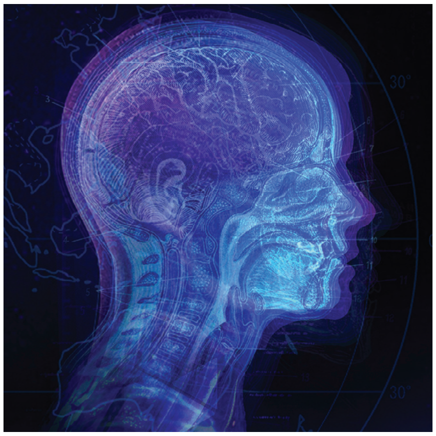
Maxillofacial Surgery

3rd EDITION

Maxillofacial Surgery



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PREFACE

The original version of this textbook, *Maxillofacial Surgery,* edited by Peter Ward Booth, Stephen Schendel, and Jarg-Erich Hausamen was first published in 1999, with a second edition revised and updated in 2007. The book quickly attracted a huge following around the world with many colleagues regarding it as the definitive text for our specialty.

Since 1999, there have been great advances across all subspecialties of oral and maxillofacial surgery. The repertoire of free flaps continues to evolve with many colleagues now doing perforator and complex composite flaps. The management of trauma, facial deformity, temporomandibular joint disorders, and craniofacial surgery, to name a few, has also advanced at a rapid rate to the point that many surgeons now only practice in one or more of these highly specialized areas. Underpinning these developments has been an exponential increase in our understanding of the biology of the diseases that affect the oral and maxillofacial region, as well as advances in adjuvant treatments, imaging, and diagnostic techniques.

Peter Ward Booth first approached Peter Brennan in 2013 with the proposal for editing a third edition. Together with Henning Schliephake, who had worked with Jarg-Erich Hausamen in Hanover, we jumped at the chance and set about completely overhauling the original chapter list and content of the new edition to bring it up to date with modern oral and maxillofacial surgery practice. We are immensely grateful to Peter for placing his trust in us and giving us the opportunity to produce a third edition, and we wish both him and Jarg-Erich long and happy retirements.

Once the book proposal had been approved by Elsevier, we realised that we would need more help, so we approached G.E. Ghali, Shreveport, LA, USA, and Luke Cascarini, London, UK, both of whom are respected surgeons and have extensive editing experience with other books. The four of us would like to thank all the section editors who have done such a great job ensuring that this book has remained on track. One of Ghali's friends, Brandon Oldenburg, kindly designed what we believe is a stunning new front cover to the book. We would also like to thank Brian Loehr, Kathy Falk, and the entire team at Elsevier in St. Louis, MO, USA, for their help, countless, never-ending emails, teleconferences, and support over the last 3 years to ensure the project was completed on time.

Along with the previous editors, many of the authors of the original chapters have since retired, and we wanted to give the book a completely new and fresh look. Therefore, there are plenty of new names in this third edition, many of whom are the future face of the specialty, who were invited for both their expertise and enthusiasm. In most cases, chapters have been written from scratch rather than reusing or updating previous chapters. The book now contains 104 chapters, and it is illustrated in color throughout, with many new areas, reflecting those changes and developments in surgical practice that have occurred in recent years. There are new chapters on biological therapies for head and neck cancer, minimally invasive salivary gland treatments and craniofacial surgery, as well as many others. With patient safety being at the core of what we do, a final chapter giving an overview of human factors has been included reflecting the importance of looking after oneself to ensure optimal performance at work and to safeguard our patients.

Inevitably with a book and project as large as this, there will be omissions and aspects of oral and maxillofacial surgery that have been overlooked, and for this we apologise in advance. We have tried to keep the book as balanced as possible across all sub-specialties, giving each area the attention and coverage that it deserves.

As with any text book, this is an ever-evolving project, and we would welcome comments or criticisms from colleagues for future editions of this book. American spelling has been used throughout the book for consistency.

Peter A. Brennan
Henning Schliephake
G.E. Ghali
Luke Cascarini

1

Etiology and Changing Patterns of Maxillofacial Trauma

Tymour Forouzanfar, Paolo Boffano

KEY POINTS

- The epidemiology of maxillofacial trauma widely varies from country to country (and even within the same country), and it is dependent on several factors, including cultural and socioeconomic background.
- Road traffic accidents (RTAs) remain the most important cause of maxillofacial trauma all over the world.
- In industrialized countries, assaults and falls have become the most important etiological factors of facial trauma.
- Sports accidents remain quite rare all over the world, with the exception of Europe where they constitute more than 10% of facial trauma.
- A thorough knowledge of the etiology and patterns of maxillofacial injuries is fundamental for the development of health services, the training of maxillofacial surgeons, and the adoption of new methods of preventing injuries.

INTRODUCTION

Maxillofacial injuries are a serious public health and economic problem, because their treatment may be expensive for national health systems. Their epidemiology varies widely from country to country (and even within the same country), depending on several factors, including the geographic area, the socioeconomic status, the cultural background, and the period of investigation.[1-61]

Maxillofacial fractures can have various causes, such as traffic accidents, falls, assaults, sports injuries, and work injuries.[1-10] The etiology of facial trauma directly affects the incidence, the clinical presentation, and the treatment modalities of facial fractures.[1-10] In many countries, traffic accidents are still the most common cause of maxillofacial fractures. In fact, road traffic accidents (RTAs) remain the most important cause of maxillofacial trauma all over the world, although in the last decades there has been a progressively decreasing trend, particularly in North America and Europe.[1,4,9-61] In these countries, assaults and falls have become more and more important, probably as a result of stricter traffic law enforcement and passenger protection devices, such as seat belt and airbags.[2,17,52,54,58] The general and progressive aging of the European population may also play a role in the increase of falls.[2,52,54,58]

A wide variation in etiology between studies from the same country, even during the same period of time, has been observed since 2000 (Tables 1-1 through 1-5).[2,9-61] This can be explained by the different social groups that refer to a particular hospital or trauma center being studied. In fact, a hospital may be a tertiary center for a mostly rural or urban population, which would reflect a different pattern of trauma. Furthermore, social behavior may differ between quarters or areas in individual cities, which would give a different role to assaults as an etiological factor for maxillofacial injuries.[1-8] In some countries (such as, North America) maxillofacial fractures are treated by multiple specialty services and without a uniform system of trauma centers, so there may also be bias in the reports of etiology of maxillofacial trauma.[1-8]

A thorough knowledge of the etiology and epidemiology of facial injuries is fundamental for the development of health services, the training of maxillofacial surgeons, and the adoption of new methods of preventing injuries.

ROAD TRAFFIC ACCIDENTS

RTAs are still among the most frequent causes of facial fractures all over the world, although assault is becoming the most frequent cause in many developed countries.[1,2,6,8]

In the recent literature, a great difference in the incidence of RTA-related facial fractures between developed countries (17% in the Republic of Korea,[34] 11% in Ireland,[54] 4% in the United Kingdom,[58] 11% in a European multicenter study[2]) and developing countries (72% to 97% in India,* 47.5% to 54.4% in China[48-50]) has been reported. This is most likely caused by the aforementioned differences in regulations and their

*References 30, 35, 37, 40, 43, 44, 47.

TABLE 1-1 Etiology of Maxillofacial Fractures in Africa: Review of the Literature Since 2000

			MAIN CAUSES			
Author(s)	**Year**	**Country**	**RTAs**	**Assaults**	**Falls**	**Sports**
Olasoji, et al[9]	2002	Nigeria	36%	**48%**	9%	4%
Adebayo, et al[10]	2003	Nigeria	**56%**	13%	24%	5%
Schaftenaar, et al[11]	2009	Tanzania	**42.3%**	39.1%	6.6%	4.9%
Hassan, et al[12]	2010	Egypt	**54%**	9.4%	—	—
Chalya, et al[13]	2011	Tanzania	**57.1%**	16.2%	14.3%	2.6%
Olusanya, et al[14]	2015	Nigeria	**79%**	11%	8%	—

RTA, Road traffic accident.

TABLE 1-2 Etiology of Maxillofacial Fractures in America: Review of the Literature Since 2000

			MAIN CAUSES			
Author(s)	**Year**	**Country**	**RTAs**	**Assaults**	**Falls**	**Sports**
Hogg, et al[15]	2000	Canada	**70%**	8%	12%	—
Brasileiro and Passeri[16]	2006	Brazil	**45%**	23%	18%	8%
Erdmann, et al[17]	2008	USA	32%	**36%**	18%	11%
Maliska, et al[18]	2009	Brazil	**48.4%**	36.4%	9.8%	—
Smith, et al[19]	2012	USA	**47%**	—	25%	—

RTA, Road traffic accident.

TABLE 1-3 Etiology of Maxillofacial Fractures in Asia: Review of the Literature Since 2000

			MAIN CAUSES			
Author(s)	**Year**	**Country**	**RTAs**	**Assaults**	**Falls**	**Sports**
Iida, et al[20]	2001	Japan	**52%**	15.5%	16.6%	9.7%
Aksoy, et al[21]	2002	Turkey	**90%**	2.7%	4.9%	0.4%
Klenk and Kovacs[22]	2003	United Arab Emirates	**59%**	4%	21.5%	5%
Motamedi[23]	2003	Iran	**54%**	9.7%	20.3%	6.3%
Ansari[24]	2004	Iran	**60%**	10%	19%	1%
Al Ahmed, et al[25]	2004	United Arab Emirates	**75%**	8%	12%	2.6%
Erol, et al[26]	2004	Turkey	**38%**	10%	36.7%	1.1%
Cheema and Amin[27]	2006	Pakistan	**54%**	8%	19%	0.5%
Kadkhodaie[28]	2006	Iran	**91%**	2.9%	5.5%	0.6%
Al-Khateeb and Abdullah[29]	2007	United Arab Emirates	**56%**	9%	20%	3%
Subhashraj, et al[30]	2007	India	**85%**	3%	7%	2%
Sasaki, et al[31]	2009	Japan	**31%**	23%	29%	14%
Abbas, et al[32]	2009	Pakistan	**38.9%**	10.7%	27%	10.9%
Ozkaya, et al[33]	2009	Turkey	**67.1%**	19.4%	12.5%	0.9%
Lee, et al[34]	2010	Republic of Korea	17%	**40.9%**	25%	11.9%
Venugopal, et al[35]	2010	India	**87%**	6%	4%	3%
Hashim and Iqbal[36]	2011	Malaysia	**61.8%**	—	19.6%	—
Gandhi, et al[37]	2011	India	**72%**	16%	9.3%	0.8%
Mesgarzadeh, et al[38]	2011	Iran	**40%**	13.5%	20.5%	9.5%
Zandi, et al[39]	2011	Iran	**43.4%**	18.4%	25.8%	6.9%
Kamath, et al[40]	2012	India	**74.7%**	15.8%	4.2%	—
Naveen Shankar, et al[41]	2012	India	**64.1%**	8.6%	24%	1%
Kapoor and Kalra[42]	2012	India	40%	**54%**	3%	1%
Singh, et al[43]	2012	India	**97%**	0.4%	2%	—
Kar and Mahavoi[44]	2012	India	**80.3%**	13.9%	3%	1%
Abdullah, et al[45]	2013	Saudi Arabia	**61%**	11.5%	20%	5.5%
Almasri[46]	2013	Saudi Arabia	**89.1%**	7.9%	0%	3%
Bali, et al[47]	2013	India	**72%**	5%	16%	2%
Jin, et al[48]	2013	China	**54.4%**	13.9%	17.2%	1.3%
Mijiti, et al[49]	2013	China	**47.5%**	17.6%	22%	3%
Zhou, et al[50]	2013	China	**52.6%**	14.1%	22.7%	1.8%

RTA, Road traffic accident.

TABLE 1-4 Etiology of Maxillofacial Fractures in Europe: Review of the Literature Since 2000

Author(s)	Year	Country	MAIN CAUSES			
			RTAs	Assaults	Falls	Sports
Gassner, et al[51]	2003	Austria	12%	12%	—	31%
Bakardjiev and Pechalova[52]	2007	Bulgaria	15.5%	**61%**	12.5%	1.5%
Pombo, et al[53]	2010	Spain	**27%**	20.5%	7.8%	11%
Walker, et al[54]	2012	Ireland	11%	14%	**38%**	35%
van den Bergh, et al[55]	2012	The Netherlands	**35.2%**	22.3%	17.4%	8.3%
Kostakis, et al[56]	2012	Greece	**50.8%**	26.3%	13.8%	3%
Kyrgidis, et al[57]	2013	Greece	**68.8%**	7.3%	4.3%	17.1%
Rashid, et al[58]	2013	UK	4%	**72%**	18%	5%
van Hout, et al[59]	2013	The Netherlands	**42%**	16%	21%	12%
Boffano, et al[2]	2015	Europe	11%	**39%**	31%	11%

RTA, Road traffic accident.

