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Treatment of Comminuted Mandibular Fractures by Closed Reduction

RICHARD A. FINN, DDS*

Few topics concerning the management of mandibular fractures are as controversial as the treatment of comminuted mandibular fractures. A comminuted fracture represents a bone that has been splintered or crushed,[1] pulverized,[2] or broken into several pieces,[3] giving rise to many small fragments.[4] Thus, for purposes of this discussion, comminution is defined as the presence of multiple fracture lines resulting in many small pieces within the same area of the mandible (ie, angle, body, ramus, symphysis). Analysis of reports involving the number of fractures per mandible demonstrate remarkable consistency, with a range of 1.3 to 1.8 fractures per patient.[5] These are obviously not comminuted.

Although there has been a rebirth of interest in traumatology as indicated by the plethora of articles in the past 15 years, the incidence of mandibular comminution is still difficult to ascertain. Recent reports on large numbers of mandibular fracture patients (approximately 4,000) have failed to mention either explicitly or implicitly the number or incidence of comminuted mandibular fractures.[6-8] Other reports imply the presence of comminution, but careful review of the data is equivocal with respect to mandibular comminution, other than use of the term.[9,10] The spectrum from relatively simple fractures[9] to avulsion[10] seems to be categorized as comminution. However, many large epidemiologic studies[11-17] of mandibular fracture patients (approximately 10,800) either do not include or do not mention a category of mandibular comminution.

The incidence of mandibular comminution can be carefully and tediously extracted from large series of mandibular fracture patients. Zacharaides et al[18] discussed the difficulty in achieving normal occlusion in six cases of mandibular comminution treated by rigid internal fixation. These six cases of comminution in 223 patients represented a 2.7% incidence. In a well-designed prospective study covering 1 year, James et al[19] discussed 15 of 253 patients (6%) with comminution. Kearns et al[20] and Peled et al[21] reported an incidence of comminution similar to that described by James et al: 6.2% and 6.5%, respectively. A survey of mandible fractures at selected army installations over a 1-year period indicated 97 comminuted fractures of the mandible in 523 patients, an 18.5% incidence.[22] Reports from urban trauma centers have cited an incidence of mandibular comminution ranging from 18.6% to 60%.[23-25]

The incidence of mandibular comminution is difficult to determine. In essence, each article written about generic mandibular fractures has to be carefully dissected and then evaluated with respect to the presence or absence of comminution. This usually represents a small subset of cases taken from a larger retrospective case series. Many times this subset of patients developed their mandibular comminution from gunshot wounds.

Two recent reports have looked exclusively at comminuted mandibular fractures without gunshot wounds as the primary causative agent. Coniglio and Norante[26] reviewed their results with open reduction and internal fixation (ORIF) in six motor vehicle accident patients, in four of which he additionally used a Kirschner wire and maxillomandibular fixation (MMF) in four. Two of six developed soft tissue infections, but all six eventually had a bony union. Smith and Johnson[27] managed 15 consecutive patients with mandibular comminution (at least two free segments of bone) by using the AO stainless steel reconstruction system. Three of the 15 patients developed complications.

This article reviews the historic management of comminuted mandibular fractures in light of the sparse information about this fracture pattern. The prototypical war injury that results in mandibular comminution provides the starting point. An anecdotal retrospective

* Associate Professor, Department of Surgery and Department of Cell Biology–Anatomy, Division of Oral & Maxillofacial Surgery, University of Texas Southwestern Medical Center; and Chief, Oral & Maxillofacial Surgery, Veterans Administration Medical Center, Dallas, TX.

Address correspondence and reprint requests to Dr Finn: Division of Oral & Maxillofacial Surgery, The University of Texas, Southwestern Medical Center at Dallas, 5323 Harry Hines Blvd, Dallas, TX 75235-9031.

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case series treated by closed reduction is reviewed. Finally, the management of an individual patient by an individual surgeon is discussed. Variables to consider relate to patient, fracture, and doctor factors.

Historical Considerations

Since the introduction of firearms in Europe during the 14th century, the prototypical comminuted mandibular fracture has resulted from low-velocity gunshot wounds.[28] This generally creates a penetrating wound with minimal avulsion and with the tissues being crushed and forced apart. Although significant avulsion of bone and soft tissue may occur, this type of perforating and avulsing wound is unique and is not discussed in the context of comminuted fractures.

Wound management and debridement of the maxillofacial area were found to be quite different from other less vascular areas of the body as early as the Crimean War (1854-55).[29] MacLeod[29] in 1862 observed that gunshot wounds to the face resulting in fractures did not require removal of small fragments that were almost detached. He suggested that the large supply of blood in the area enabled small pieces of bone to heal in a way that would be fatal to similarly displaced portions of bone in other locations. MacLeod's observations were prophetic to maxillofacial surgeons for the next 100 years.

