terminal molars. It has also been shown that the mandibular plane angle increases with closed treatment in these patients.¹⁴² When elastics are applied to the anterior teeth during treatment, the incisors extrude and the molars intrude. Therefore, given the skeletal adaptations that are occurring, dental adaptations are necessary for maintenance of the normal occlusal relationship.

Conceivably, open reduction and internal fixation of the fractured condylar process would obviate the necessity for these neuromuscular, skeletal, and dental adaptations. In fact, it has been shown that there is less loss of posterior vertical dimension and dental adaptations with open treatment.²⁸ Studies have also shown that there is less remodeling of the condylar process after open treatment, presumably because the articulation is re-established surgically.^{19,20,184}

Is MMF Necessary/Desirable?

If one peruses the literature on this topic, there are 2 main treatments advocated when performing closed treatment: 1) a period of MMF followed by functional

therapy; and, 2) functional therapy without a period of MMF. Why are there 2 main closed treatment methods that are so diametrically opposed? The reason seems to be based solely on tradition and experience.

As early as 1805, Desault¹⁸⁵ wrote: "It is important to restore contact of the fragments. Union might fail if the slightest movement of jaw occurs. If there is no contact, the callus produced might render the condyle irregular and deformed, which will impede function." Others agreed that bone contact between the condylar head and ramus is very important,^{112,148,166,186-189} and have inferred that immobilization to allow bony union was necessary.

Varying periods of MMF for condylar fractures have been suggested in the literature.^{3,7,9,13,116,129,185-204} However, the duration of MMF that is recommended ranges from no MMF by some authors^{192,199,203,206} to "until the fracture heals" or up to 6 weeks by others.^{129,185,190} For instance, Converse¹⁹⁸ indicated that the occlusion must be maintained by MMF until fibrous union of the fractured fragments is established. How can there be this disparity in opinion about the duration of MMF necessary for a good outcome when treating condylar process fractures closed?

If one reviews the many articles on this topic, one finds that a period of MMF is instituted for 3 main reasons: 1) to make the patient more comfortable; 2) to promote osseous union; and, 3) to help reduce the fractured fragment. A thoughtful analysis of all 3 of these suggestions shows that they are all unsubstantiated. For instance, does placing the patient into MMF make them more comfortable? It is unusual to have a patient ask to be immobilized because of pain. In fact, most wish to *not* be placed into MMF. The ability of MMF to help promote osseous union has also never been substantiated in the literature. The thought that the condylar process will not heal to the ramus unless the mandible is immobilized has also never been proven. It is indeed rare to see nonunion after a condylar process fracture, even in patients who do *not* undergo a period of MMF. If MMF were necessary for osseous union, then 5 to 6 weeks would be needed just as it is for other fractures of the mandible. Most surgeons who use a period of MMF for condylar process fractures do not recommend using that duration. It is therefore unlikely to assume that using MMF promotes osseous union. Studies in animals support the finding that condylar process fractures heal irrespective of whether they are immobilized.^{162,182} The ability of mandibular immobilization to help reduce the fracture is also suspect, unless one uses the principle of the hypomochlion, where a spacer is placed between the posterior dentition and the patient is then placed into MMF.^{111,124,145,157,190,206-213} The inferior distraction of the mandibular ramus may help to "upright" a displaced condylar process fracture, but this

technique also has been shown to cause extrusion of the incisors and intrusion of the molars.¹⁴⁵

Early mobilization of the jaw and functional rehabilitation is considered important by many surgeons.^{192,199,205,214-216} Amaratunga²¹⁷ showed that mandibular hypomobility is directly related to the duration of MMF after mandibular fractures. A technique that has been used by some surgeons for fractures of the condylar process involves functional therapy, avoiding immobilization, encouraging good mobility of the mandible in as short a time as possible. Avoiding MMF allows one to institute physiotherapy from the outset and helps the patient achieve their pretraumatic range of motion sooner than when a period of MMF is used. There are several ways one can treat patients with functional therapy, including the use of elastics to guide the occlusion^{192,205,216} and/or the use of activators/functional positioning devices.^{97,199} Most investigations show that this treatment provides equivalent occlusal results as when a period of MMF is instituted. Therefore, there is no compelling reason to use MMF when treating fractures of the condylar process by closed techniques.

Is Open Reduction and Internal Fixation of Condylar Process Fractures Biologically Sound?