TABLE 1-5 Etiology of Maxillofacial Fractures in Oceania: Review of the Literature Since 2000

Author(s)	Year	Country	MAIN CAUSES			
			RTAs	Assaults	Falls	Sports
Buchanan, et al[60]	2005	New Zealand	24%	**36%**	11%	18%
Cabalag, et al[61]	2013	Australia	24%	**30%**	21%	15%

RTA, Road traffic accident.

implementations. In the last 30 years, the implementation of laws that require seat belts and/or airbags in cars and helmets to be worn by motorcyclists has had an impact on the incidence of facial trauma in developed countries. Noncompliance with legislation about seat belts and habits like young people driving illegally or under the influence of alcohol, as well as young children travelling as front seat passengers without restraint, can contribute to the frequency of RTAs. Furthermore, socioeconomic reasons, such as the quality of roads and enforcement of speed limits as well as the volume of traffic and the technical standard of vehicles, are crucial factors that influence the incidence of RTAs.[1,2,6,8]

The analysis of the etiology of RTAs gives us important information, in particular regarding the progressive decrease of pedestrians suffering from RTA-related injuries in industrialized countries. This may be the first result of the establishment and enforcement of more severe laws and regulations with regard to alcohol drinking and speed limits.[1,2,6,8]

As for motorcycle accidents, the crucial role of helmets has to be acknowledged. Three types of helmets can be used: (1) fixed full-face, (2) articulated full-face, and (3) open-face. Not only are people who do not wear helmets three to four times more likely to sustain a head injury than those who do, but full-face helmets in particular seem to be mostly effective in protecting the face. Studies on the wearing of helmets by motorcyclists in urban areas have highlighted the fact that the enforcement of laws makes helmet use compulsory, and helmet use provides protection against fatal brain injuries and reduces the incidence of facial injuries.[6,62-64]

In view of the overall costs of care, emphasis should be placed on prevention of RTAs. In fact, the enforcement of legislation about seat belts and crash helmets, measures for speed control, restrictions about driving under the influence of alcohol, the use of surveillance cameras in the streets, the development of subways, and the control of heavy truck traffic can reduce the number of RTAs.[6]

ASSAULTS

Assault-related maxillofacial fractures involve physical, emotional, and psychological abuse of the victim. The face is frequently the target for most acts of physical aggression because of its prominent and easily reachable position, although it has also been suggested that the main purpose of the aggressor in injuring the face would be to cause a blow to the victim's self-esteem.[4,65]

Since the implementation of programs to reduce RTAs and apply restraints in some countries, the ease of acquiring weapons and increasingly aggressive behavior in urban centers have led to a rise in the number of assaults and replaced RTAs as the leading cause of maxillofacial injuries in industrialized countries.[4,65]

Assaults and interpersonal violence have been reported to be responsible for more than 70,000 deaths annually in Europe; and for fatal injury, about 20 to 40 victims need hospital treatment, which does not include unrecorded and untreated patients.[4,66]

Because of the prominence and accessibility of the face in violent conflicts, maxillofacial fractures are frequently observed in patients coming to emergency departments after assaults and violence.[4,65,67]

Nevertheless, assault-related facial fractures are often underreported and difficult to assess because of a frequent association with illegal activities (alcohol or drug abuse, firearms).[4,65,67]

Crimes of violence are increasingly recognized as a major public health problem. Moreover, such fractures have social implications (e.g., family fragmentation, violence against women and children, unemployment, depression). These backgrounds may frequently be the cause of fear, shame, low self-esteem, and serious psychological issues in the victims, who prefer not to divulge the true causes of their injuries.[4,65,67]

The increase in assault-related maxillofacial fractures has been considered to be associated with an escalation of violence in general in today's society as a result of social and economic factors (unemployment, economic crisis, and so on). The role of assaults as an etiological factor in maxillofacial fractures is also inversely related to the decrease in motor vehicle accident–related maxillofacial fractures due to enforced passenger protection and legislation.[4,65,67]

There are regional differences in the frequency and pattern of assault-related facial injuries. They may depend on differences in social customs and alcohol intake, such as some specific religious customs or social habits that may limit or forbid the drinking of alcohol. Excessive consumption of alcohol is strongly associated with assaults, because it impairs judgement, encourages aggression, and often leads to interpersonal violence. The stricter enforcement of laws governing the sale and consumption of alcohol may have effectively prevented alcohol-related injuries in some countries.[4]

Assault-related fractures tend to affect a particular demographic group. The greater occurrence in male and young people seems related to their greater involvement in situations of both domestic and extradomestic violence.[4]

Fists and kicks are the main causative mechanisms of assault-related maxillofacial fractures. The pattern and distribution of facial fractures are strongly associated with the mechanism of assault-related injuries. In fact, the aggressor often aims at the most prominent points on the face, which are the nose, the zygoma, and the chin (with the condyle being susceptible to a direct impact injury to this region).[4] Patients with isolated maxillofacial fractures may be the victims of physical aggression, making maxillofacial surgeons often the first health care professionals to provide care to the victims.[4,65,67] Finally, turbulent political transitions, insurrections, rebellions, and civil wars may be responsible for a dramatic increase in the rate of assaults and war injuries in some countries.[68-71] Firearm injuries to the face can have minor or, more often, devastating consequences. The timing, sequence, and application of appropriate surgical procedures and techniques used for reconstruction and rehabilitation of maxillofacial warfare injuries have proved to be influential on the final outcome and aesthetic result.[68-71] This is addressed in Chapter 13.

The severity of injury resulting from facial gunshot wounds varies according to the caliber of the weapon used and the distance from which the patient is shot. Although close-range, high-velocity gunshot wounds can result in devastating functional and aesthetic consequences, shrapnel and mortar shell projectiles may be just as destructive depending on the size, irregular shape, high-velocity, and jagged edges of the fragments. Emergency care of warfare-injured patients focuses first on the basics of resuscitation and status of the airway because bleeding and subsequent swelling can compromise breathing.[68-71]

FALLS

Maxillofacial fractures following falls are relatively frequent. Furthermore, maxillofacial injuries associated with falls are influenced not only by age but also by the nature of the fall. Falls occur as a result of a complex interaction of biological (such as, age and gender), behavioral (e.g., multiple medications use, excess alcohol intake), environmental (such as, slippery floors and stairs), and socioeconomic risk factors.[1-3]

The height of the fall determines the kinetic energy transmitted to the victim, which (together with the landing position, the location of contact, and the impact surface) determines the pattern and severity of maxillofacial trauma.[1-3]

Falls on level surfaces are responsible for most fall-related maxillofacial injuries. In more than half of cases, falls follow slipping, tripping, or stumbling. Adults and elderly patients are almost equally involved, with a predominant incidence of fractures of the middle third of the facial skeleton.[1-3]

Falls due to loss of consciousness mainly involves males of all ages, being caused by lipothymia (often following hypotension) or fever following influenza, with amnesia for the traumatic event. In this category, the lower third of the face is the most frequently involved facial region.[1-3]

Finally, falls from heights are an important cause of maxillofacial trauma, frequently associated with severe injuries to multiple organs. Patients involved in these accidents are often males, between 17 and 59 years old, because many falls from heights occur in the workplace. In this category, maxillofacial fractures of the middle third are the most frequently encountered.[1-3]

SPORTS-RELATED INJURIES

Sports-related activities account for a considerable rate of maxillofacial injuries seen in large trauma centers. Social and cultural factors are crucial in sports injuries because the popularity of contact sports, such as rugby or boxing, can dramatically increase the rate of sport-related maxillofacial injuries.[1,2,5,72]

Mechanisms of injury can be divided into three categories: (1) impact with another individual, (2) impact with the ground, and (3) impact with equipment.[1,2,5]

Although age is not considered to be a risk factor, youthful temperament and vigor may contribute to a style of play that predisposes one to injury. Of course, young people certainly participate more in sports, and they probably participate in a more competitive and aggressive manner than older people.[1,2,5]

The type of sport determines the rate, the frequency, and the patterns of facial trauma. In countries where soccer is the most popular sport, it may account for hospitalization of 62.3% of sports-related maxillofacial injuries.[1,2,5]

Fractures due to skiing accidents are often caused by the impact of the head with another individual or with the ground. Overcrowding of the slopes and poorly controlled high speed play a major role in the occurrence of these injuries. Maxillofacial fractures resulting from horseback riding are mostly caused by falls or by hoof kicks to the face, which often occur due to inexperience or inattention of the rider.[1,2,5]

Facial injuries due to impact with equipment are found in ball sports (such as, golf, tennis, and baseball) where the impact with the ball may be responsible for several types of fractures, with a predilection for orbital injuries.

Two peculiar sports deserve separate consideration: bicycle riding and combat sports.[1,2,5,72] Bicycle-related injuries constitute an important etiological mechanism of maxillofacial fractures, being responsible for 1.1% to 18% of all maxillofacial fractures according to the various epidemiological studies. Bicycle-related injuries can even be considered an important, increasing, and separated etiological factor in maxillofacial fractures with typical and specific patterns, such as a peculiar seasonal incidence. The major risk groups include young people between the ages of 10 and 30. Men are more frequently affected than women, and the mandible is the most frequently involved facial bone, followed by the zygoma. Among the mandibular factures, the most commonly involved site is the condyle that appears to be associated with direct impact on the chin after falls from bicycles.[1,2,5,72]

Facial trauma is frequent in combat sports, whose aggressive offensive/defensive nature may be responsible for the high risk of sustaining dangerous injuries to the face. Hence, maxillofacial fractures are common in athletes engaged in these sports. The nose and teeth have been reported to be the most frequently injured parts, thus requiring more attention with regard to prevention. Kickboxing has been reported to be the most injurious combat sport, producing a substantial number of maxillofacial injuries.[72]

WORK-RELATED ACCIDENTS

Accidents occurring at work are well recognized as a direct cause of numerous illnesses and injuries throughout history.[1,2,7,73,74] The rate of accidents at work differs from country to country and even within the same country, because specific categories of workers may be at higher risk for facial injury. Professions involving great physical strain or the use of tools and machines have proved to be more dangerous. Hence, construction workers, forestry workers, and craftsmen have been reported to be the most often injured. In these categories, the most common causes of work-related injury seem to be blows and falls. Enforcement of work protection legislation in these professions is therefore fundamental.[1,2,7,73,74]

Regional differences may also be due to different traditions and cultures. In some countries, men commonly work outdoors and women are mainly confined to the house or work as teachers, nurses, and doctors, and only a few of them drive cars. This has resulted in an increase in the male-to-female ratio in several countries. Moreover, an increasing age of people at work in conjunction with increased life expectancy and a more active lifestyle is associated with an increase in the age of people with such injuries.[1,2,7,73,74]

Work-related accidents are commonly related to three causes: (1) human error, (2) technical failure, and (3) improper use of equipment due to a lack of training and/or instruction.[1,73,74] However, besides misuse of equipment without proper training or instruction, overtax at work, fatigue, or inattentiveness, the role of alcohol consumption should not be ignored.[1,2,74]

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2

Primary Care of Maxillofacial Injuries

Jan Roodenburg, Ken M. Lavery, Laurence Newman

KEY POINTS

- Maxillofacial injuries are common in patients with multiple traumas.
- These patients should be managed by a systematic initial care process, as outlined in Advanced Trauma Life Support (ATLS). This systematic process should begin at the site of injury and continue into the emergency department of the admitting hospital.
- The areas of most relevance to patients with facial injuries are Cervical spine injuries, Airway and breathing, Circulation, and Neurological injuries.
- The special difficulties of primary care of facial injuries demand the presence of a specialist maxillofacial surgeon.
- Following primary stabilization, a thorough secondary survey is required by a specialist maxillofacial surgeon, with particular attention to Head injuries, Uncontrolled facial/oral bleeding, and Abdominal and extremity trauma.

INTRODUCTION

Maxillofacial injuries are common. They occur in a variety of situations: road traffic accidents (RTAs), interpersonal violence, as a result of criminal activity, or during contact sports. In general, trauma care in the past decade has received a far higher profile than it was accorded previously, with many organizations now involved in a multi-professional approach to ensure the best possible outcome.

PREHOSPITAL CARE

It is well known and accepted that mortality from trauma has a trimodal distribution with three clearly defined peaks. The first peak in mortality is within seconds or minutes of the event, when the degree of injury received is such that survival is only a remote possibility, even in the most optimal circumstances. Deaths in this group are due to severe injury to the brain and the major cardiovascular structures, such as the heart and great vessels. The second peak occurs some minutes to 1 or more hours after the event. Deaths in this group are attributed to unrecognized serious complications, such as airway and ventilatory compromise, hemorrhage, and head injury. The third peak occurs days to weeks after the event, when multiorgan failure occurs and leads to death.

Mortality rates in the first group are recognized as not being amenable to secondary preventative measures; improved survival requires a change in attitudes and legislation, in particular the further development of safety features in automobiles, the separation of the automobile from pedestrians, and a reduction in the number of weapons carried and used in society.

The second peak of mortality, however, is amenable to active professional intervention. The development of ATLS, first popularized and promulgated by the American College of Surgeons Committee of Trauma, has led to a systematic approach to the treatment of trauma in many countries in the world. Increasing awareness of trauma care within the hospital services has been reflected in an increase in the training and expertise of prehospital personnel, such that optimal trauma care can now be delivered at the scene of the event. This active and aggressive approach to the management of trauma has also reduced the number of patients dying in the third peak, as active resuscitation leads to fewer instances of late organ failure. Where this approach has not been adopted, outcome studies show that up to 12% of patients suffer long-term morbidity.

Developed countries and, increasingly, developing countries have recognized that active and appropriate prehospital care delivered by fully trained paramedical personnel enhances the survivability of the accident victim. The delivery of such skilled "at-the-scene care" has been available in continental Europe with the service d'aide medicale urgente system in France and the equivalent system in Germany for some time. Other systems of prehospital care rely on a national ambulance service providing appropriately trained paramedical personnel to attend all significant trauma incidents (Fig. 2-1). The training of paramedical personnel now encompasses securing an airway with appropriate cervical spine control, securing appropriate intravenous access and initiating fluid resuscitation, and stabilizing the patient before rapid transfer to an appropriate dedicated accident and emergency department. The model of a trauma center as promulgated in the United States, although it has many merits, is not one that has gained worldwide acceptance. Still, the concept of ready availability of senior medical staff, organized as a trauma team, all working within recognized protocols, would seem to have much merit. Oral and maxillofacial surgeons play an important part in this group[1] and ideally

FIG 2-1 Road traffic accident (RTA) with trapped driver receiving care at scene: Oxygen and intravenous fluids started at scene of RTA.

FIG 2-2 Lateral cervical spine radiograph showing fracture of arch of atlas. Male patient involved in road traffic accident also had fractures of zygoma and mandible. (Courtesy Dr. W. Bowley, Consultant Radiologist, Queen Victoria NHS Trust, East Grinstead, United Kingdom.)

should undergo the same systematic training in trauma care as other colleagues.

HOSPITAL CARE

The first duty of the receiving hospital is to triage the casualties. Clearly, civilian triage and military triage (the sorting of casualties) are different, with priorities being assigned depending on the facilities available. In the United Kingdom, most patients with multiple injuries have usually suffered blunt injuries as a result of RTAs. The management of such patients is to identify and manage life-threatening problems; ideally, each accident and emergency department would have a trauma team led by a senior specialist in Accident and Emergency supported by anesthetists, with other doctors and nurses all working toward the same objectives:

- To identify and correct life-threatening injuries
- To resuscitate the patient and stabilize the vital signs
- To identify and quantify any other injuries
- To arrange definitive care including preparing the patient for transfer to other centers

In civilian practice, this triage will identify and treat the most seriously injured patient first and give a lower priority to the less seriously injured patient. Such a methodology may be summarized as follows:

Airway with cervical spine control
Breathing and ventilation
Circulation and hemorrhage control
Disability due to neurological deficit
Exposure and environment control

Particular importance has been attached to the integrity of the cervical spine in the patient with multiple traumas. Indeed, all patients who have been subjected to maxillofacial or head trauma should be presumed to have sustained a cervical spine injury until proven otherwise (Fig. 2-2). One should not forget the possibility of coexisting trauma to both the thoracic and lumbar spine. This ideology of "assuming the worst injuries" can indeed be applied to all facets of the care of the polytraumatized patient. Thus one should assume that the worst scenario exists until disproved. This will hopefully prevent the examining personnel from missing potentially life-threatening injuries.