The American Expeditionary Forces in Europe during World War I sustained approximately 8,000 maxillofacial injuries from missiles, with over 3,000 proving to be fatal.[30] Trench warfare resulted in low-velocity maxillofacial injuries of almost epidemic proportions. Converse[31] described the circumstances and types of wounds encountered during the first World War, emphasizing the incredibly common maxillofacial injury. Ivy[32] reported on perhaps the largest series of comminuted mandibular fractures resulting from trench warfare. He discussed the cumulative experiences of the American Expeditionary Forces in managing approximately 1,125 gunshot fractures of the mandible. Most of these were comminuted with and without avulsion. Surprisingly, only 123 patients, or 11%, required bone grafting at some point. Ivy concluded: "The almost universal preservation of a good occlusal relationship in these cases, and the exceptionally large percentage of good functional results in cases cured without bone grafting are principally due to the efficient and painstaking work of the dental officers."[32]

Open reduction of these compound and comminuted fractures was strongly discouraged because experience had demonstrated that these maneuvers inevitably were associated with infection and necrosis.[33] Treatment principles centered around conservation of tissue, and early fixation and immobilization. It was believed that delayed fixation was the major determinant for delayed healing and facial deformity.

Fixation methods used during this time were modifications and adaptations of older techniques. The capped splints of Hullihen, the open splint of Gunning (1866), interdental splints of Bean and Gunning, and Gilmer's interlocking plane (1887) were innovatively used.[30] Combined with these techniques were a variety of bandages, caps, and external devices. In essence, the face, usually containing a comminuted mandible, was bandaged together. A cardinal principle in fracture management was forevermore elucidated at this time; occlusion is the key to fracture reduction and stabilization. Thus, interdental wiring was refined and immobilization greatly simplified. The results obtained, however, were not significantly influenced by the different techniques, but the application of sound principles and attention to detail by the surgeons were of utmost importance.[30,33]

During World War II, the number of comminuted mandibular fractures was only a fraction of that managed during World War I.[33] The applicability of various interdental wiring techniques, band and wire splints, and Gunning-type splints was reviewed by Kazanjian[34,35] in 1942, based on his experience during the first world war, but still considered contemporary and quite effective in the 1940s. The essence of mandibular comminution was pointed out by Kazanjian[35] as being ". . . multiple lines of fracture which radiate in many directions. The mobility of the parts is greater, and there is little or no tendency for the segments to interlock rigidly." In treating mandibular comminution in the 1940s, Kazanjian recommended modalities that were fast, efficient, and simple, and could be accomplished on the second or third day postinjury. He also suggested that ". . . strong, simple appliances are the best."[35] Kazanjian suggested early fixation of fragments to be one of the most important means of controlling infection and preventing complications.

External skeletal-pin fixation devices (Roger Anderson) were ingeniously adapted for use in maxillofacial injuries during the second world war.[33] Combining external fixation with MMF was a popular combination in dentate patients. This greatly decreased the rate of pin loosening.[36] Although external pin fixation was highly controversial, the fundamental concept was biologically sound, and subsequently it underwent significant modifications with respect to compatible biomaterials and lightening of the apparatus.[37]

Perhaps the most definitive prospective study of maxillofacial war injuries (comminuted mandible fractures) was performed by a group of Navy oral and maxillofacial surgeons.[33] Although the number of maxillofacial injuries during the Vietnam conflict has been estimated at 30,000 to 45,000, the long-term maxillofacial casualty study followed 197 patients with man-

dibular injuries through early, intermediate, and long-term care. Twenty-three patients had comminuted mandibular fractures, and another 44 patients had comminution with partial avulsion not requiring bone grafts. Thus, 67 patients were longitudinally followed for mandibular comminution. Closed comminuted fractures were treated by closed reduction (62%). If overlying lacerations were present, very conservative open reductions (38%) were performed, with the reduction of only a limited number of larger fragments to positively assist the healing process. Interdental wiring, MMF, splints, circumferential wiring, and external fixators were used to provide passive stability of bone fragments, and not as active reduction devices. The admonition regarding ORIF of these comminuted fractures was emphasized: "Extensive open reduction of comminuted fractures by multiple direct wiring or plating resulted in devitalization of bone fragments as a result of soft tissue stripping . . . ."[33] Aggressive or inappropriate open reductions were used infrequently once the merit of conservative reduction combined with stable fixation became fully understood. The average length of MMF was 52 days, with a range of 19 to 168 days.

The overall wound infection rate in these comminuted mandibular fractures was 30%. The locale where the infection was diagnosed was the continental United States in 76% of the cases, and generally this occurred 2 to 3 weeks after the injury. The need for secondary reduction occurred in 9% of the patients. Facial asymmetry was usually the impetus of early secondary reductions.

It has been estimated that 10% to 15% of all war wounds involve the maxillofacial complex.[33] The four major wars involving the United States in this century have provided the oral and maxillofacial surgeon with unprecedented experience in the management of comminuted mandibular fractures. Contemporary military conflicts have once again demonstrated the usefulness of closed reduction.[38,39] Shuker[38,39] reported on some 249 patients with comminuted mandibular fracture managed by closed reduction and circumferential wiring. He concluded: "The procedure is simple, the instruments and materials are readily available, operating time is short, recovery is uneventful, and the results are satisfactory." Our heritage and legacy managing this fracture pattern are as obvious as the harsh memories of war that provided us with this medical lesson.

