Complications of Rigid Internal Fixation

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ABSTRACT

Over the past 20 years, there have been many advances in the development of bone fixation systems used in the practice of craniomaxillofacial surgery. As surgical practices have evolved, the complications of each technologic advance have changed accordingly. Interfragmentary instability of interosseous wiring has been replaced by the risk of exposure, infection, and palpability of plate and screw fixation systems. The improved rigidity of plate fixation requires anatomic alignment of fracture fragments. Failure to obtain proper alignment has led to the phenomenon known as "open internal fixation" of fracture fragments without proper reduction. The size of the plates has decreased to minimize palpability and exposure. However limitations in their application have been encountered due to the physiologic forces of the muscles of mastication and bone healing. In the pediatric population, the long-standing presence of plates in the cranial vault resulted in reports of transcranial migration and growth restriction. These findings led to the development of resorbable plating systems, which are associated with self-limited plate palpability and soft tissue inflammatory reactions. Any rigid system including these produces growth restriction in varying amounts. In this discussion, we review the reported complication rates of miniplating and microplating systems as well as absorptive plating systems in elective and traumatic craniofacial surgery.

KEYWORDS: Rigid internal fixation, craniomaxillofacial trauma, craniofacial, facial fracture, complications

INTEROSSEOUS AND SUSPENSION WIRING

Up through the 1970s, the approach to the patient with craniofacial fractures had not significantly deviated from the techniques described by Milton Adams.[1] Open reduction and internal fixation of the infraorbital rim was performed with interosseous wires, and the lower midface was treated in a closed fashion with suspension wiring and intermaxillary fixation (IMF).

Closed suspension of the midface and IMF were techniques employed to preserve appropriate midface height and premorbid occlusion. The compression afforded by this technique was useful in overcoming the pull of the medial pterygoid muscles, which contributed to the open anterior bite deformity and maxillary retrusion.[2] However, midface retrusion and shortening as well as maxillary rotation have been reported as complications of suspension wiring resulting in malocclusion in as much as 19.6% of cases.[3,4]

When subcondylar fractures accompanied midface fractures, posterior and superior compressive forces were exerted upon the mandible, exacerbating retrusion of the maxillo-mandibular unit. Open reduction and internal fixation of subcondylar fractures helped obviate mandibular retrusion and served as vertical support for pterygomaxillary buttress healing.[5]

Interosseous wiring of the infraorbital rim was intended to prevent malar flattening and preserve orbital volume after zygomaticomaxillary fracture.[1] However, 2-point wire fixation of fractures of the infraorbital rim

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did not provide the required stability. Rotational deformity, enophthalmos, malar flattening, and fracture nonunion were common sequelae of this mode of fixation.

Interosseous wire fixation of craniofacial fractures with limited exposure carried with it prolonged recovery and significant surgical morbidity.[6] Because of the limited stability of the technique, IMF was prolonged, making nutritional optimization difficult. Ankylosis at the temporomandibular joint after prolonged immobilization required protracted rehabilitation, contributing to the functional impairment of the injury. Closed reduction and wire suspension of the lower midface did not allow for stable buttress reconstruction, requiring more bone grafts to maintain projection and height of the midface, along with significant loss of bone graft volume.

Improved stability of midface fractures was obtained by extending exposure and increasing the number of points of fracture fixation. Manson described open exposure of the zygoma and maxilla followed by 4-point wire fixation and use of bone grafting.[2] Acceptable alignment of the zygoma was achieved, with minimal bone graft resorption. Wide exposure of fracture fragments and multiple points of fixation became the method of choice for improved results even as plating systems were developed to supplant the use of interosseous wires.

PLATING SYSTEMS

Current treatment of panfacial fractures consists of reconstruction of physiologic buttresses in anatomic reduction upon which the remainder of the facial skeleton is built. With the development of plating systems, bone fragments could be held in rigid fixation, preventing fracture fragment mobility and thereby contributing to primary bone healing without callus formation. Enhanced bone graft volume retention was also possible with more rigid fixation techniques.[6]

Plates provide more points of fixation for each fracture fragment. In so doing, the tensile forces acting upon the facial skeleton may be shielded from fracture fragments when load-bearing fixation is applied.[7] This stress-shielding phenomenon was theorized to carry the potential to lessen the induction of cell-mediated bone remodeling required for strong bone healing. This is in contrast with load-sharing constructs, where fracture fragments each bear some of the forces across the fracture, which has been described for mandibular fractures with adequate bone stock and without comminution. A third technique was the application of compressive forces across a fracture line to encourage early primary bone healing. In direct comparisons of mandibular fractures, multiple points of fixation demonstrated fracture healing with fewer complications compared with compression plating.[8] From this body of knowledge, the prevailing technique of craniofacial plating is load-bearing, rigid internal fixation of vertical and horizontal buttresses with fracture fragments held in anatomic alignment, without compression.