AIRWAY AND CERVICAL SPINE CONTROL

Cervical Spine

Cervical spine injury should be suspected in all patients with an altered level of consciousness, multisystem trauma, or blunt trauma above the clavicle. A conscious patient with paralysis is usually able to identify pain at the level of the spinal cord injury with loss of sensation below. An unconscious patient who has been involved in either an RTA or a fall has up to a 10% chance of having sustained a cervical spine injury. An accurate accident history from all available witnesses—paramedics, police, or members of the public—can be valuable. The consequences of cervical spine damage can be so catastrophic that every effort should be made to prevent any further harm to the patient. Therefore until the cervical spine has been examined by an experienced clinician, it should be immobilized in the neutral

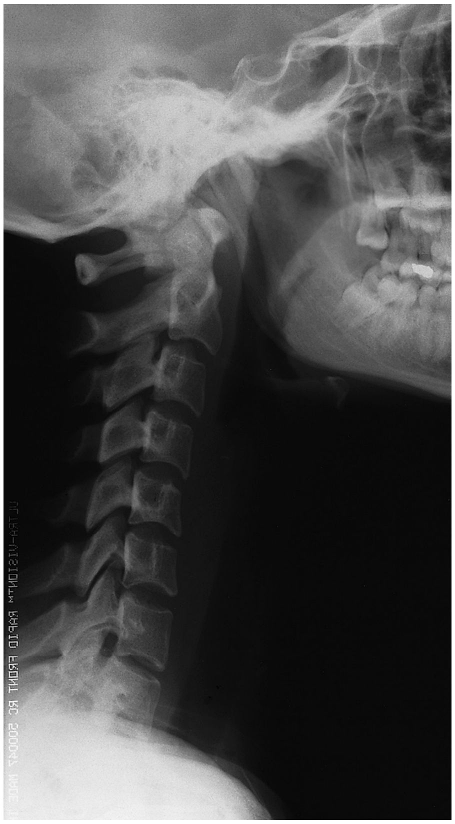

FIG 2-3 Normal lateral cervical spine radiograph showing all seven cervical vertebrae and first thoracic vertebra. (Courtesy Dr. W. Bowley, Consultant Radiologist, Queen Victoria NHS Trust, East Grinstead, United Kingdom.)

position by means of a semirigid cervical collar, spine board, and bolstering devices. Definitive radiographs showing all seven cervical vertebrae and the first thoracic vertebra are essential. A standard cross-table cervical spine radiograph may need to be supplemented with a swimmer's view if there is difficulty in visualizing the lower cervical vertebrae (Figs. 2-3, 2-4, and 2-5).

Airway

As cervical spine control is established, the patient is asked, "Are you all right?" A coherent response signifies not only that a satisfactory airway is present at that point but also that the patient satisfies criteria B, C, and D as described earlier. For the patient to respond verbally, there must be an adequate airway together with sufficient breathing and ventilation (B) to allow for cerebration. Consciousness will be lost when in excess of 50% of circulating volume (C) has been hemorrhaged. Thus by inference the patient who responds verbally to direct questioning has lost less than half the circulating volume. Similarly, coherent verbal response would exclude a significant head injury at this stage (D).

The provision of an unobstructed airway is of prime importance in order to maintain cerebral oxygenation and to avoid hypercarbia with subsequent possible permanent cerebral impairment. A high index of suspicion is required as early intervention can yield dramatic improvements. Remember that an apparently agitated and aggressive patient may actually be acting inappropriately because of hypoxia and not assumed intoxication.

FIG 2-4 Inadequate lateral cervical spine radiograph showing only five vertebrae. Patient had fracture of C7. (Courtesy Dr. W. Bowley, Consultant Radiologist, Queen Victoria NHS Trust, East Grinstead, United Kingdom.)

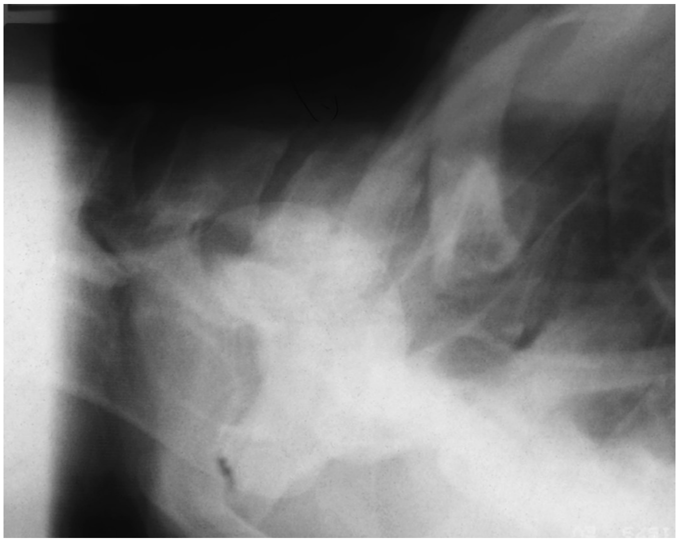

FIG 2-5 Normal swimmer's view to show C7 and T1. (Courtesy Dr. W. Bowley, Consultant Radiologist, Queen Victoria NHS Trust, East Grinstead, United Kingdom.)

A patient who is conscious and has no evidence of major oral, pharyngeal, or laryngeal injury can be assumed to have a safe airway. If the patient does not respond, the mouth should be opened and any secretions removed by suction with a rigid sucker. Patients with multiple injuries have a high risk of vomiting, and it is unsafe to place these patients in the recovery position because this may compromise the cervical spine.

Several techniques exist to provide an unobstructed airway. It is suggested that these should be adopted in a logical stepwise manner, progressing from the simple to the more complex depending on the success achieved. Techniques such as a chin lift and jaw thrust must be familiar to all personnel dealing with trauma. Suction for the removal of secretions, blood, and foreign bodies from the airway must be available and be used. Simple techniques such as oral or nasopharyngeal airway insertion will, in the majority of cases, secure the airway. If the patient has more severe damage, has no gag reflex, or requires ventilation, intubation may well be necessary and appropriately skilled personnel should be available.

Orotracheal/Nasotracheal Intubation

The positioning of a cuffed endotracheal tube is indicated in several circumstances. These include the inability to maintain an airway by any of the techniques described earlier. Alternatively, there may be a requirement to hyperventilate the patient due to a closed head injury to avoid hypercarbia. This decision should be made only after consultation with neurosurgical colleagues. Ideally, a nasotracheal tube is preferred to an orotracheal tube when cervical spine damage is suspected. The ultimate determining factor, however, should be the skill of the personnel attempting endotracheal intubation. Either technique is safe and effective if performed competently.

Failure to obtain an airway by either simple or advanced techniques necessitates a surgical airway. The fastest and safest method of obtaining a surgical airway is cricothyroidotomy (Fig. 2-6). This technique should be part of the armamentarium of all maxillofacial surgeons. Many severe maxillofacial injuries will at some stage require a tracheostomy as part of their definitive care, but tracheostomy is not recommended as part of the initial resuscitation of the patient because it is not only time consuming but technically difficult and can unnecessarily delay the securing of a definitive airway. However, in the rare case where there is laryngeal fracture—characterized by hoarseness, crepitus, and surgical emphysema—tracheostomy rather than cricothyroidotomy is indicated.

Cricothyroidotomy

A needle cricothyroidotomy provides an adequate airway for approximately 45 minutes, being limited in duration by the onset of hypercarbia. Carbon dioxide is a potent cerebral vasodilator. Hypercarbia consequently increases cerebral blood flow, and when intracranial hemorrhage has occurred, this serves to elevate an already rising intracranial pressure with a subsequent decrease in cerebral perfusion pressure. This is obviously an undesirable outcome. The placement of a needle cricothyroidotomy gives the attendant medical personnel a window of opportunity during which time other life-saving interventions can be performed. However, it should be remembered that this particular surgical airway will have to be replaced with another one. Endotracheal intubation may be reattempted; if it is still unsuccessful because of extensive midfacial disruption, a semielective tracheostomy may be performed in the more controlled environment of the operating room.

Supplemental oxygen delivered at high flow rates should be given by an appropriate method (i.e., mask and reservoir bag, Ambu bag). Clearly, once an airway has been established, the patient must be monitored to ensure that the respiratory status is satisfactory to maintain an adequate level of tissue oxygenation. This is best monitored with a noninvasive pulse oximeter technique, by which a relatively valid assessment of tissue oxygenation can be made. End-tidal carbon dioxide estimation by capnography confirms that satisfactory intubation of the airway has been achieved.

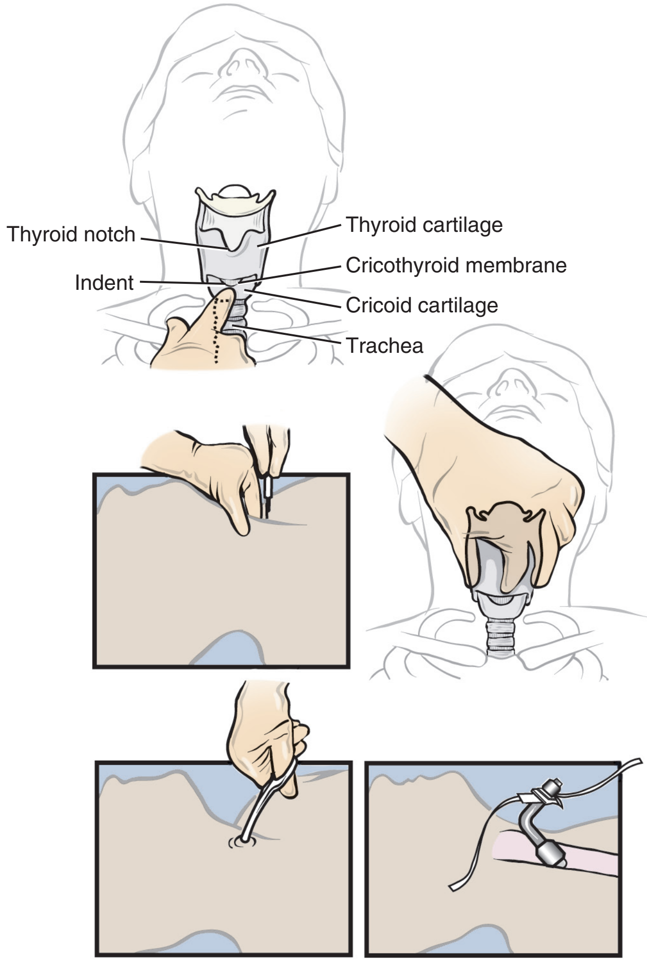

FIG 2-6 Surgical cricothyroidotomy.

BREATHING

An adequate airway is a prerequisite. Once this is ensured, the efficiency of ventilation must be assessed. Both sides of the chest should be auscultated including the axillae to assess ventilation of the periphery of the lungs. The respiratory rate should also be determined. Serious chest injuries that compromise ventilation are as follows:

- Tension pneumothorax (Fig. 2-7)
- Massive hemopneumothorax
- Open sucking pneumothorax
- Cardiac tamponade
- Ruptured diaphragm

Diagnosis of these potentially life-threatening conditions is essential and is made on the combination of the following clinical signs:

- Deviated trachea
- Absence of breath sounds in one hemithorax
- Dullness on percussion over one or both lung bases
- Muffled heart sounds

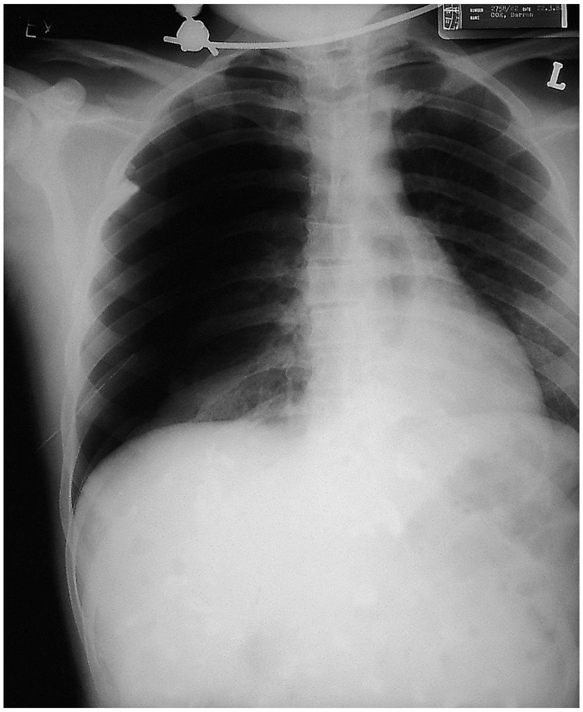

FIG 2-7 Pneumothorax in patient with fractured mandible. (Courtesy Dr. W. Bowley, Consultant Radiologist, Queen Victoria NHS Trust, East Grinstead, United Kingdom.)

Diagnosis is also made based on these radiographic appearances:

- Loss of lung markings
- Deviated trachea
- Raised hemidiaphragm
- Fluid levels

The emergency treatment of the majority of these conditions requires chest drainage with the chest drain placed in the fourth interspace anterior to the midaxillary line (Fig. 2-8).

In the case of cardiac tamponade, the use of a spinal needle to decompress the pericardium with the wandering lead of the electrocardiogram connected to the needle helps to prevent inadvertent cardiac puncture. Again, supplemental oxygenation is required.

CIRCULATION

Adequate intravenous access with two short, wide-bore needles (14-gauge) in peripheral veins (such as, the antecubital fossa) is required. The elbow and ankle are sites of election for cut-downs if percutaneous access is not possible. Occasionally an over-the-wire Seldinger technique to place a catheter in the femoral vein is useful.