Personal Experience

Patients and Methods

To obtain further information on the subject, those comminuted mandibular fractures (multiple fracture lines resulting in many small pieces) that the author was directly associated with and managed by closed reduction techniques were reviewed. These cases were treated in the residency program at John Peter Smith Hospital in Ft. Worth, Texas, Parkland Memorial Hospital in Dallas, Texas, and the Dallas Veterans Administration Medical Center between 1977 and 1993. A total of 22 patients with sufficient documentation for review were included. Data obtained from the records included demographics, mechanism and site of injury, treatment regimen, and treatment outcome. Treatment options included closed reduction with external fixation (CREF) with MMF, lingual splints, circumferential skeletal fixation, and external fixators. Treatment outcome variables included infection, clinical evidence of fracture healing, occlusal alterations, and facial symmetry.

Results

Eighteen (82%) of the 22 patients were young men with a mean age of 28.2 years (range, 16 to 52 years). Mechanisms of injury included 10 low-velocity gunshot (not shotgun) wounds (45%), 5 motor vehicle accidents (22.7%), 5 aggravated assaults (22.7%), 1 horse kick (4.5%), and 1 bull goring (4.5%). Anatomically the comminuted fractures were located in the ramus (27%), angle (18%), body (36%), and symphysis (18%). Some overlap between sites was common. Wound debridement (23%) was infrequent, and the use of drains (9%) was rare.

Erich-type arch bars were applied to the stable dentition, unstable or unsalvageable teeth were extracted, and MMF was established in all cases. The six comminuted fractures of the mandibular ramus were treated by CREF using MMF. Two of the angle fractures were managed by MMF alone; the two gunshot wounds resulting in angle fractures were treated by external fixators. Three mandibular body fractures resulting from gunshot wounds were treated with external fixators, two aggravated assault fractures received MMF, and three other fractures were reduced and stabilized with MMF, lingual splints, and circumferential mandibular wiring. One comminuted symphyseal fracture was managed with MMF, another with MMF combined with a lingual splint, and two additional symphyseal fractures were managed with external fixators. All seven cases treated with extraskeletal pin fixation had various lengths of MMF with elastics or wires to facilitate maximal interdigitation of the remaining dentition.

All comminuted ramal fractures healed uneventfully after a mean MMF period of 6.2 weeks. One patient had lateral flaring of the inferior border that was clinically discernible, but no malocclusions were noted. Both of the angle fractures managed by MMF (mean, 6.3 weeks) healed without infection, malocclusion, or facial asymmetry. One angle comminution resulting

from a gunshot wound and managed by external fixation developed a wound infection that required incision and drainage, sequestrectomy, and intravenous antibiotics. This patient in whom the fixator was in place 65 days, had a normal occlusion and facial symmetry. The other patient with a comminuted angle fracture and extraskeletal pin fixation healed uneventfully, with the apparatus in place 48 days.

Of the eight patients with mandibular body comminution, two developed minor dentoalveolar infections associated with teeth, two failed to maintain their preestablished occlusion, and one had a lateral flaring of the mandibular body that was clinically noticeable. In the four symphyseal fractures, two had uncomplicated healing, one became infected, requiring incision, drainage, sequestrectomy, and intravenous antibiotics; and the fourth case developed an end-to-end class III malocclusion.

In summary, of the 22 patients treated, 4 developed infections (18%), 3 had malocclusions (13.6%), and 2 had clinically discernible facial asymmetries (9%).

Discussion

There is a general assumption among surgeons that the more information (data) accrued about what we do (treatment process) and the results obtained with the technique (outcome), the more it will enhance our chances of improving whatever it is we are doing for our patients. Unfortunately, the information (data) published regarding mandibular fractures many times fails to mention the presence or absence of comminution[6-8] Other very large series of patients[11-17] do not describe any comminution, and some studies demonstrate a broad spectrum of occurrence, ranging from 1%[40] to 60%.[25] Well-designed outcome studies for simple mandibular fractures are generally unavailable and are nonexistent for comminuted mandibular fractures.

The wisdom associated with the tautology—one can only measure what one is measuring—seems applicable to the management of mandibular fractures in general[19,41-43] and to comminuted mandibular fractures specifically.[27,30-39] Contemporary information about comminuted mandibular fractures usually represents a small subset of patients taken from reports representing philosophies of treatment of heterogenous groups of patients. Such information provides fertile ground for much debate, sometimes with great fervor. The most problematic aspect of reports of treatment philosophy is that they do not assess individual aspects of the patients or their treatment but give a global impression of what can generally be achieved with a particular approach or philosophy. Recent discussions of such philosophies of treatment for simple, noncomminuted mandibular fracture by rigid internal fixation (RIF) have reviewed the pros and cons of large rigid plates[44] versus mini-dynamic compression plates,[42] an intraoral[41] versus an extraoral approach,[45] interfragmentary compression[46] versus noncompression,[47] use of tapped versus self-threading screws,[42] drains versus no drains, early[41] versus delayed treatment, and generous broad subperiosteal exposure[48] versus limited subperiosteal exposure.[41] It is obvious that many details regarding RIF of simple mandibular fractures are controversial and poorly understood. Thus, the controversy relative to the management of the most complicated mandibular fracture, the fracture comminuted, is multiplied manyfold by our lack of hard data.