Enthusiasm for open treatment of condylar process fractures has increased over the past 20 years with the wide availability of plate and screw fixation systems. While there may be good reasons to perform this surgery, a prerequisite is that it can be safely performed. With any skeletal fracture, the biology of the components must be understood to assure that one can reduce the fracture and provide stability to the components without undue harm. As early as 1943, Berger²¹⁸ warned that open reduction and internal fixation of condylar process fractures using wires would cause infection and/or necrosis of the condylar fragment. However, similar problems were mentioned about using internal wire fixation for fractures of other portions of the mandible.^{219,220} On the opposite extreme of this argument are individuals who believed that the condyle can, if necessary, be used as a free bone graft.^{3,6,112,148,187,221-227}

To determine whether or not open treatment of condylar process fractures is biologically sound, one must first determine: 1) the blood supply to the condyle, and 2) whether or not the blood supply is essential to open treatment.

WHAT IS THE BLOOD SUPPLY TO THE CONDYLE?

There have been many investigations performed to determine the vascular supply to the condyle.²²⁸⁻²³⁶ Different methodology has yielded similar findings.

The TMJ as a whole is supplied by a very rich plexus of vessels that runs throughout the tissues of the area. There are vessels of assorted sizes and it is difficult to determine which nearby major vessel provides the largest contribution. Every named vessel within 2 or 3 cm gives off 1 or more articular branches. The density of the plexus increases as the articular surfaces are approached.

Concerning the condyle itself, its blood supply is mostly derived from 3 sources. A branch of the inferior alveolar artery courses upward through the neck of the condylar process, where it anastomoses liberally with vessels from the attached musculature. Another major component to the condyle and its articular surface is derived from the TMJ capsule, with its lush vascular plexus. There is also a large contribution of blood supply from branches of the lateral pterygoid muscle through its attachment at the pterygoid fovea. Of these 3 sources, the medullary blood supply from a branch of the inferior alveolar artery was found to be the most important source in monkeys²³³ and presumably in man.

Fracture of the subcondylar or neck region of the condylar process could therefore disrupt the main vascular supply to the condyle. There are several ramifications to this alteration in blood supply. First is the maintenance and/or re-establishment of sufficient blood supply to confer viability to the condyle and its surrounding tissues. It has been shown that when the inferior alveolar artery is occluded at the mandibular foramen in monkeys, retrograde blood flow from other surrounding vessels occurs throughout the mandible.²²⁸ It is therefore likely that with disruption of the medullary source of blood supply, the other sources of vasculature that normally contribute to the condyle (capsule, lateral pterygoid muscle) become more active and essential to its viability. Such hypervascularity from surrounding vessels has been demonstrated in the condyles of monkeys after vertical ramus osteotomies.²³⁴

There is another ramification of the loss of medullary blood supply from fracture of the condylar process. Surgical access to the condylar process to perform open reduction and internal fixation requires exposure and dissection of some of the soft tissues from the condylar process to permit manipulation and attachment of fixation devices. Therefore, surgery further diminishes the blood supply to a segment of bone that has already had a severe compromise. If maintenance of blood supply to the condyle is important, one should therefore choose a surgical approach that can minimize the amount of soft tissue stripping from the fractured condylar process and maintain, as much as possible, the attachment of the TMJ capsule and the lateral pterygoid muscle. Thus, if the preauricular approach is chosen, one should not enter the

capsule of the joint as one might do for an intraarticular surgery. Doing so can disrupt the already compromised blood supply to the condyle.²³⁶ Instead, the dissection should be superficial to the capsule to a point inferior to where it attaches to the condylar process before incising to bone. Similarly, if one approaches the condylar process from a retromandibular or submandibular approach, one should strip soft tissues from the inferior portion of the condylar process up to the point where the capsule attaches. Leaving the capsule intact will help maintain that important source of blood supply.

CAN THE CONDYLAR PROCESS OF THE MANDIBLE BE USED AS A FREE BONE GRAFT?