Fluids for Resuscitation

Hypotension in the trauma patient should be assumed to be due to hypovolemia in the first instance. The circulating volume

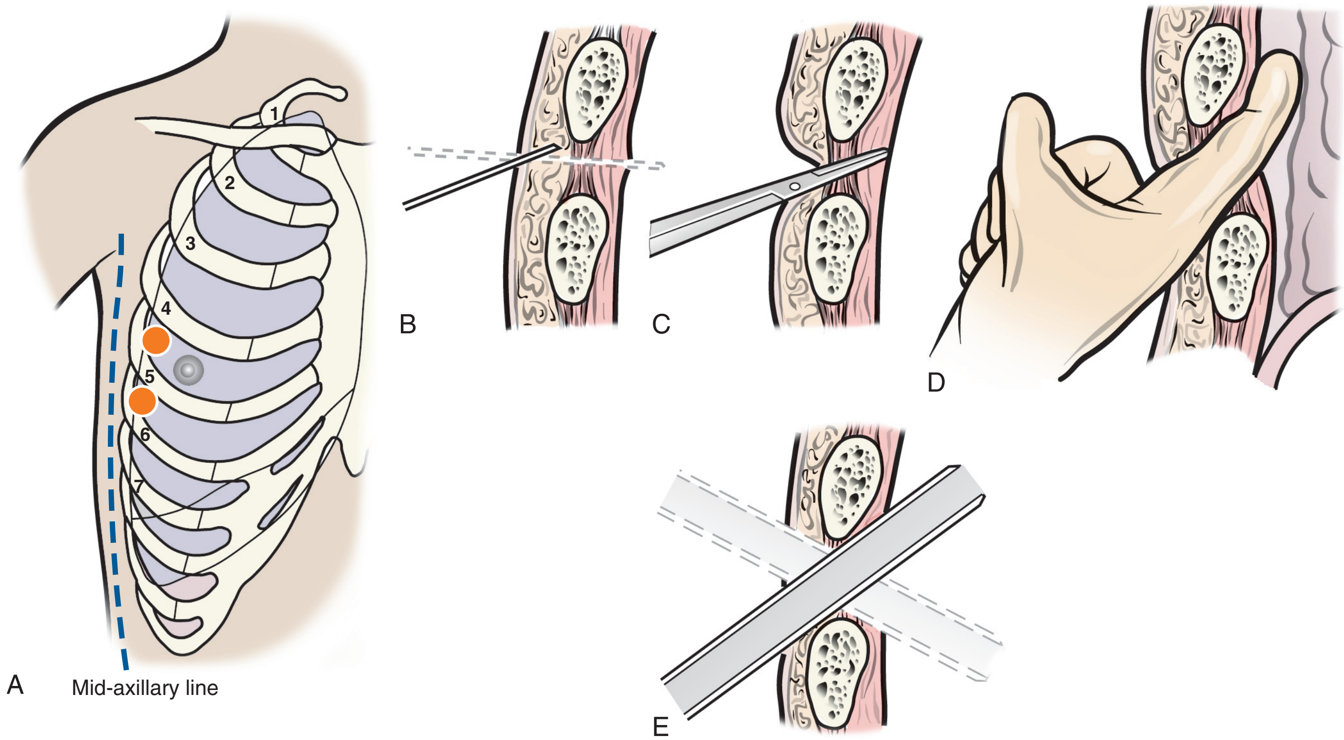

FIG 2-8 **A,** Fourth interspace anterior to anterior axillary line. **B,** Local anesthesia to skin, muscles, and pleura. **C,** Skin incision deepened with blunt forceps. **D,** Blunt dissection with finger to sweep away adhesion; explore pleural cavity. **E,** Chest drain inserted posterosuperiorly if hemopneumothorax, posteroinferiorly if mainly hemothorax.

of the adult is 7% of body weight, or approximately 5 L in the 70-kg patient and about 80 to 90 mL/kg body weight in a child. The resuscitation fluid can be either crystalloid, colloid, or blood depending on local protocols. If crystalloid is used, it should be transfused in the ratio of 3 mL of crystalloid to 1 mL blood; an appropriate initial bolus in an adult patient would be 2000 mL transfused as quickly as possible (or 20 mL/kg in the child). The response of the patient can be assessed, and further fluid can be transfused depending on the patient's response. Clearly, if the patient presents at this stage with recognizable surgical shock (being cold or clammy, with obtunded consciousness and impalpable peripheral pulses), not only will aggressive fluid resuscitation be necessary, but there will also be a requirement for blood transfusion; in an emergency, group O negative blood can be used. If the patient can be stabilized until type-specific blood is made available, then the chance of transfusion reactions is diminished.

The effectiveness of the resuscitation can be ascertained by an improvement in the patient's condition and by monitoring the urine output. Parameters reflecting the degree of hypovolemia are as follows:

- Tachycardia
- Hypotension
- Narrowing pulse pressure (systolic minus diastolic)
- Tachypnea
- Delayed capillary return
- Falling urinary output
- Deteriorating mental status (i.e., increasing confusion)

Care must be exercised when treating fit athletes, because they may compensate to a significant degree, masking the signs identified previously until a significant volume loss has occurred. Similarly, older adults may not demonstrate normal physiological responses to volume loss because of β-adrenoceptor blocking medication. *Tachycardia* is defined as a heart rate greater than 100 beats/min in an adult, greater than 120 beats/min in a school-age child, greater than 140 beats/min in a preschool-age child, and greater than 160 beats/min in an infant (younger than 2 years old).

Urine output is a sensitive indicator of cardiac output. Therefore placement of a urinary catheter is essential in all significant trauma patients. In the male patient, urethral catheterization is contraindicated in the presence of a urethral tear, as suggested by a scrotal hematoma, blood at the penile meatus, or a high-riding or impalpable prostate. Urethral tears are exceptionally rare in the female. Suprapubic catheterization is performed if urethral catheterization is contraindicated. An adult should produce 50 mL of urine per hour. A child should void 1 mL/kg body weight per hour, and a child younger than 1 year old should void 2 mL/kg body weight per hour. Levels below these suggest inadequate fluid replacement.

A wide-bore nasogastric tube decompresses the stomach and allows aspiration of food, alcohol, or swallowed blood. Again, in severe maxillofacial injuries care must be taken to ensure that the nasogastric tube passes into the stomach and does not complicate a high-level craniofacial fracture.

NEUROLOGICAL DEFICIT

A rapid assessment of the patient's neurological disability can be made by noting the patient's response on the four-point AVPU scale:

- Responds appropriately—is awake
- Responds to verbal stimuli
- Responds to painful stimuli
- Does not respond—unconscious

This, coupled with an assessment of the pupil reaction, allows rapid assessment of the degree of head injury.

All trauma patients must be fully exposed. Therefore the environment must be warm and appropriately protected to ensure that the patient suffers no further harm by being exposed to the surrounding ambient temperature. The patient should be fully examined including an examination of the back, if necessary, by using a logroll technique to ensure that otherwise hidden areas have been inspected.

SECONDARY SURVEY

Most maxillofacial patients will have been resuscitated and stabilized by the trauma team. The maxillofacial surgeon may or may not be part of the trauma team but will certainly be involved in the definitive treatment of the facial injuries. It is important at all stages of the management of the trauma victim that reassessment is regularly carried out to ensure that the patient is still stable and to detect any early deterioration. This head-to-toe examination involves examination of all body systems.

HEAD INJURIES

Head injuries fall into two broad categories: open or closed. The local effect of injury may be limited to a scalp laceration or extend to full penetrating injury to the skull and therefore to the underlying brain. Therefore all scalp lacerations, however minor their appearance, should be explored with a protected finger to ensure that the underlying skull is intact before they are closed (Fig. 2-9). Obvious open head injuries indicate a severe head injury and mandate the involvement of the neurosurgeon at this stage.

Closed head injuries are more common. In mild concussion, there is a momentary loss of consciousness and possibly a short period of apnea with mild changes in intracranial and arterial blood pressure also being noted. However, the patient completely recovers from this relatively minor injury and shows no

FIG 2-9 Scalp lacerations should be explored before being closed.

residual deficit. More severe closed injuries result in unconsciousness with changes in the intracranial pressure, the arterial blood pressure, and temperature. The injury to the brain results from both direct and indirect (contrecoup) injury due to a mixture of potential movements of the brain and brainstem within the closed environment of the skull. Severe diffuse axonal injury leads to unconsciousness with bilateral decerebrate posture and is associated with a poor outcome.

Intracranial hematoma can form in any area of the brain but is potentially common in the frontal lobes and temporal lobes. These injuries can range from minor to severe, with late rises in intracranial pressure due to the associated edema of the brain tissue. Intracranial hemorrhages occur in a high percentage of patients rendered unconscious as a result of head injury.[2] The classic extradural hematoma occurs rarely, in less than 1% of patients admitted with head injury. Acute subdural hematoma is more common and is also associated with a higher mortality than extradural bleeds. The effect of the subdural hematoma as a space-occupying lesion results in a rapid rise in intracranial pressure. The compensatory mechanisms in the brain—reduction in cerebrospinal fluid (CSF) volume and a compensatory decrease in arterial blood pressure due to the effect of the rising intracranial pressure on the baroreceptors—can alleviate some of this mass effect. Only when the compensatory mechanisms are exhausted does a rapid rise in intracranial pressure occur with a rise in blood pressure and the patient demonstrating the signs of brainstem compression. If this is not treated, the patient progressively deteriorates and will die within 24 hours. With any damage to the brain substance, edema and a rise in intracranial pressure develop within 48 to 72 hours of trauma. Cerebral blood flow is affected by both the partial pressure of oxygen (PO_2) and the partial pressure of carbon dioxide (PCO_2): Arterial PO_2 less than 7 kPa causes an increase in cerebral blood flow; PCO_2 greater than 6 kPa also causes an increase in cerebral blood flow. This leads to an increase in edema and therefore a rising intracranial pressure. The ability of the brain to autoregulate the cerebral blood flow is impaired by the following:

- Ischemia
- Hypoxia
- Brain trauma

All of these conditions are seen in significant head injuries (Fig. 2-10). It is clear that adequate fluid resuscitation and oxygenation, as well as prevention of a rise in intracranial pressure by elective positive ventilation to reduce the PCO_2, will help to minimize the effect of the rise in intracranial pressure as a result of head trauma.

Assessment of Head Injuries

Once the patient is stabilized, a detailed assessment of the level of head injury is made. As has already been discussed, many patients are admitted with head injuries, but few require neurosurgical intervention. The aim is to prevent further damage by thorough resuscitation of the patient.

In the initial assessment the degree of head injury is rapidly ascertained by using the AVPU schema; during the secondary survey, after adequate resuscitation, a more careful assessment of the patient's head injury should be made using a combination of the pupil reactions and the Glasgow Coma Scale[3] as well as a thorough examination of the head and neck area. At each stage, documenting the response in a reproducible objective form is important (Table 2-1).

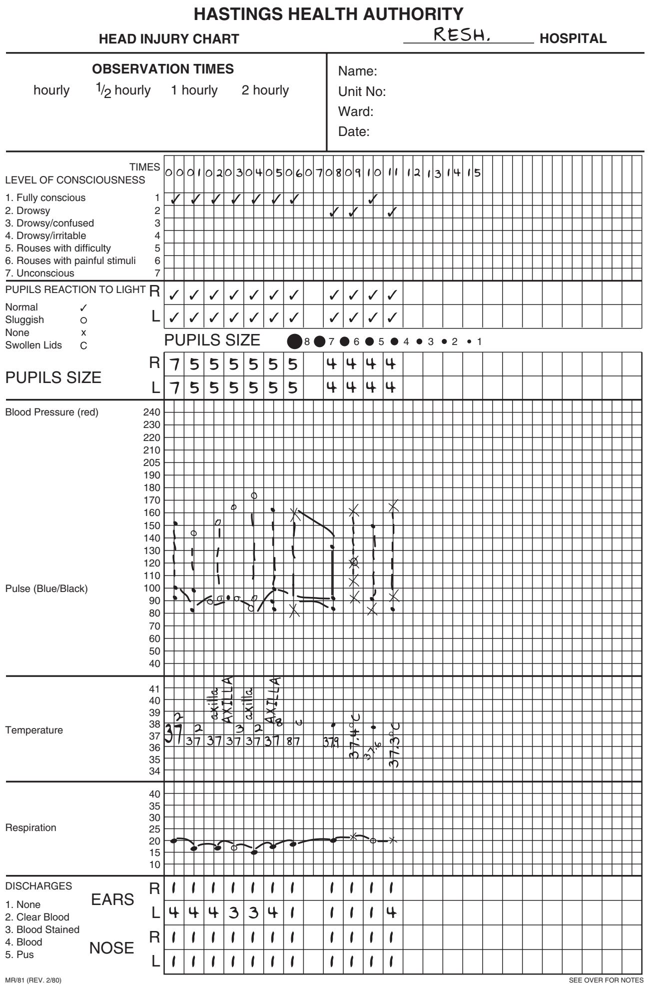

FIG 2-10 Head injury chart.

TABLE 2-1 Glasgow Coma Scale*

Assessment	Score
Eye Opening (E)	
Spontaneous	4
To speech	3
To pain	2
Nil	1
Best Motor Response (M)	
Obeys	6
Localizes	5
Withdraws	4
Abnormal flexion	3
Extensor response	2
Nil	1
Verbal Response (V)	
Orientated	5
Confused conversation	4
Inappropriate words	3
Incomprehensible sounds	2
Nil	1

From Jennett B, Bond M: Assessment of outcome after severe brain damage, *Lancet* 1(7905):480-484, 1975.
*Coma score = E + M + V (minimum = 3; maximum = 15)

Clinical Examination

Level of Response

The level of response is assessed using the Glasgow Coma Scale. This scale measures the best response on three parameters: eye opening, verbal performance, and motor responsiveness (see Table 2-1). Some further information can be obtained by assessing both the best and the worst motor responses.

Pupil Response

Documenting the pupillary response and repeatedly examining the pupillary response until the patient is stable are important. The sign of an ipsilateral dilating pupil (when previously the pupils were equal and reacting) is a sinister sign of a focal lesion, causing an increase in intracranial pressure. However, unilateral dilatation may have other causes, such as the following:

- Direct injury to the eye
- Optic nerve damage
- Ocular motor nerve compression

The combination of a dilating ipsilateral pupil with a decreasing level of consciousness is a sign of an increase in intracranial pressure and the need for neurosurgical intervention. When the pupil is dilated immediately following a head injury, the likeliest cause is damage to the optic nerve itself; the pupil is dilated and not reacting to light. In the situation where a dilated pupil reacts to light directly or consensually, the likeliest cause is damage to the ocular motor nerve. In an optic nerve lesion, the pupil reacts consensually.