The individual patient with a comminuted mandibular fracture ultimately is treated by an individual surgeon. At that point, the decision tree relative to treatment includes at least three important variables: patient factors, fracture factors, and doctor factors. The most significant patient factor related to problems with healing of mandibular fracture is the frequency of alcohol abuse.[5] Eid et al[49] demonstrated higher complication rates in alcoholics with poor oral hygiene and suggested that open reduction was overtreatment for many of these mandibular fractures. Furthermore, Eid et al recommended the simplest fixation methods with a minimal amount of surgery for the "problem patient." Cannel and Boyd[50] lamented the slow rate of bony healing in vagrant alcoholics in spite of prolonged hospitalization. They also concluded that alcoholics had poor tissue tolerance to infections and recommended that open reductions be avoided. They theorized that osteoporosis, osteomalacia, vitamin deficiencies, and impaired local blood supply secondary to hepatic fatty emboli may all be operational in the alcoholic patient. Adele et al[51] demonstrated alcohol abuse and patient age to be the two most important patient factors resulting in delayed union of mandibular body fractures. Passeri et al[52] reviewed the rate of complications in intravenous drug abusers (30%), nonintravenous drug abusers (19%), and alcoholics (15.5%). Patients in Passeri's study who did not abuse substances had only a 6% complication rate.

Another patient factor that has a powerful influence on fracture healing is cooperation and compliance. Adele et al[51] identified removal of MMF by noncompliant patients to be the most influential treatment variable resulting in delayed healing. Marciani et al[53] demonstrated a 60% noncompliance rate in 25 trauma cases. These authors were alarmed at this incidence. They noted that the important clinical characteristics that would positively affect patient compliance were the care setting, the practitioner-patient relationship, and the therapeutic regimen. The nature and quality of the doctor-patient relationship can significantly impact on cooperation and compliance.[54] Daniels[55] and Sackett[56] noted that age, race, sex, socioeconomic status, and educational level did not correlate with compliance.[55,56]

It may indeed be difficult to identify the noncompliant individual.

In reviewing his experience with poorly compliant patients, Ellis[25] suggested extremely rigid fixation (AO technique) to "take the patient's cooperation out of the formula for success." Thaller[17] was also quick to indict his patient population as being mobile and indigent and suggested that this directly related to his complication rate. James et al[19] reported on 253 patients with 422 mandibular fractures who were indigent, not very cooperative, and sporadically came in for follow-up. Although James et al assumed the complication rate may be high in this group because of willful misconduct, 60% of the patients were treated with CREF by MMF, and only 1.5% developed a postoperative infection. Maloney et al[57] also reviewed a large series of mandibular fracture patients (n = 131) who were indigent and inconsistently complied with antibiotics and follow-up, but found that this resulted in only a 0.6% infection rate in 161 fractures treated by closed or open reduction. Olson et al[16] reported 935 fractures in 580 patients, only six demonstrating noncompliance (1%). Thus, many patient factors can contribute to misadventures in the management of a comminuted mandibular fracture. The ability to prospectively determine what factors in which patients will deleteriously affect outcome is not possible.

Nicoll,[58] in 1964, referred to the so-called personality of a fracture. Determinants of poor outcome results were the degree and severity of the initial displacement, the amount of comminution, damage to the soft tissue envelope, and the presence of infection. Soft tissue damage tended to parallel the degree of damage to bone, and comminuted fractures were associated with severe impairment of the associated soft tissue on which fracture healing was dependent.

Rhinelander[59] observed centrifugal blood flow (endosteum to periosteum) in long bones, and other investigators[60,61] confirmed this pattern in the human mandible. When the medullary (endosteal) blood supply to the mandible is interrupted (experimentally, trauma, orthognathic surgery), centripetal circulation ensues within certain limitations.[62-69] This mechanism is clearly at risk in the event of significant soft tissue injury. Further surgical perturbations through the elevation of significant soft tissue flaps would have to be carefully considered in this less than optimal "biologic" environment.