Several reports have appeared in the literature where the condylar process has been completely stripped of all soft tissue attachments and removed from the wound, followed by immediate replacement.^{3,6,112,148,187,221-227} This procedure was used not only to treat fractures of the condylar process but to immediately reconstruct the mandible after tumor excision or provide access for vascular surgery deep in the temporal fossa. Follow-up showed that patients having had condylar removal and replantation developed reasonable function of their mandibles. However, the histologic appearance of such procedures performed in laboratory animals showed that there were significant histologic aberrations in the condylar process that resulted.^{234,237}

Bell and Kennedy²³⁴ performed vertical ramus osteotomies in monkeys and detached the entire proximal segment before replanting it. They found that the viability and vascularity of the proximal segment was lost concomitantly with stripping the segment completely from its soft tissue attachments. The bone degenerated and was replaced with the development of new trabecular bone. In time, a new functional condyle resulted but was histologically abnormal in appearance.

Perhaps the most ideal methodology to answer the question, "what happens when the mandibular condyle undergoes complete vascular disruption and necrosis" was used by Marciani et al.²³⁸ They exposed the mandibular condyles in monkeys, entered the capsule of the joint, and used a cryoprobe to freeze the entire condyle. Freezing devitalized the majority of the condyle but it still remained attached to the remainder of the mandible. This could therefore be considered a model to see what would happen to a completely detached condylar process that was reinserted into the wound and rigidly stabilized. Not surprising, there was osteonecrosis followed by the development of new bone which, in time, took the shape of a mandibular condyle, although it was irregular and its articulating surface was bone, not fibro-

cartilage. The function was preserved although the range of motion decreased significantly. Of note, however, was that the mandible maintained its position in all 3 planes of space.

Will an avascular condyle heal to the mandible? Orthopedic studies in the appendicular skeleton have shown that repositioned avascular bone fragments can heal by primary intention if rigidly immobilized.²³⁹⁻²⁴¹ Thus, if one must replant the condyle, it can still heal to the ramus if rigidly stabilized.

Follow-up of patients treated by condylar removal and immediate re-implantation showed that the condyles undergo variable amounts of resorption.²²⁴⁻²²⁶ Good results were reported by Boyne²²⁴ in 15 patients followed for greater than 8 years after resection and immediate replantation of the condyle. During the first 2 years there was some resorption of the condyle, but thereafter, the condyles remained morphologically stable for up to 15 years.²²⁴ The condylar morphology was altered, with flattening, but no occlusal changes were noted. Patients were asymptomatic and functioned well on their re-implanted condyles.

However, less favorable results were shown by Iizuka et al,²⁴² who removed and immediately replanted 10 high condylar process fractures using miniplates to stabilize the segments. Postoperative MMF was used for 0 to 36 days (average, 14 days). Follow-up ranged from 7 to 60 months (average, 19.1 months). Mouth opening at the last follow-up examination ranged from 22 to 50 mm, with an average of 38.5 mm. None of these patients had any pain during mastication or palpation, and only 2 had pain on palpation of the joint. However, 6 patients had partial and 4 had total resorption of the condyle on follow-up radiographs. The earliest sign of resorption was noted from 2 to 12 weeks after surgery.

Not surprisingly, it would probably be desirable to try and maintain viability of the condyle when treating patients with condylar process fractures. It is likely that more consistent results would be achieved by doing so. This means the surgical approaches and fixation techniques must respect and preserve the soft tissues still remaining attached to the condylar process as much as possible. However, when one feels compelled to perform open treatment on a small condylar fragment, one can do so even if it means devitalizing the fragment. However, the results will be more variable because of the resorption that may occur.

Summary

Successful treatment of condylar process fractures depends on the biologic character and adaptive capability of the masticatory system. These will differ

widely among patients, and it is the lack of sound biology and adaptation that can lead to an unfavorable outcome. Unfortunately, the data are not yet available to help us decide which patients may have the inability to adapt well to their condylar process fracture. If we could identify these patients, perhaps altering the treatment would be beneficial.

Concerning the character of the injury, we do know that bilateral fractures of the condylar processes requires more extensive adaptations within the masticatory system to provide a favorable outcome compared with the unilateral condylar fracture. If one chooses to treat these patients closed, one must understand that adaptations in the musculature, skeleton, and dentition will all be necessary, and that some of these adaptations will create visible alterations, such as an increase in the mandibular plane angle.

Open treatment of condylar process fractures probably requires fewer adaptations within the masticatory system to provide a favorable functional outcome. However, one must weigh the risk of open surgery against the possible improvement in outcomes. The risks are not just surgical risks, but biological risks as well, such as the disruption of the blood supply to the condyle that can lead to resorption/remodeling.

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