The best motor function of the patient is then assessed, as well as the patient's best verbal performance. This allows a numerical score of the Glasgow Coma Scale to be given, and this is documented and recorded. The routine measurements of vital signs continue until the patient is stable. Even in patients with obvious severe head injury associated with polytrauma, a low blood pressure should be assumed to be due to hypovolemia and treated aggressively, rather than the assumption being made that this is as a secondary response to the head injury.

Careful examination of the rest of the head and neck must be carried out. Epistaxis may result from a fracture to the midface or may indicate a fracture of the floor of the anterior cranial fossa, with CSF rhinorrhea. This should be carefully documented; most CSF rhinorrhea resolves on treatment of the facial fractures, but the presence of the dural tear renders the patient more liable to complications (such as, meningitis) at a later stage. At some stage in either the primary or secondary survey, the patient should be logrolled to ensure that the back is inspected. During this time the alignment of the spine can be inspected and palpated. Other elements of spinal injury develop as later features (i.e., retention of urine and absence of sweating to the level of the lesion). In a conscious patient, reduction in the sensation of pain below the level of the spinal injury and the presence of these elements must all be noted and recorded.

Never assume that unconsciousness is due to alcohol or drugs until all other potential causes have been cleared. Whenever there is any doubt about the head injury status of the patient, it is important to discuss this at an early stage with the neurosurgical service.

ABDOMEN

The abdomen is a potential site for major occult blood sequestration: A high index of suspicion is invaluable when managing the multisystem trauma patient. Up to 20% of patients with acute hemoperitoneum may not demonstrate any signs of peritonism; this can therefore be potentially fatal if overlooked. Bleeding may occur into the peritoneal cavity, the retroperitoneal space, or the pelvic cavity. The most salient feature regarding abdominal trauma is to establish that an injury exists rather than to establish an accurate initial diagnosis.

Abdominal examination proceeds in the standard manner of inspection, palpation, percussion, and auscultation and includes examination of the rectum and perineum. Rectal examination may indicate spinal injury when either absent or diminished sphincter tone exists. Pelvic fractures may be palpated. An impalpable or high-riding prostate suggests urethral damage. Urethral tears are rare in the female. Urethral damage in the male is further suggested by scrotal hematoma or blood at the penile meatus. If such an injury is suspected, urethral catheterization should be delayed until an ascending urethrogram has been performed.

Nasogastric intubation should be performed unless there are midfacial fractures, in which case orogastric intubation should be achieved. Gastric decompression is of value in the trauma patient because it reduces the risk of aspiration of stomach contents into the lungs and prevents acute gastric dilatation, which can impede venous return.

Patients who have sustained abdominal, brain, or spinal cord injury may not demonstrate any signs of intraabdominal pathology; diagnostic peritoneal lavage (DPL) is therefore essential in such cases. This procedure is 98% sensitive for intraperitoneal bleeding and is deemed *positive* if any of the following is obtained:

- Frank blood on aspiration
- White cell count greater than 500 cells/mm^3
- Red cell count greater than 100,000 cells/mm^3
- Bowel content (i.e., bile, fecal material or bacteria)
- Urine

A positive DPL necessitates emergency laparotomy. If there are signs of an acute abdomen, there is no need to perform a DPL because the indications for emergency laparotomy already exist. Relative contraindications to DPL include previous abdominal surgery, advanced liver disease, and coagulopathies. The use of DPL in pregnant patients remains controversial. Computerized tomography may replace DPL in the pediatric patient, but consultation with pediatric surgical colleagues is essential.

EXTREMITY TRAUMA

Extremity trauma (although rarely life threatening) remains one of the most important aspects of trauma. Braithwaite and colleagues[4] reviewed 157 patients with an injury severity score greater than 15 and showed one quarter of these patients to be permanently disabled by long-term orthopedic problems.

Extremity trauma is a potential cause of major occult blood loss. Fractures of the tibia and fibula, femur, and pelvis can result in the loss of 1.5 units, 3 units, and 6 units of blood, respectively. The particular points of interest in this category are as follows:

- Impaired distal limb perfusion
- Traumatic amputation
- Compartment syndrome

Grossly deformed limbs should be straightened as part of circulation control (C) in the primary survey and placed in traction during the secondary survey. Devices, such as a Thomas splint, achieve traction quickly and effectively. Perfusion may be reestablished by a combination of limb traction and the repletion of intravascular volume. Once the patient is stable, arterial imaging studies may be performed as appropriate following consultation with vascular surgical colleagues. Initially, any obvious hemorrhage is simply controlled with local pressure.

Amputated limbs may be suitable for replantation. The transected part should be cleansed and wrapped in a sterile towel moistened with saline, placed in a sealed plastic bag, and transported in an appropriate container filled with crushed ice. Amputated limbs can remain viable for up to 18 hours if managed as described earlier; if left at room temperature, their viability decreases to 6 hours. The patient should be administered tetanus toxoid and appropriate antibiotics.

Compartment syndrome is suggested by pain, particularly on passive movement of the limb, decreased sensation of the affected part, and tense swelling with paralysis. This situation requires urgent attention, probably including fasciotomy. Consultation with colleagues is mandatory.

Dr. W. Bowley, Consultant Radiologist, Queen Victoria NHS Trust, East Grinstead, United Kingdom, provided the radiographs shown in this chapter. We wish to acknowledge the knowledge and inspiration we have both gained from the Advanced Trauma Life Support courses that we have attended and taught.

PITFALLS

- Severe facial injuries will bleed and produce swelling; a common pitfall is to assume this is the cause of the following:
  - Airway/breathing difficulties
  - Loss of circulating volume
- Other causes, such as the following, must be excluded first:
  - Chest injuries: Airway/breathing difficulties
  - Abdominal or extremity trauma: Loss of circulating volume
- Although not life threatening per se, facial/oral bleeding can obstruct the airway, and adequate suction and supervision must be available during primary and secondary ATLS surveys.
- The absence of specialist maxillofacial surgery in complex facial injuries may lead to suboptimal initial care.

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3

Establishing a Clinical Diagnosis and Surgical Treatment Plan

Riitta Seppänen-Kaijansinkko, Juha Kalervo Paatsama, Christian Lindqvist

KEY POINTS

- Careful examination is required for an accurate diagnosis.
- Correct diagnosis will facilitate correct treatment planning.
- Careful treatment planning will result in an optimal treatment plan.
- Accurate surgical technique will lead to optimal surgical outcome.

GENERAL CONSIDERATIONS

In maxillofacial trauma surgery, treatment protocols have changed enormously during the past two decades. With ever-increasing patient expectations, readily available modern diagnostic equipment, and high levels of clinical audit, a good diagnosis and good treatment planning are expected to lead to excellence in the outcome of the primary treatment. Because of the advances in emergency care and transportation facilities, more severely injured patients survive to receive surgery at regional trauma centers.

In the past, it was sufficient to establish a proper occlusion; today, however, patients also demand good esthetic and functional results, and with the methods and equipment currently available, maxillofacial surgeons can meet these demands.

Where children are concerned, injuries most often occur at play.[1] In adults, however, the etiology of injuries varies greatly. In a large series from Austria published by Gassner and colleagues, activity in daily life and sports accounted for 69% of the facial trauma, whereas only 12% was caused by violence.[2] However, in a study by Alvi and colleagues, 41% of the facial fractures in Chicago were caused by assault.[3] In Bulgaria, mandibular fractures occur five times as often in males as in females and predominate in young patients (20 to 29 years of age). The causes for fractures of the lower jaw vary; the leading factor being assault and alcohol abuse (68%).[4] Alcohol abuse seems to be an important factor in maxillofacial trauma: In the United Kingdom, at least 22% of all the facial injuries in all age groups were related to alcohol consumption within 4 hours of the injury. In the older than 15-year-old age groups, alcohol consumption was associated with 90% of facial injuries occurring in bars, 45% on the street, and 25% at home. Assault, road traffic accidents, and alcohol consumption conveyed an increased risk of serious facial injury.[5] In Finland, 72% of patients with mandibular fractures were under the influence of alcohol at the time of the injury.[6]

If the patient has multiple injuries, adequate consultations and examinations must be carried out before entering the operating room (Box 3-1). Although the use of air bags has greatly decreased the incidence of severe facial injuries in traffic accidents, many high-velocity trauma mechanisms still may cause severe injuries in the facial skeleton.[7] In patients fatally injured in airplane accidents, the most commonly occurring bony injuries were fracture of the ribs (72.3%), skull (55.1%), facial bones (49.4%), tibia (37.9%), and pelvis (36%). A fractured larynx was seen in 14.7% of the patients. Also observed was that patients who sustained brain hemorrhage were more likely to have fractures of the facial bones rather than skull fractures.[8] The incidence of life-threatening trauma in patients with facial fractures varies in different studies. In a series of 1025 patients with facial fractures, 64 (6.2%) required a lifesaving intervention: 21 patients had a cerebral trauma requiring craniotomy, 19 had hemorrhagic shock, 17 had airway compromise, and seven had pulmonary injuries requiring tube thoracotomy.[9] In another series by Fischer and colleagues, among patients with mandibular fractures sustained in motor vehicle accidents, 65% of the patients had a life-threatening associated injury and cause of mortality.[10] The mortality rate in this study was 8%. Carlin and colleagues reported on 828 patients with significant mandibular or midfacial trauma.[11] The maxilla was the most often injured bone (61%), with the zygoma (45%) and mandible (42%) following (Figure 3-1). If the trauma has been sufficient to fracture facial bones, one should always bear in mind the possibility of a cervical spine injury, which Fischer and colleagues documented in 22% of patients with mandibular fractures caused by motor vehicle accidents.[10] This may be caused by a sharp extension movement of the head and neck, especially in patients over 60 years of age. A skull fracture was seen in 43% of patients with mandibular fractures sustained in traffic accidents. Often it is possible for different specialists to treat patients with multiple trauma simultaneously, thereby shortening the operation time.

A maxillofacial surgeon of this millennium must be capable of evaluating and treating hard and soft tissue injuries of the head and neck with equal competence. To achieve these high standards, a logical and well-documented approach must begin as soon as the surgeon is asked to see the patient.

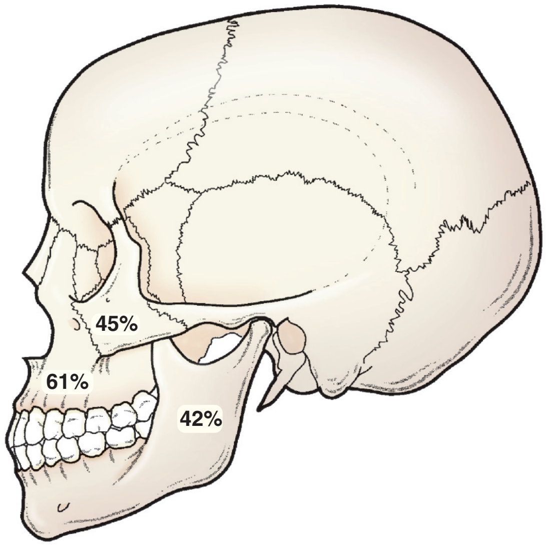

FIG 3-1 Facial bone fractures in 158 polytrauma patients involved in traffic accidents: frontal, 2; orbit, 4; zygoma, 27; nasal, 15; maxilla, 4; mandible, 44; panfacial, 62. (Data from David DJ, Simpson DA: *Craniomaxillofacial trauma,* New York, 1995, Churchill Livingstone.)

BOX 3-1 Indications for Consultation in Maxillofacial Trauma

Ophthalmologist
Blindness or impaired vision
Eyeball or large eyelid laceration
Direct eyeball trauma
Amnesia
Comminuted midface trauma

Oculoplastic Surgeon
Large soft tissue defect in periorbital region and/or eyelid defect greater than half of the lid

Ear, Nose, and Throat Surgeon
Posttraumatic hearing problems related to trauma
Large defects in external ear
Vertigo

Neurosurgeon
Intracranial problem: bleeding and/or air in intracranial space
Cerebrospinal fluid otorrhea/rhinorrhea

EYEWITNESS REPORTS OF THE INCIDENT

Reports of the incident given by the patient or eyewitness will give a clue as to what has happened and what might be expected to be found. The patient with a high-energy injury (e.g., a motor vehicle accident) is likely to have a more complex fracture pattern than a patient who has been assaulted. The severity of the trauma also depends on the mechanism—being hit compared with being kicked or being stabbed with a knife. These examples have different effects: the first, predominately hard tissue damage; the second, a mixture of hard and soft tissue injuries; and the stabbing injury, predominately soft tissue damage. The surgeon must have a logical system of examination

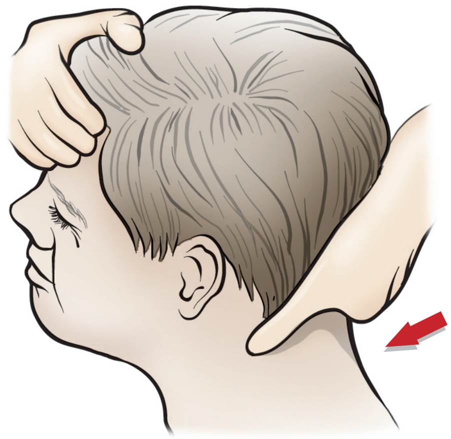

FIG 3-2 Examination of cervical spine by traction. Hold the head firmly in place. Look for ecchymotic areas, and palpate to find tenderness and steps indicating deformities or subluxations in vertebrae.

for the whole patient. The acute trauma life system is a popular standard approach that is becoming an international norm. This immediate management is discussed in Chapter 2.

Social background and living conditions influence treatment options and sometimes the cooperation of the patient as well.

CLINICAL DIAGNOSIS OF MAXILLOFACIAL TRAUMA

When one is examining a trauma patient, one should make a full written documentation of the patient's condition, indicating all positive and negative signs and symptoms in a consecutive, systematic way. Simple drawings of the injuries can be useful and so can firsthand digital pictures, if available. Before starting the clinical examination of the maxillofacial area, make sure that any other systemic injuries have been evaluated, such as cervical spine injury or chest trauma. Further cervical trauma can be prevented by cervical spine stabilization in such a manner that the head and neck are maintained in a stable position (Figure 3-2).