Subperiosteal exposure of the lateral and medial ramus, angle, and posterior body of the mandible in a quantitative experimental monkey model of sagittal split ramus osteotomy caused drastic reductions in blood flow to the soft tissues and bone.[65,68] These reductions were sufficient to cause bony devitalization. Bell[66,67,69] has repeatedly demonstrated that periosteal reattachment or revascularization takes days to weeks rather than hours. This low-flow state is so dramatic and prolonged that avascular necrosis may result.[65,68] Superficial osteonecrosis, as evidenced by empty lacunae subjacent to elevated mucoperiosteal flaps, has been repeatedly demonstrated by Bell's work.[66,67,69] This superficial osteonecrosis is limited to the outer cortical bone and osteotomy (fracture) site but was evident for 10 to 14 days in all studies. Any relationship between the superficial osteonecrosis secondary to mucoperiosteal flap elevation and hardware (RIF) loosening is currently unknown. A possible disadvantage of primary bone healing in this situation, unlike callus healing, is the failure to progress in an ischemic environment.[70]

One can only assume that the endosteal vascular response associated with the significant traumatic event necessary to create a comminuted mandible would be similar to or worse than the "clean osteotomy" in the animal models used. The vulnerability of the cortical blood flow and angiogenesis when the periosteum has been circumferentially elevated highlights the importance of extraosseous blood flow during the early phases of healing. The clinical outcome for comminuted mandibular fractures may well be independent of the fixation device chosen, but rather reflects the degree of devascularization and the establishment of an optional biologic environment to enhance, and not hurt, revascularization.

Recent reports on simple angle fractures have demonstrated unacceptably high complication rates (29% to 40%).[42,43] Vascular insult secondary to elevation of mucoperiosteal flaps was discussed as a causative factor. In a more recent article on management of angle fractures using noncompression miniplates, Ellis and Walker[71] once again reported unacceptable rates of infection (28%) and suggested that surgical disruption of the blood supply secondary to periosteal stripping ". . . may be the most important factor." In an earlier study,[25] which contained 31 comminuted mandibular angle fractures (one or more free segments larger than 1 cm^2) treated with the AO reconstruction system, a 7.5% complication rate was noted. In the discussion section, the importance of vascularity was noted: "It is probable that immobilization of the major fracture segments is as important, or perhaps more so, then preserving the full soft-tissue pedicles to the fragments." Although no dogma relative to CREF for treatment of comminuted mandibular fractures is promoted in this article, it is apparent that important issues about "fracture factors" are sometimes embraced and at other times disregarded. Such is the nature of clinical research.

Another factor that may impact on outcome is the severity of the fracture. Cooter and David[72] in 1989 described the alphanumeric system of computer-based coding for fracture severity. Edwards et al[73] recently

reported on 324 patients with mandibular fractures who were coded for fracture severity and monitored for complications. All fractures were treated by the Champy technique, and the results indicated that complications with miniplate fixation increase as the severity of fracture increases. The correlation was strongly positive (0.96). This objective and reproducible system of fracture classification has taken us from intuition to a standardized assessment of fracture severity and outcome. Comminuted mandibular fractures were the most severe and thus were associated with the highest complication rate. This system has identified a critical factor that may allow us to identify patients at a greater risk of developing complications.

Although there are important patient factors and fracture factors in the individual case of a comminuted mandibular fracture, the experience of the surgeon also varies tremendously and perhaps represents the most important single element in successful management. One may judge experience by the quality and duration of training and the number of cases performed annually. Trauma surgery is delivered by a spectrum of surgeons, ranging from the infrequent operator (private practicioner) to the almost pure subspecialist in urban trauma centers (academic).

There was a 289% increase (2,189 vs 6,331) in the number of oral and maxillofacial surgeons (OMFS) practicing between 1970 and 1991.[74] The manpower study of 1987[75] indicated that the average OMFS managed 20.9 mandibular fractures per year in 1974 and 17.2 in 1984. A survey of 70 OMFSs in 1992[76] demonstrated that all forms of trauma accounted for only 10% of their practices. In 1988, a survey of the American Association of Oral and Maxillofacial Surgeons (AAOMS) members[77] regarding trauma management demonstrated that bone plating and compression plating were seldom (56%) or never (69.7%) used. The paucity of comminuted mandibular fractures in the general population, the ever-increasing number of OMFSs, and the diminutive caseload annually that is seldom or never managed by RIF could limit the experience of most operators.

The technically demanding nature of RIF was described by Schilli[48] in 1977: "Rigid fixation of mandibular bone fragments is extremely difficult." Schilli went on: "The fragments must be exactly reduced, and the plate must be adapted exactly. This can be quite tedious and requires great precision." Dodson et al[78] similarly discussed the technically demanding nature of RIF and the associated "learning curve" previously experienced by others.[79,80] The University of California, San Francisco, group[78] reported a complication rate of 37% during the first 6 months of using RIF and a 10% complication rate during the next 9 months. They concluded that most complications were directly attributable to failure in technique. Theriot et al[79] had a marked reduction in infection rate with RIF as time progressed and attributed this to experience and better technique. Frost et al[80] reported a 47% plate removal in their series and indicated technical errors to be the culprit. Iizuka et al[81] reviewed their experience in 214 patients with RIF and concluded that erroneous techniques were used in almost all cases that became infected. Kearns et al[20] demonstrated a downward, but not statistically significant, trend in complications with RIF as experience increased. They concluded that technical errors are an important source of complications. Complications in the management of these simple fractures (noncomminuted) are strongly related to techniques and operator skill. How much and how often this technique needs to be used to minimize complications is unknown, but all authors indicate a strong relationship between volume and outcome.