There remains some controversy over the number of fixation points and number and size of plates required to provide rigid fixation given certain anticipated force loads. Generally, it is agreed that the forces of mastication acting directly on bone fragments require larger plates to be used on these fragments within the spectrum of availability.[9] Exact forces that plates should withstand for any given fracture pattern are unknown, as maximal forces exerted upon the facial skeleton in specific clinical situations are unknown.[10]

Materials selected for use in plating systems have evolved as characteristics of the substances chosen have been better defined in clinical practice. Stainless steel plating systems were found to produce metal sensitivity reactions in animal studies.[8] When these plates were removed, evidence of surface oxidation, corrosion, and toxic ion release were found. Subsequent materials, Vitallium (cobalt-chromium-molybdenum) and titanium, produce a substantially less aggressive foreign body reaction.[11] Titanium is favored over Vitallium further still for its lack of significant artifact on postoperative computed tomography and magnetic resonance imaging scans.

In terms of strength characteristics, titanium plating systems tolerated greater loads in both distraction and compression models compared with Vitallium.[12] This ability to tolerate greater loads before failure makes titanium alloy well suited to resist the distraction of muscles of mastication transmitted across fracture fragments, thereby preserving anatomic alignment.

Potential complications of internal rigid fixation systems include infection, nonunion, palpable or painful hardware, and the often underrecognized issue of misalignment of the fracture fragments during the reduction. This latter phenomenon has been termed OIF, or "open internal fixation" without reduction. Review of indications for hardware removal at a major university center cited plate palpability as the most common reason, followed by pain, loosening of hardware, and exposure of plates.[13] Early positions on rigid internal fixation maintained that a secondary procedure was mandatory for hardware removal. Review of the incidence of these complications, however, suggested that this practice was not uniformly adhered to.[14,15]

To avoid inadequate or improper fracture reduction, and to ensure proper plate placement, greater exposure and soft tissue manipulation was required. This then led to renewed concerns over possible increases in infection rates. Direct comparison between open reduction with wire fixation versus plate infection showed no difference in infection rates.[16]

With the advent of miniplates (1.2 to 1.5 mm) and microplates (0.8 to 1.0 mm), smaller, lower profile plates could be employed for naso-orbito-ethmoid fractures, frontal sinus, and inferior orbital rim to provide three-dimensional stability with decreased palpability in these regions.

MINIPLATE SYSTEMS

In the 1980s, early open reduction and internal fixation with interosseous wiring gave way to miniplate systems. Plating systems were designed to provide multiple points of bone fragment fixation thereby maintaining facial dimensions, preventing rotational migration of fragments, and providing interfragment stability. Rigid internal fixation would thus contribute to rapid bone healing and accelerated convalescence after craniofacial surgery.

Adverse outcomes of miniplates requiring removal include prominence and palpability of plates, infection, plate migration, exposure, and temperature intolerance. Infection and exposure have been shown to be the most common causes for plate removal associated with maxillo-mandibular fracture patterns, and prominence and pain are the main causes for craniofacial plate removal of the midface.[2]

The incidence of plate removal after miniplate use from traumatic injuries varies with the severity of craniofacial injury. In a review by Francel et al of 507 patients with 1112 facial fractures, 12% of patients required hardware removal.[17] Of patients with isolated fractures, only 6.5% required plate removal, whereas 14% of patients with multiple fractures required plate removal. O'Sullivan et al reported their experience with 100 patients with primarily maxillary fracture patterns, with a hardware removal rate of 3%.[18]

Rates of infection vary with history of open fracture with contamination, multiple fractures, and the presence of mandibular fractures carrying a higher complication rate. Francel et al reported a 7% infection rate in their series of significantly injured craniofacial cases, and O'Sullivan et al reported 4% incidence of infection in the series described previously. In a series of 590 facial fractures by Ewers and Harle, infection rates of 1.1% and osteomyelitis of 2.2% were reported.[19] Beals and Munro reported no infections in their series of 74 patients treated for traumatic craniofacial injury, elective midface craniofacial surgery, and cranial vault reconstruction.[20]

Among these series of patients, the reported rates of plate exposure were 1.7 to 3.7%. Plate palpability occurred at a rate of 1.6 to 3% (Table 1).