The first examination should eliminate immediate problems, such as excessive bleeding, airway obstruction, and severe ocular injuries. These must be attended to first and the clinical examination continued later. Chapter 2 deals with these immediate management details. Later, it is important to repeat the examination in case any new signs or symptoms have developed.

Neurological Examination

The neurological examination should begin with an overall impression of the patient (Table 3-1). The Glasgow Coma Score (GCS) gives an indication of the neurological status and its progression as GCS recordings are repeated, but the maxillofacial surgeon also should pay attention to the status of the cranial nerves. Table 3-2 lists the function and testing of all cranial nerves.

External Examination

Start the maxillofacial examination by inspecting the scalp and cranium for lacerations and gross contour deformities, hematomas, or bruising (Box 3-2). Such injuries can be concealed easily by hair. Follow this examination with palpation to find any tenderness, crepitation, depressed or penetrating bone fragments, or contour irregularities.

Continue the inspection of the rest of the maxillofacial region by examining from different angles: anterior, lateral, and above (Figure 3-3). Check for and document any asymmetries, deformities, swellings, and hematomas. Look for evidence of a cerebrospinal fluid leak, which is seen as a flow of clear, watery fluid, often running between lines of clotted blood ("tramlines"). Document any skin lacerations, especially looking for any that might have damaged ducts or nerves. The parotid duct is cut easily in knife attacks, and naturally any damage to the facial nerve must be detected (Figure 3-4). In a conscious patient, one may easily ascertain facial nerve damage by asking the patient to move the muscles of facial expression.

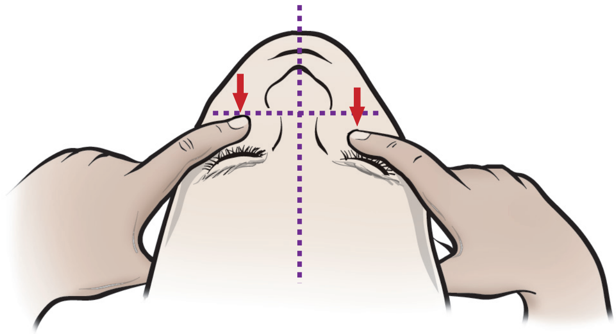

FIG 3-3 Extraoral inspection should be carried out from different angles. Overhead view reveals an impression in the zygomatic area.

TABLE 3-1 Glasgow Coma Scale*

Motor Responsiveness	Best Verbal Performance	Eye Opening
6. Obeys	5. Oriented, converses	4. Spontaneous
5. Localizes pain	4. Disoriented, converses	3. To verbal stimuli
4. Flexion, withdrawal	3. Inappropriate words	2. To pain
3. Flexion, abnormal	2. Incomprehensible sounds	1. Never
2. Extension	1. No response	
1. No response		

From Jennett B, Bond M: Assessment of outcome after severe brain damage. *Lancet* 1(7905):480-484, 1975.
*During the first 24 hours but after 6 hours of the trauma, scores of 4 or less correlate with poor prognosis, and scores of 11 or more correlate with good prognosis.

BOX 3-2 Extraoral Examination

Inspection
Asymmetry
Swelling
Hematoma
Skin laceration or defect
Facial nerve
Mouth opening

Palpation
Tenderness
Fracture line/step
Crepitation
Trigeminal nerve
With special attention to base of the mandible and temporomandibular joint area

TABLE 3-2 Function and Testing of Cranial Nerves

Number	Name	Function	If Injured
CN I	Olfactory	Olfaction	Loss of the sense of smell
CN II	Optic	Sight	Affected sight
			Direct light reflex missing, contralateral eye: no indirect light reflex (light reflex also via CN III)
CN III	Oculomotor	Musculus sphincter pupillae	Both direct and indirect light reflex missing (light reflex also via CN II)
		Most extraocular muscles	Eye turned outward because of the lack of the function of most eye muscles
		Musculus palpebrae superior	Ptosis
CN IV	Trochlear	Musculus oblique superior	Eye turned inward
			Diplopia
CN V	Trigeminal	Sensory nerve to face	Diminished sensation in the skin of the face
		Corneal reflex	Diminished strength in masticatory muscles
		Masticatory muscles	Missing corneal reflex
CN VI	Abducens	Musculus rectus lateralis	Eye turned inward, reaches midline at the most
CN VII	Facial	Facial muscles	Paralysis of mimic facial muscles
		Taste in the anterior two thirds	Partial: Severed nerve
			Total: Cranial base injury
CN VIII	Vestibulocochlear	Hearing	Loss of hearing
CN IX	Glossopharyngeal	Function of the soft palate and pharynx	Asymmetrical elevation of palate
			No gag when posterior pharynx is touched
CN X	Vagus		Endotracheal suctioning does not trigger coughing
CN XI	Accessory	Musculus sternocleidomastoideus and upper trapezius lifts the shoulder	Head turned to side; ability to resist force decreased
			Decreased ability to lift shoulder
CN XII	Hypoglossus	Tongue	Atrophy, fasciculation, and weakness

CN, Cranial nerve.

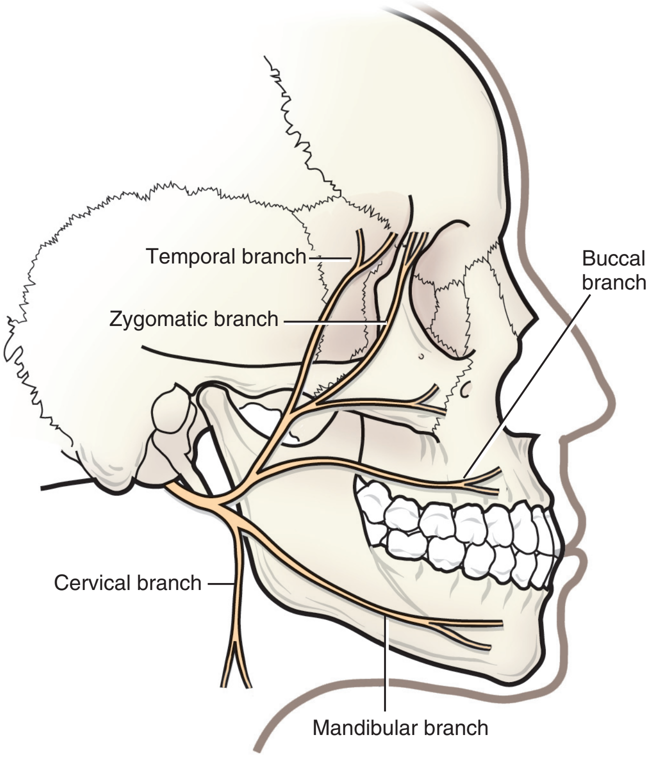

FIG 3-4 Distribution of the facial nerve branches.

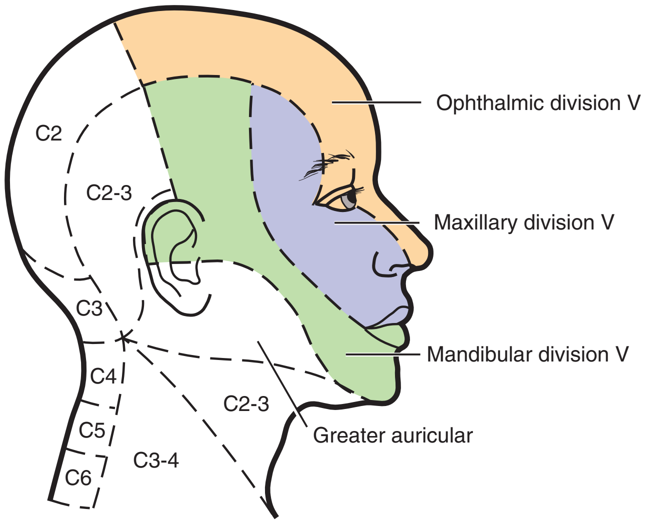

FIG 3-5 Cutaneous branches of the trigeminal nerve.

In the unconscious patient, damage may have to be suspected by the location of the injury and exploration undertaken to confirm the damage by direct examination or electrical stimulation. Note stabbing injuries because these can penetrate deeply, often in unpredictable directions. Be alert for deeply impacted foreign bodies (e.g., wood fragments).

Document the patient's mouth opening, both deviation and limitation. Bear in mind that limited mouth opening may be caused by a fractured condyle, displacement of the zygomatic arch on the coronoid, or just by pain and impaired muscle function. Preexisting temporomandibular joint dysfunction also must be taken into account. Compare these findings with earlier photographs of the patient (e.g., from a driver's license) if they are available. In a severe trauma patient, the surgeon should always obtain a photograph before reconstructing the face. These images then can be digitized and stored in the same folder as other digital radiographs and photographs of the patient.

Continue by palpating the bony contours of the midface and mandible, starting from the lateral areas toward the midline and downward. Check for any tenderness or palpable fracture lines in key areas: zygomatic arch, frontozygomatic suture, nasofrontal area, infraorbital rim, base of the mandible, and temporomandibular joint area. Document any crepitation, which indicates the presence of air in soft tissues. Document the function of the trigeminal nerve (Figure 3-5). Check any mobility of the maxilla. This normally is carried out by grasping the maxilla by the anterior alveolus (not the teeth, which may have been loosened) and feeling for any motion. This is most easily appreciated by gripping above the maxilla—for example, by the nasal bridge at the frontal suture or the frontozygomatic suture—and feeling for any movement between these two points (Figure 3-6).

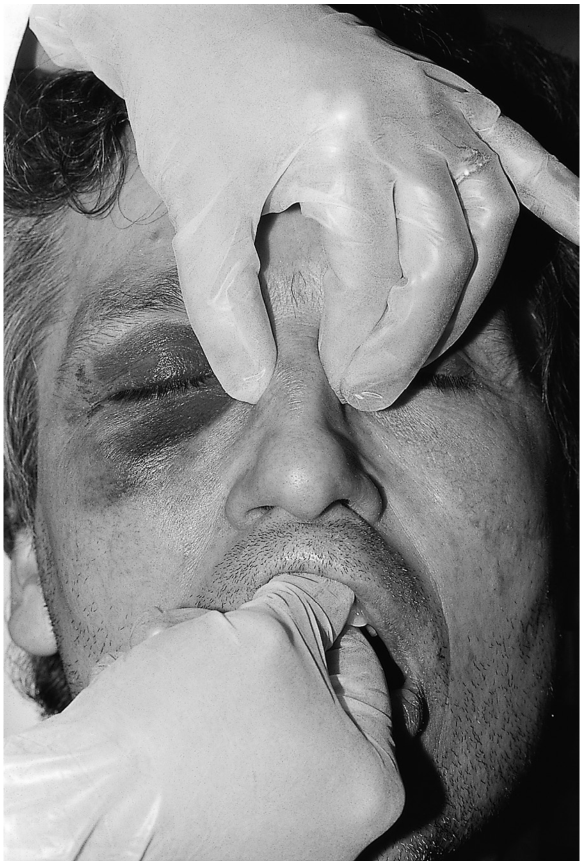

FIG 3-6 Checking for mobility of the maxilla. Grasp the anterior alveolus firmly by the fingers. Remember to beware of loose teeth. Note any mobility of the maxilla. This is normally carried out by grasping the maxilla by the anterior alveolus (not the teeth that may have been loosened) and feeling for any motion. This is appreciated most easily by gripping above the maxilla, such as the nasal bridge at the frontal suture or the frontozygomatic suture, and feeling for any movement between these two points. (Courtesy Dr. Juha Paatsama.)

A simple method of detecting mandibular fractures extraorally is to press carefully but firmly at both angles of the mandible. This should produce medial compression and flex the whole mandible, producing motion and discomfort if a fracture is present in any part.

The examination also should always include the ear and orbital contents. In patients with midfacial fractures, 81% suffered eye injuries of varying degrees.[12]

Examination of the Ear

Check the external ear for any hematomas, lacerations, and defects that might need evacuation in connection with the surgical procedure. Perform a uroscopy in all maxillofacial trauma patients to examine the external auditory canal and the tympanic membrane.

An obstruction, laceration, or hematoma in the wall of the canal might indicate a fracture of the temporomandibular joint fossa and/or posterior dislocation of the condylar head. Clean the auditory canal of blood to enable adequate identification of the bleeding site and to examine the tympanic membrane and observe blood in the middle ear (hemotympanum), which suggests a skull base fracture. Sometimes cerebrospinal fluid leakage also can be observed, usually mixed with blood in the case of a ruptured tympanic membrane. Use a tuning fork to evaluate the function of the middle and inner ear. If there are problems, consult an ear, nose, and throat specialist.