To eliminate patient and fracture factors, Assael[82] evaluated plate application in a teaching laboratory using a mandibular fracture model. The iatrogenic complications and failures were 32% for body/symphysis fractures that were plated and 61% for lag screws in the symphysis. These experienced surgeons could produce stable fixation only 71% of the time in the angle area on a dry, hand-held specimen. Assael concluded that the application of RIF for simple mandibular fractures resulted in a high rate of doctor-induced complications. Haug and Schwimmer[83] recently reviewed 27 patients with 32 fibrous unions of the mandible. Eleven patients were managed by RIF. Ten of the 11 managed by RIF (91%) failed to meet any of the AO or Champy guidelines. These were distinctly doctor errors.

In the Hartford, Connecticut, area the average OMFS performs six ORIFs of mandible fractures per year.[82] Whether the individual surgeon can be efficacious in obtaining the desired results with RIF in comminuted mandibular fractures with this annual case load is certainly questionable. One would have to assume that years may pass between the treatment of one comminuted fracture and the next. A recent review[84] of RIF in angle fractures contained the following statement: "However, poorly applied rigid internal fixation will likely produce the highest rate of nonunion. Periosteal stripping, bacterial contamination, and plates and screws that do not produce stable osteosynthesis result in massive, acute infection and nonunion." The applicability of RIF in comminuted fractures, with their biologic tenuousness and sporadic encounter, is questionable solely on the basis of technical expertise.

Bone growth, fracture healing, and bone remodeling are incredibly complex processes modulated by systemic hormones, local growth factors, and local fracture factors. More than 18 factors[85] have been identified as being integral to bone homeostasis, and these factors must be part of any equation that purports to explain

how different mechanical systems (open, closed, rigid, nonrigid) affect bone healing.

Comminuted mandibular fractures represent the most infrequent and most complicated of all fracture patterns. When the individual OMFS is confronted with a comminuted mandibular fracture, three factors—the patient, the fracture, and the doctor's expertise—ultimately determine treatment alternatives. The first steps in the management of any jaw fracture are the application of arch bars; establishment of the preinjury occlusion, facial symmetry, balance and form; and application of MMF. With comminuted mandibular fractures, perhaps these should also be the last steps in many instances.