Orbital complications, such as enophthalmos and malar flattening after midface repair with miniplates, have been reported with a wide range, up to 20%, underscoring the necessity of open reduction of fracture fragments.[21] Rigid internal fixation without careful attention to anatomic alignment of the fracture contributes to the variability that persists in outcome, despite the benefits of three-dimensional stability afforded by plating.

A direct comparison to interosseous wiring of zygoma fractures was performed to address the benefits of miniplate fixation with regard to malar projection, globe position, and cheek sensation compared with the contralateral side. Rigid plate fixation demonstrated significance over wire fixation in terms of malar symmetry ($p < 0.002$), and approached significance in improvement of globe position ($p = 0.06$). No differences were found in cheek sensibility.[22]

The incidence of complications of craniofacial surgery with miniplate fixation varied with the severity of the original injury and the involvement of mucosa. Open maxillo-mandibular fractures with significant mucosal disruption have the highest rates of infection, plate exposure, and plate removal. Postoperative infection occurred at a rate of 0 to 7%, plate exposure 1 to 2%, and plate palpability 0.5 to 3%. With direct comparison with interosseous wiring, miniplate fixation resulted in improved malar symmetry and globe position due to improved stability of repair.

MICROPLATING SYSTEMS

Because of the need for precise three-dimensional orientation of thin, brittle bones, the microsystems were developed as a modification of existing systems designed for maxillary and mandibular fracture fixation.[23] The lower profile microplates led to a decrease in plate palpability, pain, and exposure in midface fracture treatment. Smaller bone fragments could be stabilized with microplates, which may have fractured with the use of larger systems. Microsystems demonstrated greater adaptability to the contours of the facial skeleton due to easier malleability.

The stress shielding phenomenon of the larger plating systems spanning multiple fracture fragments is minimized with use of smaller plates at key points of fixation. However, these smaller plating systems could only be used where torsional forces from muscles of mastication would not disrupt the reduction.

First presented in Atlanta in November 1987, Hans Luhr defined clinical indications for use of microplating systems, including nasoethmoidal fractures, infraorbital fractures, frontal sinus fractures, and calvarium reconstruction.

In calvarium reconstruction, use of low-profile microplates has allowed for advancement of bone while minimizing needs for interpositional bone grafts. When bone grafts or bone fragments are incorporated into the repair, microplates are useful for spanning these fragments. Forward projection can be maintained with

Table 1 Complications of Miniplating Systems

Study	Patient Number	Indication	Complications Reported	Incidence (%)
Francel et al (1992)[17]	507	Craniofacial trauma	Hardware removal	12
			Infection	7.3
			Exposure	1.8
			Palpability	1.6
			Pain	1.4
O'Sullivan et al (1999)[18]	100	Maxillary trauma	Hardware removal	3
			Infection	4
			Palpability	3
			Exposure	2
			Orbital*	20
			Malocclusion	8
Ewers and Harle (1985)[19]	590 (fractures)	Craniofacial trauma	Infection	1.1
			Osteomyelitis	2.2
			Nonunion	1.0
			Malocclusion	5.0
Beals and Munro (1987)[20]	74	Craniofacial trauma	Infection	0
			Exposure	2.7
			Nonunion	0
Jack et al (2005)[26†]	54	Craniofacial	Malocclusion	5.5
			Orbital	13
			Exposure	3.7
			Reoperation	16
Klotch and Gilliland (1987)[6]	22	Midface fractures	Extrusion	13.6
			Removal	13.6
			Nonunion	4.5
			Infection	0
Bell and Kindsfater (2006)[37]	222	Midface, frontal sinus, and mandible	Infection	3
			Malunion	1.3
			Nonunion	1
			Orbital*	3
Brown et al (1989)[14]	109	Trauma	Removal	18
		Orthognathic	Infection	12
			Pain	5.5

*Enophthalmos, dystopia, canthal deformities.
†Miniplating and microplating systems were used.

microscrews without the palpability of miniplates and screws that were formerly evident under the scalp.