Examination of the Eye

Ocular injuries often are associated with midfacial fractures. Ideally, an ophthalmologist should examine all patients who have facial or craniofacial fractures. According to Al-Qurainy and colleagues, 63% of patients who had midfacial fractures also had minor or transient ocular injuries, 16% suffered moderately severe ocular injuries, and 12% experienced severe ocular injuries.[12,13] Road traffic accidents were associated with the highest incidence of severe ocular disorder (20%), whereas tripod fractures with or without a distracted frontozygomatic suture were the most frequent fractures and also the most common cause of mild ocular injuries. Patients who sustained a head injury sufficient to cause amnesia also were more likely to suffer from a disturbance to their visual system.[12]

Significant periorbital ecchymosis and swelling impair the examination of the eyes, but this must never be an excuse for not performing this. The swelling, however, might mask a number of signs and symptoms, and the surgeon must undertake a structured evaluation of both eyes and meticulously record all signs and symptoms:

1. Ophthalmic data
    - Visual acuity and perception of light (Figure 3-7): Use a standard chart if possible; if not, use available text and at least establish the ability to count fingers
    - Position of the eye, pupillary levels, and enophthalmos and proptosis
    - Intraocular examination, conjunctiva (edema, hemorrhage), and pupils (symmetry and reaction)
    - If possible, examine the eye with an ophthalmoscope, checking the cornea (concussion necrosis or laceration; edema and hematoma), lens, choroid, retina (detaching; Figure 3-8), optic nerve, and chambers (hyphema; Figure 3-9)
2. Ocular motility data: signs and symptoms
    - Diplopia or history of transient diplopia, with recovery and/or abnormal head posture to compensate

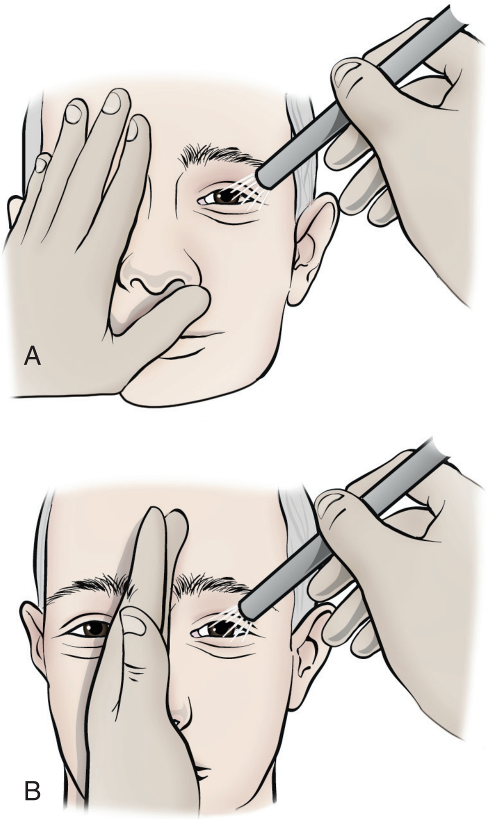

FIG 3-7 Checking the light reaction. **A,** First, the examiner covers the right eye and points a penlight to the left eye, where the pupil responds by contracting. **B,** The examiner points light to the left eye, inhibiting any direct light from reaching the right eye. The examiner then observes the reaction in the right eye. In normal situations, the right pupil also should respond by contracting.

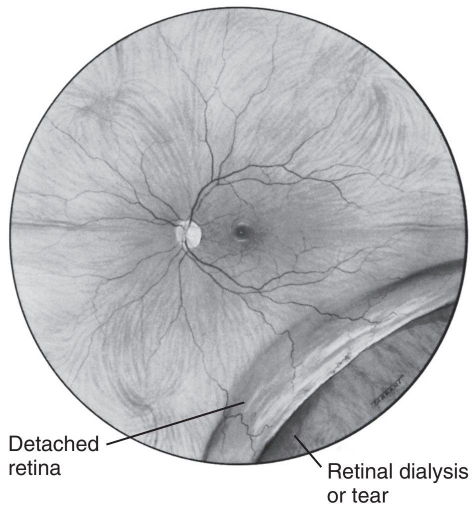

FIG 3-8 Detached retina. (From Rowe NL, Williams JL, editors: *Maxillofacial injuries,* ed 2, vol 2, London, 1994, Churchill Livingstone.)

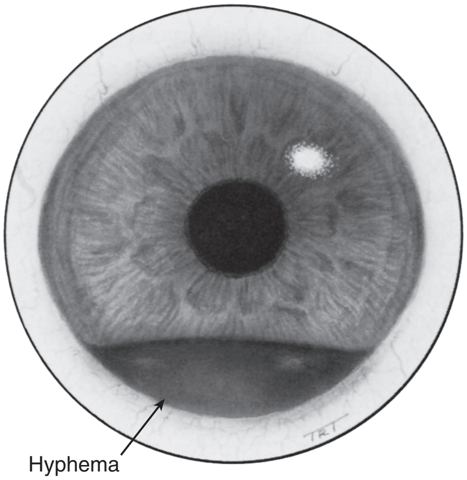

FIG 3-9 Hyphema. (From Rowe NL, Williams JL, editors: *Maxillofacial injuries,* ed 2, vol 2, London, 1994, Churchill Livingstone.)

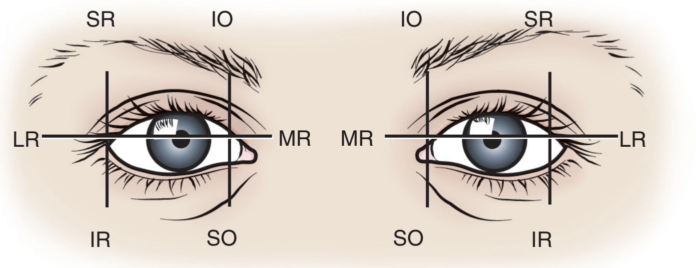

FIG 3-10 The movement of the globe reveals the function of the extraocular muscles. The superior oblique is innervated by the trochlear nerve (cranial nerve [CN] IV), the lateral rectus by the abducens (CN VI), and the rest by the oculomotor nerve. *IO,* Inferior oblique; *IR,* inferior rectus; *LR,* lateral rectus; *MR,* medial rectus; *SO,* superior oblique; *SR,* superior rectus.

- Pain on eye movement and/or restriction of extraocular movements found on clinical examination (Figure 3-10)
- Manifest deviation of the eye in the primary gaze position
- Convergence insufficiency

3. Periocular examination
   - Lids (hemorrhage, laceration, and ptosis)
   - Canthi: measure the intercanthal distance (Figure 3-11), and check for instability of the medial canthal ligament area (Figure 3-12)
   - Lacrimal system
4. Associated injuries that strongly suggest ocular injury
   - Amnesia
   - Cranial nerve palsies (see Table 3-2)

Significance of findings. Any injury leading to an acute significant reduction in visual acuity or the possibility of a retrobulbar hematoma (Figure 3-13), which may lead to the loss of vision within a few hours, should be considered and managed. The clinical signs suggesting retrobulbar hematoma are severe pain, progressive loss of vision (pupil becomes fixed and dilated), exophthalmos, ptosis, subconjunctival hemorrhage, and swelling of the eyelids (Box 3-3).

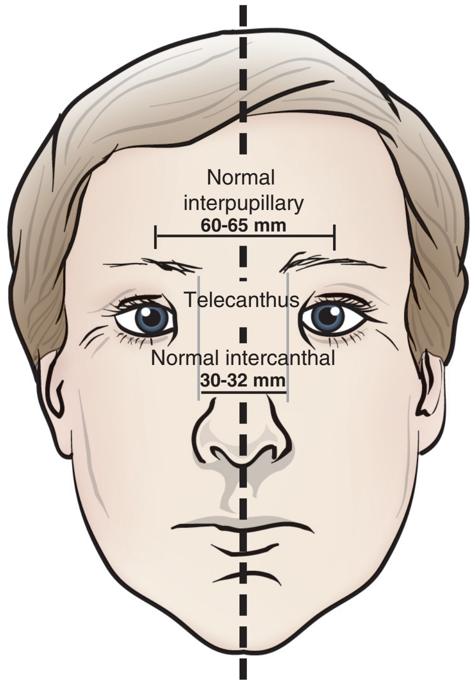

FIG 3-11 In high-energy nasoethmoid-orbital (NEO) trauma, the intercanthal distance is increased. The normal intercanthal distance is 30 to 32 mm, and the interpupillary distance is 60 to 65 mm (ratio 1 : 2).

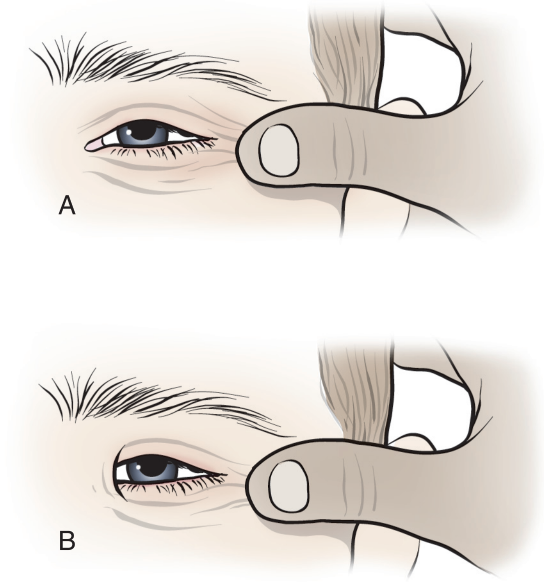

FIG 3-12 By pulling along the tarsus of the lid, one can examine the medial canthal area. **A,** A sharp angle in the medial canthal area is formed in the normal situation. **B,** The medial angle remains rounded if the medial canthal ligament area is not stable.

Ecchymosis of the sclera, which stays bright red as a result of atmospheric oxygen diffusing through the conjunctiva, suggests a fracture of the bony orbit—the wall, floor, or roof. Alterations in the position of the globe support this assumption.

An increase in the intercanthal distance, flattening of the bridge of the nose and rounding of the medial corner of the eye should alert you to possible problems in the medial canthal area. An increased intercanthal distance suggests a nasoethmoid-orbital (NEO) trauma (see Figure 3-11), whereas a raised interpupillary distance indicates a NEO trauma together with a fracture of the frontal bar, resulting in a widening of the face. Pulling along the tarsus of the lid normally creates a sharp angle in the medial canthal area; however, if there is a problem in the medial canthal area, it follows the tarsus, and the medial angle remains rounded (see Figure 3-12).

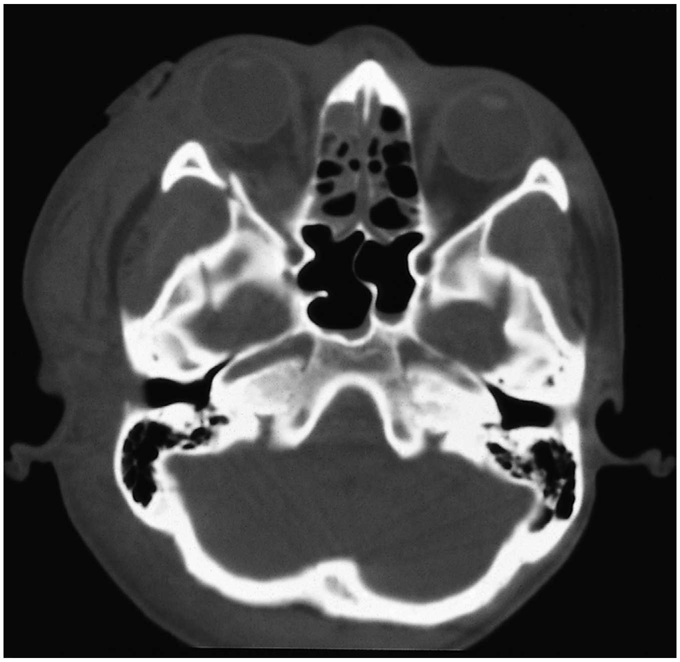

FIG 3-13 A retrobulbar hematoma requires immediate treatment.

Diplopia can be caused by an altered globe position resulting from a fractured orbit. A restriction in the movement of the globe also can be caused by dysfunction of the extraocular muscles. Injury to cranial nerves (CNs) III, IV, and VI also can cause impaired eye movement and diplopia.

Palsy of the oculomotor nerve (CN III) results in ptosis (double vision if the lid does not cover the eye), a dilated pupil that does not react to direct or indirect light, and dysfunction in the extraocular muscles, except the lateral rectus (CN VI) and superior oblique muscle (CN IV). Document any soft tissue lacerations and possible defects in the lid area, including the lacrimal apparatus. A penetrating wound in the lid is assumed to have affected the globe until proved otherwise. Figure 3-14 illustrates the management of wounds to the eyelid margin.

Consult an ophthalmologist when any of the BAD ACT criteria, shown in Box 3-4, are fulfilled and obviously in the case of direct eyeball trauma, blood in the anterior chamber (hyphema), or laceration. Table 3-3 shows a detailed scoring system to determine the need for ophthalmological consultation.[13] Often, however, there is a spontaneous recovery, and no referral is needed (Table 3-4).

BOX 3-3 Signs and Symptoms of Retrobulbar Hematoma

- Severe pain
- Progressive loss of vision (pupil becomes fixed and dilated)
- Proptosis
- Ptosis
- Subconjunctival hemorrhage
- Swelling of the eyelids

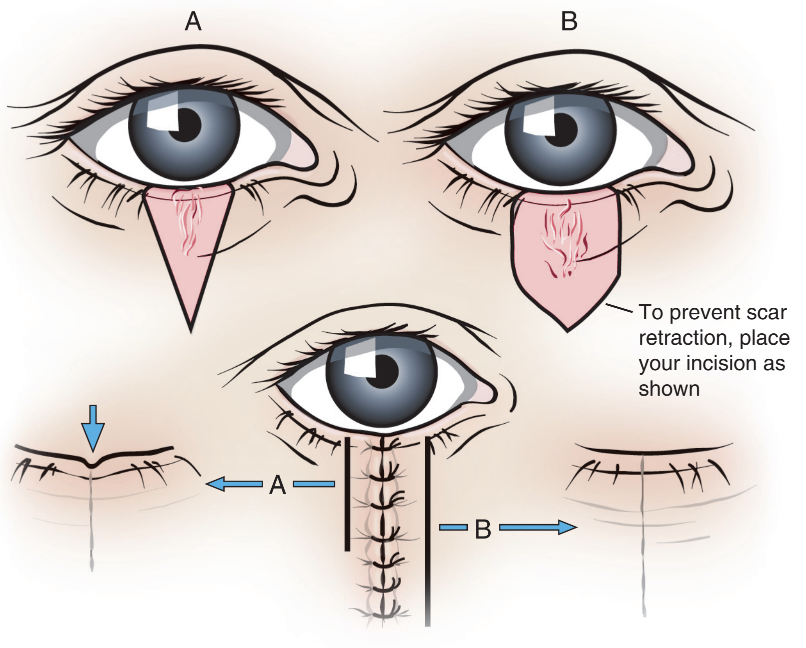

FIG 3-14 Repair of eyelid margin. **A,** Repair of eyelid with conventional incision results in scar contraction. **B,** Modified incision to prevent scar contraction. (Modified from Rowe NL, Williams JL, editors: *Maxillofacial injuries,* ed 2, vol 2, London, 1994, Churchill Livingstone.)