References

1. Dorland's Illustrated Medical Dictionary (ed 27). Philadelphia, PA, Saunders, 1988
2. McGraw-Hill Dictionary of Scientific and Technical Terms (ed 2). New York, NY, McGraw-Hill, 1978
3. Stedman's Medical Dictionary (ed 25). Baltimore, MD, Williams & Wilkins, 1990
4. Harkess JW, Ramsey WC: Principles of fractures and dislocations, *in* Rockwood CA Jr, Green DP, Bucholz RW (eds): Fractures in Adults. Philadelphia, PA, Lippincott, 1991
5. Bruce R, Fonseca RJ: Mandibular fractures, *in* Fonseca RJ, Walker RV (eds): Oral & Maxillofacial Trauma, vol I. Philadelphia, PA, Saunders, 1991
6. El-Degwi A, Mathog RH: Mandible fractures: Medical and economic considerations. Otolaryngol Head Neck Surg 108:213, 1993
7. Timoney N, Saiveau M, Pinsolle M, et al: A comparative study of maxillofacial trauma in Bristol & Bordeaux. J Craniomaxillofac Surg 18:154, 1990
8. Allan BP, Daly CG: Fractures of the mandible: A 35 year retrospective study. Int J Oral Maxillofac Surg 19:268, 1990
9. Klotch D: Use of rigid internal fixation in the repair of complex and comminuted mandible fractures. Otolaryngol Clin North Am 20:495, 1987
10. Raveh J, Vuillemin T, Ladrach K, et al: Plate osteosynthesis of 367 mandibular fractures: The unrestricted indication for the intraoral approach. J Craniomaxillofac Surg 15:244, 1987
11. Ellis E, Moos KF, El-Attar A: Ten years of mandibular fractures: An analysis of 2,137 cases. Oral Surg 59:120, 1985
12. Fridrich KL, Pena-Velasco G, Olson R: Changing trends with mandibular fractures: A review of 1067 cases. J Oral Maxillofac Surg 50:586, 1992
13. Zachariades N, Papavassiliou D, Popaemetriou I, et al: Fractures of the facial skeletion in Greece. J Maxillofac Surg 11:142, 1983
14. Bochlogyros PN: A retrospective study of 1,521 mandibular fractures. J Oral Maxillofac Surg 43:597, 1985
15. Kelly DE, Harrigan WF: A survey of facial fractures: Bellevue Hospital, 1948-1974. J Oral Surg 33:146, 1975
16. Olson RA, Fonseca RJ, Zeitler DR, et al: Fractures of the mandible: A review of 580 cases. J Oral Maxillofac Surg 40:23, 1982
17. Thaller SR: Management of mandibular fractures. Arch Otolaryngol Head Neck Surg 120:44, 1994
18. Zachariades N, Papademetriou I, Rallis G: Complications associated with rigid internal fixation of facial bone fractures. J Oral Maxillofac Surg 51:275, 1993
19. James RB, Fredrickson C, Kent JN: Prospective study of mandibular fractures. J Oral Surg 39:275, 1981
20. Kearns GJ, Perrott DH, Kaban LB: Rigid fixation of mandibular fractures: Does operator experience reduce complications? J Oral Maxillofac Surg 52:226, 1994
21. Peled M, Laufer D, Helman J, et al: Treatment of mandibular fractures by means of compression osteosyntheses. J Oral Maxillofac Surg 47:566, 1989
22. Salem JE, Lilly GE, Cutcher JL, et al: Analysis of 523 mandibular fractures. Oral Surg 26:390, 1968
23. Anderson T, Alpert B: Experience with rigid fixation of mandibular fractures and immediate function. J Oral Maxillofac Surg 50:555, 1992
24. Busuito MJ, Smith DJ, Robson MC: Mandibular fractures in an urban trauma center. J Trauma 26:826, 1986
25. Ellis E III: Treatment of mandibular angle fractures using the AO reconstruction plate. J Oral Maxillofac Surg 31:250, 1993
26. Coniglio JU, Norante JD: Augmented fixation of mandibular fractures with a threaded Kirschner wire. Arch Otolaryngol Head Neck Surg 115:699, 1989
27. Smith BR, Johnson JV: Rigid fixation of comminuted mandibular fractures. J Oral Maxillofac Surg 51:1320, 1993
28. Osborne TE, Bays RA: Pathophysiology and management of gunshot wounds to the face, *in* Fonseca RJ, Walker RV (eds): Oral & Maxillofac Trauma, vol 2. Philadelphia, PA, Saunders, 1991
29. Macleod GH: Notes on surgery of war in Crimea. Philadelphia, PA, Lippincott, 1862
30. Blair VP: Relation of the early care to the final outcome of major face wounds in war surgery. Military Surgeon 92:12, 1943
31. Converse JM: War injuries of the face. Trans Am Acad Opthalmol 46:250, 1942
32. Ivy RH: Late results of treatment of gunshot fractures of the mandible. JAMA 75:1316, 1920
33. Kelly JF: Management of war injuries to the jaw and related structures. Washington, DC, US Government Printing Office, 1977
34. Kazanjian VH: An outline of the treatment of extensive comminuted fractures of the mandible (based chiefly on experience gained during the last war). Am J Orthod Oral Surg 28:265, 1942
35. Kazanjian VH: Immobilization of wartime, compound, comminuted fractures of the mandible. Am J Orthod Oral Surg 28:551, 1942
36. Stout TD: War surgery and medicine: Official history of New Zealand in the Second World War, 1939-45. Willington, New Zealand, War History Branch, Department of Internal Affairs, 1954
37. Morris JH: Biphase connector external skeletal splint for reduction and fixation of mandibular fractures. Oral Surg 2:1382, 1949
38. Shuker S: Inter-Rami intraoral fixation of severely comminuted mandibular war injuries. J Maxillofac Surg 13:282, 1985
39. Shuker S: Management of comminuted mandibular war injuries with multiple circumferential wires. J Oral Maxillofac Surg 44:152, 1986
40. Oikarinen K, Ignatius E, Silvennoinen U: Treatment of mandibular fractures in the 1980s. J Craniomaxillofac Surg 21:245, 1993
41. Champy M, Lodde JP, Schmitt R, et al: Mandibular steosynthesis by miniature screwed plates via a buccal approach. J Maxillofac Surg 6:21, 1978
42. Ellis E, Karas N: Treatment of mandibular angle fracutres using two mini-dynamic commpression plates. J Oral Maxillofac Surg 50:958, 1992
43. Ellis E, Sinn DP: Treatment of mandibular angle fractures using two 2.4 mm dynamic compression plates. J Oral Maxillofac Surg 51:969, 1993
44. Prein J, Kellman RM: Rigid internal fixation of mandibular fractures: Basics of AO techniques. Otol Clin North Am 20:441, 1987
45. Spiessl B: Internal Fixation of the Mandible: A Manual of AO/ASIF Principles. Berlin, Germany, Springer-Verlag, 1989
46. Schenk R, Willenegger H: Morphological findings in primary fracture healing. Symp Biol Hung 7:75, 1967
47. Rittmann WW, Perren SM: Corticale Knochenheilung Nach Osteosynthese und Infektion. New York, NY, Springer-Verlag, 1974