The indications for use of microplating systems are currently being expanded. Clauser et al reported use of the microsystem for open reduction and internal fixation of condylar fracture dislocations in a patient series without complications.[24] His report includes 22 adults and 23 children requiring craniofacial surgery for multiple indications including traumatic, neoplastic, and congenital craniofacial indications. No cases of plate palpability, pain, exposure, or infection were reported (Table 2).

Schortinghuis et al reported a clinical series of 44 patients who sustained craniofacial trauma repaired by open reduction and internal fixation with microplates.[25] No plate-related infections, palpability, or malunion were reported. However, three patients required reoperation for complaints of pain. Only one patient's complaints were attributed to the microsystem as a loosened screw was noted, whereas the other two patients had persistent pain after plate removal.

Long-term follow-up was reported for a series of 54 patients undergoing open reduction and internal fixation of complex craniofacial fractures with miniplating and microplating systems. Two patients experienced miniplate exposure at gingivobuccal-sulcus incisions, but there were no exposures, infection, or palpability at sites where microplates were employed. Sixteen percent of patients, however, required reoperation due to errors in anatomic reduction of zygomaticomaxillary complex fracture repair (telecanthus, malar contour abnormalities and enophthalmos), underscoring the need for proper alignment of fragments that are rigidly fixated with microplating systems.[26]

Table 2 Complications of Microplating Systems

Study	Patient Number	Indication	Complications Reported	Incidence (%)
Clauser et al (1994)[24]	45 adults	Trauma	Palpability	0
		Tumors	Pain	0
		Craniofacial	Infection	0
		Deformity	Exposure	0
Schortinghuis et al (1999)[25]	44	Trauma	Plate removal	6.8
			Pain	6.8
			Infection	0
			Nonunion	0
Jack et al (2005)[26]*	54	Craniofacial	Malocclusion	5.5
			Orbital	13
			Exposure	3.7
			Reoperation	16
Goldberg et al (1995)[34]	27	CVR	Transcranial migration	14
			Intracranial plate	6.6

*Miniplating and microplating systems were used.
CVR, cranial vault reconstruction.

From the clinical descriptions of each series, craniofacial reconstruction with the addition of lower profile systems involves the establishment of the integrity of the upper midface with miniplates, followed by midface and periorbital fixation with microplating systems. Within each anatomic subgroup, microplate fixation of local bone fragments minimizes the extent of bone grafting from distant sites. There were no reports of palpability, infection, or plate exposure among the articles reviewed. The incidence of pain associated with microplate fixation ranged from 0 to 2%. Similar incidences of ophthalmologic complications associated with increased orbital volume and malar flattening were noted with microplate fixation compared with that in use of miniplates in previous series.

RESORBABLE SYSTEMS

The risk of growth restriction, transcranial migration of long-standing internal hardware, and the need for eventual hardware removal in pediatric patients has led to the development and use of resorbable polylactic, polyglycolic, and polydioxanone acid plates in pediatric patients with traumatic injuries and those requiring reconstruction of congenital conditions. Resorbable plates retain sufficient strength until healing has taken place and then are resorbed by the process of hydrolysis within 12 to 14 months, minimizing growth restrictions.

Animal studies revealed the potential for growth restriction with rigid internal fixation in juvenile subjects. A feline model was employed to evaluate the difference between wire fixation and rigid plate fixation on cranial growth and remodeling after osteotomy. A regional growth restriction was reported for both groups, however the plating group demonstrated a compensatory growth phenomenon by craniometric analysis. These findings suggested a dynamic interplay between the developing cranium and rigid internal fixation.[27] Similar findings were reported in a rabbit model where miniplate and screw fixation were applied across the right coronal suture resulting in a significant reduction in growth across the suture.[28]

Several case reports have described transcranial migration of miniplates as well as wires after pediatric craniofacial surgery.[29–31] The physiologic explanation for this finding is the resorption of the inner table with deposition of new outer table bone that is greatest until 5 to 7 years of age.[32] Rates of migration between wires, screws, and plates are reported to be similar,[33] and in less than one half of cases does the hardware penetrate the inner table. In a series of 27 patients having undergone cranial vault reconstruction for craniosynostosis, 14% showed evidence of transcranial migration, yet only 6.6% showed evidence of intracranial plates.[34]

Complications of resorbable plates that were identified include palpability of plates, self-limited local inflammatory reactions, infections, and trauma-induced plate breaking. Sanger et al reported self-limited palpability of resorbable plates after cranial vault reconstruction in 5 of 52 patients.[28] In a series of 100 patients receiving 912 resorbable plates for cranial vault reconstruction, only 4 required screw removal due to prominence or need for contour revision.[35] In a review of 22 patients undergoing craniofacial surgery with bioabsorbable plates, two patients had a palpable plate beneath the skin[36] (Table 3).