48. Schilli W: Compression Osteosynthesis. J Oral Surg 35:802, 1977
49. Eid K, Lynch DJ, Whitaker LA: Mandibular fractures: The problem patient. J Trauma 16:658, 1976
50. Cannel H, Boyd R: The management of maxillofacial injuries in vagrant alcoholics. J Maxillofac Surg 13:121, 1985
51. Adele R, Eriksson B, Nylin O, et al: Delayed healing of fractures of the mandibular body. Int J Oral Maxillofac Surg 16:15, 1987
52. Passeri LA, Ellis E, Sinn DP: Relationship of substance abuse to complications with mandibular fractures. J Oral Maxillofac Surg 51:22, 1993
53. Marciani RD, Haley JV, Kohn MW: Patient compliance: A factor in facial trauma repair. Oral Surg 70:428, 1990
54. Wartman S, Morlock L, Molity F, et al: Patient understanding and satisfaction as predictors of compliance. Med Care 21:886, 1983
55. Daniels L, Kochar M: What influences adherence to hypertension therapy. Nurs Forum 18:231, 1979
56. Sackett D, Haynes R: Compliance with therapeutic regimens. Baltimore, MD, John Hopkins University Press, 1974, p 28
57. Maloney PL, Welch TB, Doku HC: Early immobilization of mandibular fractures: A retrospective study. J Oral Maxillofac Surg 49:698, 1991
58. Nicoll EA: Fractures of the tibial shaft: A survey of 705 cases. J Bone Joint Surg 46B:373, 1964
59. Rhinelander FW: The normal microcirculation of diaphyseal cortex and its response to fracture. J Bone Joint Surg 50A:784, 1968
60. Castelli WA: Vascular architecture of the human adult mandible. J Dent Res 42:786, 1963
61. Bradley JC: A radiological investigation into the age changes of the inferior dental artery. Br J Oral Surg 13:82, 1975
62. Castelli WA, Nasjleti CE, Diaz-Perez R: Interruption of the arterial inferior alveolar flow and its effects on mandibular collateral circulation and dental tissues. J Dent Res 54:708, 1975
63. Redden DR, Bishop JG, Matthews JL, et al: Vascular anastomoses in the region of the mandibular symphysis. J Dent Res 40:97, 1961
64. Hellem S: Blood supply and microvascular flow in mandibular bone. Linköping University Medical Dissertations, No. 175, Linköping, Sweden, 1984
65. Grammer F, Meyer M, Richter K: A radioisotope study of the vascular response to sagittal split osteotomy of the mandibular ramus. J Oral Surg 32:578, 1974
66. Bell WH, Levy BM: Revascularization and bone healing after anterior mandibular osteotomy. J Oral Surg 28:196, 1970
67. Bell WH, Schendel SA: Biologic basis for modification of the sagittal ramus split osteotomy. J Oral Surg 35:362, 1977
68. Grammer FG, Carpenter AM: A quantitative histologic study of tissue responses to ramal sagittal splitting procedures. J Oral Surg 37:482, 1979
69. Bell WH, Kennedy JW: Biological basis for vertical ramus osteotomies: a study of bone healing and revascularization in adult rhesus monkeys. J Oral Surg 34:215, 1976
70. Rahn BA, Gallinaro P, Baltensperger A, et al: Primary bone healing: An experimental study in the rabbit. J Bone Joint Surg 53A:783, 1971
71. Ellis E III, Walker L: Treatment of mandibular angle fractures using two noncompression miniplates. J Oral Maxillofac Surg 52:1032, 1994
72. Cooter RD, David DJ: Computer based coding of fractures in the craniofacial region. Br J Plast Surg 42:17, 1989
73. Edwards TJ, David DJ, Simpson DA, et al: The relationship between fracture severity and complication rate in miniplate osteosynthesis of mandibular fractures. Br J Plast Surg 47:310, 1994
74. Waldman HB: Changing distribution of oral & maxillofacial surgeons: 1982-1991. J Oral Maxillofac Surg 51:1380, 1993
75. Kelley JPW: Oral and maxillofacial surgery manpower in the United States: Current scope and future needs. J Oral Maxillofac Surg 45:S1-14, 1987
76. Mercuri LG: Outcome assessment in oral and maxillofacial surgery advanced education programs. J Oral Maxillofac Surg 50:1314, 1992
77. Laskin DM, Best AM: Current trends in the treatment of maxillofacial injuries in the United States. J Oral Maxillofac Surg 46:595, 1988
78. Dodson TB, Perrott DH, Kaban LB, et al: Fixation of mandibular fractures: A comparative analysis of rigid internal fixation and standard fixation techniques. J Oral Maxillofac Surg 48:362, 1990
79. Theriot BA, Van Sickels JE, Triplett RG, et al: Intraosseous wire fixation versus rigid osseous fixation of mandibular fractures: A preliminary report. J Oral Maxillofac Surg 45:577, 1987
80. Frost DE, El-Atter M, Moos KF: Evaluation of metacarpal bone plates in the mandibular fracture. Br J Oral Surg 21:214, 1983
81. Iizuka T, Lindqvist C, Hallikainen D, et al: Infection after RIF of mandibular fractures: A clinical and radiological study. J Oral Maxillofac Surg 49:585, 1991
82. Assael LA: Evaluation of rigid internal fixation of mandible fractures performed in the teaching laboratory. J Oral Maxillofac Surg 51:1315, 1993
83. Haug RH, Schwimmer A: Fibrous union of the mandible: A review of 27 patients. J Oral Maxillofac Surg 52:832, 1994
84. Assael LA: Treatment of mandibular angle fractures: Plate and screw fixation. J Oral Maxillofac Surg 52:757, 1994
85. Canalis E, McCarthy T, Centrella M: Growth factors and the regulation of bone remodelling. J Clin Invest 81:277, 1988