The incidence of plate breaking due to postoperative trauma was 3.8% in the series by Sanger et al. However, union had been achieved, and no plates were removed. In a multicenter review of 1883 patients undergoing cranial vault reconstruction for craniosynostosis,

Table 3 Complications of Resorbable Plating Systems

Study	Patient Number	Indication	Complications Reported	Incidence (%)
Sanger et al (2007)[28]	52	CVR	Palpability	9.6
			Plate breaking after union	3.8
			Infection	2
			Inflammation	14
			Plate removal	2
Kumar et al (1997)[36]	22	CVR and trauma	Palpability	9
			Inflammation	4.5
			Wound	4.5
Eppley et al (1997)[35]	100	CVR	Palpability	4
			Screw removal	4
Eppley et al (2004)[10]	1883	CVR	Plate breaking	0.3
			Inflammation	0.7
			Infection	0.2
			Reoperation	0.3
Eppley (2005)[21]	29	Mandible/midface fractures	No complications	
Bell and Kindsfater (2006)[37]	59	Midface, frontal sinus, and mandible	Infection	1.7
			Malunion	1.7
			Nonunion	0
			Enophthalmos	0
			Ectropion/entropion	0

CVR, cranial vault reconstruction.

only 0.3% of patients experienced loss of plate integrity due to trauma.[10]

The incidence of self-limited inflammatory reactions in these series ranges from 0.7 to 14%, and of infection from 0.2 to 2%. The incidence of all causes of plate or screw removal ranged from 0.3 to 4%.

Resorbable plating systems have also been used to repair midface and mandibular fractures in the pediatric population with encouraging results. Twenty-nine displaced mandibular fractures were repaired with resorbable plates and screws, using either 1.5- or 2.0-mm plates. Subcondylar fractures in this series were repaired with resorbable screws and IMF, and midface fractures were repaired with resorbable 1.5-mm plates and screws. No long-term complications were noted.[21]

The indications for resorbable plate usage have been expanded to all age groups. In a series of 281 patients of all ages, 21% of patients were deemed appropriate for 70:30 polylactic acid biodegradable plate and screws (1.5 or 2.0 mm) for treatment of facial fractures based chiefly on complexity of fracture pattern.[37] Midface, frontal sinus, and mandibular fractures were treated in this manner for pediatric patients and those of advanced age alike. One patient experienced infection and another malunion among those who received resorbable plate treatment. It was observed that resorbable plates were bulkier than titanium equivalents to support a given load and were not as durable, making treatment of comminuted or displaced midface fractures unattractive.

Adequate fixation and successful recontouring were achieved in pediatric craniofacial reconstruction without significant incidence of plate-related complications. In the large, representative, multicenter experience of cranial vault reconstruction reported above, there was less than a 1% incidence of inflammation, infection, plate breaking, palpability, or removal. When resorbable polymer plating system use was extended to adult patients, craniofacial trauma repair was successful when cases with significant midface comminution were avoided.

CONCLUSION

Improvements in craniofacial fixation techniques began with improved exposure of fracture fragments to increase the number of points of fixation for placement of interosseous wires. Unfortunately, the attempts with suspension and interosseous wire fixation to combat the forces of muscles of mastication did little to preserve facial height and dental occlusion.

The advent of plating systems allowed for increased points of fixation and improved three-dimensional stability but also introduced the phenomenon of open internal fixation without proper reduction of fracture fragments. The plating systems were then miniaturized to reduce the incidence of hardware-associated pain, palpability, infection, and exposure while maintaining biomechanical strength.

Use of resorbable polymer systems revolutionized pediatric craniofacial surgery, allowing for self-limited rigid fixation to minimize the risk of clinically significant growth-restriction and transcranial migration of hardware. Use of resorbable plates has been extended to adult craniofacial surgery with only minimal reported incidence of malunion.

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