TABLE 3-3 When to Refer to an Ophthalmologist

Clinical Feature	Initial Score	Final Score
Visual Acuity		
6/6 or better	0	
6/9 to 6/12	4	
6/18 to 6/24	8	
6/36 or less	12	
No light perception	16	( )
Zygomatic Fracture Type		
Comminuted	3	
Blow-out	3	
Other	0	( )
Motility Abnormality		
Present (diplopia or squint)	3	
Absent	0	( )
Amnesia		
Retrograde + posttraumatic	5	
Other	0	( )
Total score*		

Modified from Al-Qurainy A, Stassen LFA, Dutton GN, et al: The characteristics of midfacial fractures and the association with ocular injury: a prospective study. *Br J Oral Maxillofac Surg* 29:291-301, 1991; and Al-Qurainy A, Titterington DM, Dutton GN, et al: Midfacial fractures and the eye: the development of a system for detecting patients at risk of eye injury. *Br J Oral Maxillofac Surg* 29:363-367, 1991.

*Consider adding one point to the total score if one of the following factors exists and the total score is 11:
- Patient is female.
- Age is between 30 and 39 years old.
- Cause of injury is road traffic injury.

Referral to the ophthalmologist:
- Do not refer if total score is less than 4.
- Consider routine referral if total score is 5 to 11.
- Consider urgent referral if total score is higher than 12.

BOX 3-4 BAD ACT

Consult an ophthalmologist if the patient suffers from the following:
*B*lindness
*A*mnesia
*D*iplopia
*A*cuity or impaired vision at any stage of treatment
*C*omminuted *T*rauma in midfacial region and obviously in the case of direct eyeball trauma/laceration

Examination of the Nose

Isolated nasal fractures, like all facial fractures, are difficult to examine if the nose is swollen or bleeding extensively. Nevertheless, palpation usually shows motility or crackling if fractures are present. Deviation usually can be appreciated by examination and palpation. However, not all patients have a strictly midline position of the nose or septum. Radiographs have little initial value in pure nasal fractures. Examination of the nasal airway is certainly difficult in the acute phase. Internal examination of the nose is directed to the septum to identify hematoma or deformity. An overlooked septal hematoma can lead to later deformity. Mucosal lacerations should be noted. Cerebrospinal fluid leakage is important and suggests a more severe nasoethmoid or maxillary fracture extending through the cribriform plate. Cerebrospinal fluid can be identified as a clear fluid containing beta-2 transferrin, and the patient may complain of a metallic taste. If anosmia is documented immediately after the trauma, it may indicate a fracture involving the cribriform plate to the anterior cranial base (Figure 3-15).

In the case of an isolated nose fracture, it might be useful to wait until the swelling has resolved and the contours of the nose, as well as its function, can be evaluated.

TABLE 3-4 Non-Referral Category of Ophthalmic Injuries

Eye Abnormality	Remarks
Posttraumatic neuralgia or anesthesia	Spontaneous recovery
Coronal eye displacement	Should respond to facial fracture treatment
Orbital emphysema	Absorbs spontaneously
Eyelid swelling/bruises	Clears spontaneously
Conjunctival chemosis	Clears spontaneously
Subconjunctival hemorrhage	Clears spontaneously
Corneal abrasion	Heals spontaneously
Mild failure of accommodation	Usually spontaneous recovery
Mild reduction of visual acuity with recovery	May be due to corneal abrasion, and no treatment usually is needed
Mild retinal commotion	Spontaneous resolution

Modified from Al-Qurainy A, Stassen LFA, Dutton GN, et al: The characteristics of midfacial fractures and the association with ocular injury: a prospective study. *Br J Oral Maxillofac Surg* 29:291-301, 1991; and Al-Qurainy A, Titterington DM, Dutton GN, et al: Midfacial fractures and the eye: the development of a system for detecting patients at risk of eye injury. *Br J Oral Maxillofac Surg* 29:363-367, 1991.

Examination of the Facial Soft Tissues

Soft tissue injuries often are related to maxillofacial trauma with or without fracture. The range of such injuries is wide, from a simple contusion caused by a fall to a major tissue loss resulting from the firing of a shotgun. All these injuries must always be inspected thoroughly, which often requires local anesthesia. Carry out inspection in sterile conditions if possible, looking in particular for foreign bodies in the wound that might cause subsequent infection or skin tattoos. Also pay special attention to lacerations that might have injured nerves or salivary/lacrimal ducts.

In addition to the clinical examination, ultrasound and soft tissue radiographs can give valuable information on possible foreign bodies lodged in the soft tissues. Computed tomography (CT) commonly is required for fracture evaluation.

After inspection, meticulously document the condition of the wounds and other soft tissue injuries (a photograph is always of great help) and thoroughly cleanse the wounds of dirt and foreign bodies before revision and closure. Also review tetanus status and initiate prophylaxis if necessary. The detailed management of these injuries is discussed in Chapter 11.

Intraoral Examination

Documentation of the intraoral status of a trauma patient starts with inspection (Box 3-5). Check the occlusion, which may give a good clue as to the possible problem area. An anterior open bite suggests bilateral condylar or angular fracture or a low Le Fort fracture (Figure 3-16). Unilateral malocclusion (Figure 3-17) in the premolar-molar region may indicate a fracture in the condylar region on the opposite side or the angular region on the same side. A tilted Le Fort fracture also may give the same impression. When checking the occlusion in an edentulous mandible, use the denture whenever possible. If this is

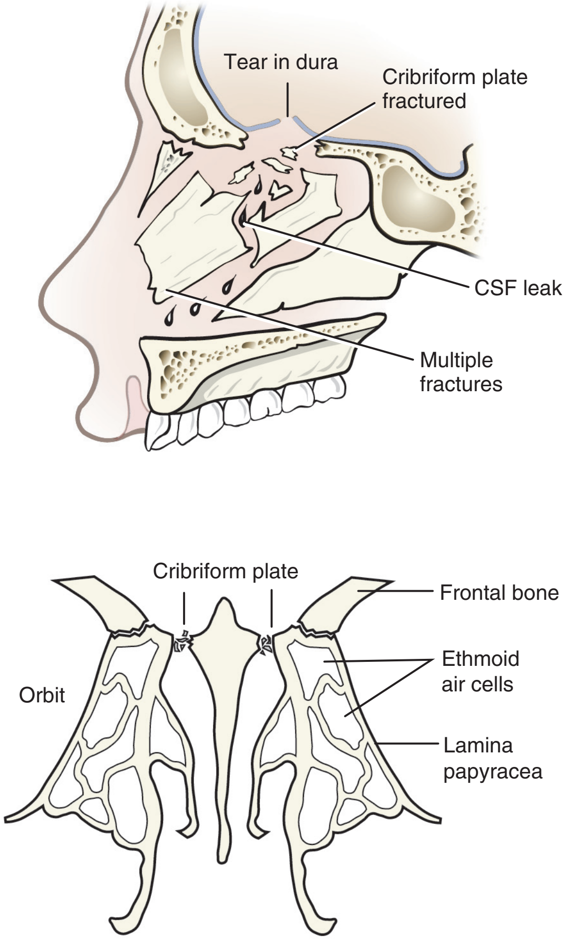

FIG 3-15 A fracture in the cribriform plate may result in cerebrospinal fluid *(CSF)* leakage and anosmia.

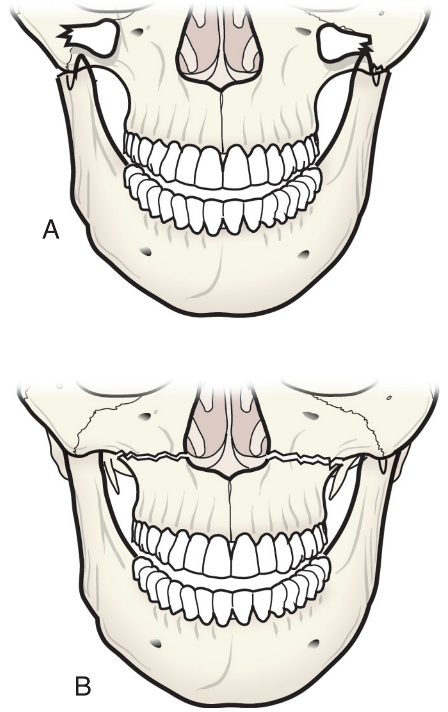

FIG 3-16 Anterior open bite may be caused by a bilateral condylar or angular fracture **(A)** or a Le Fort fracture **(B).**

BOX 3-5 Intraoral Examination

Inspection
Asymmetry
Bleeding
Hematoma
Swelling
Occlusal plane
Fracture lines/steps
Mucosal laceration
Teeth: Fracture/exarticulation/dislocation

Palpation
Bimanual
Tenderness
Fracture line/steps
Crepitation
Teeth: Movement, number, missing parts (where?)
Inferior alveolar nerve

missing, carry out the final occlusal reconstruction after the surgical treatment.

Deviation or discontinuity in the occlusion also strongly indicates the presence of a fracture (Figure 3-18). Hematoma and swelling in the buccal or labial sulcus or in the floor of the mouth, as well as mucosal lacerations, are well-known indirect signs of fracture. Document the possible soft tissue defects, paying special attention to those requiring reconstruction simultaneously with the fracture treatment. Look for missing or fractured teeth and parts of the teeth that may be dislocated in the neighboring soft tissues or even in the trachea.

Perform palpation, taking into account the discomfort of the procedure to the patient. Document swelling in the floor of the mouth, and if necessary, take appropriate precautions to maintain the airway. Palpate the buccal sulcus, palate, and lingual sulcus, and document any tenderness, crepitation, or steps. Bimanual testing over the fracture line is needed to evaluate the stability of the fracture (Figure 3-19). Use bimanual palpation (Figure 3-20) to examine all Le Fort fracture levels (Figure 3-21), the sagittal plane of the maxilla, and the different parts of the mandible. Be aware that the soft tissue envelope can be moved easily by bimanual palpation, simulating Le Fort II and III fractures. In the palate, perform the bimanual testing in the molar region, spreading and compressing the alveolar ridge. Palpation of the teeth and alveolar ridge is also essential for the treatment plan. Check the functions of the maxillary and infraorbital nerves in the maxilla and the inferior alveolar and lingual nerves in the mandible. A proper dental status is necessary for simultaneous treatment with other maxillofacial injuries. Evaluate patient compliance, general condition, and oral hygiene status, because these have an important role in the preliminary treatment plan.

Salivary Glands

Examine the salivary glands and ducts for lacerations, and check the orifices of the ducts for saliva outflow when palpating the glands. These findings should be included in the preliminary treatment planning. The detailed management of these injuries is discussed in Chapter 33.

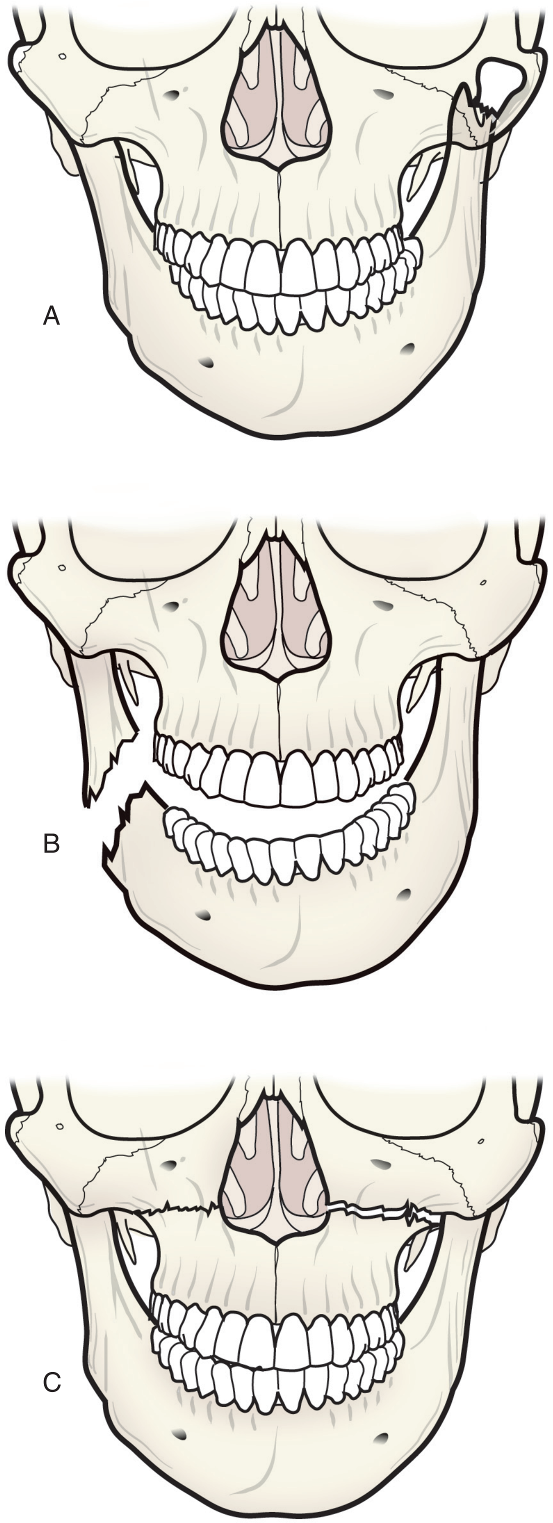

FIG 3-17 Unilateral malocclusion in the premolar-molar region may be caused by a fracture in the condylar region in the opposite side **(A),** a fracture in the angular region in the same side **(B),** or a tilted Le Fort fracture **(C).**

FIG 3-18 Step in the occlusion indicating a mandibular fracture. (Courtesy Dr. Juha Paatsama.)

FIG 3-19 Bimanual testing over the fracture line is needed to evaluate the stability of the fracture. (Courtesy Dr. Juha Paatsama.)

Radiological Evaluation of Maxillofacial Fractures

The radiological examinations are guided by the findings of the clinical examination. The latter gives a clue to the location of the fracture and the severity of the trauma. Based on these findings, the surgeon then must apply the appropriate targeted radiological examinations. Maxillofacial injuries only occasionally require emergency surgery, which is usually for airway related problems or perfuse hemorrhage; both can be managed without preoperative imaging, although the management of profuse hemorrhage might require interventional radiology intraoperatively. In most cases, therefore, adequate radiological imaging can be carried out after any emergency lifesaving treatment and before the preliminary treatment planning of maxillofacial injuries. A huge selection of different examination methods exists, from plain films to CT and its three-dimensional applications, as well as rapid prototypes (Figure 3-22).

Radiological examination should always be considered as a whole. If there are additional facial or intracranial injuries or injury to the cervical spine, or if the patient's general condition is poor, this becomes even more important. If scanning equipment is modern, the image capture time is now very quick and CT imaging of the facial skeleton should be obtained at the same time imaging of other anatomical areas, and all except the

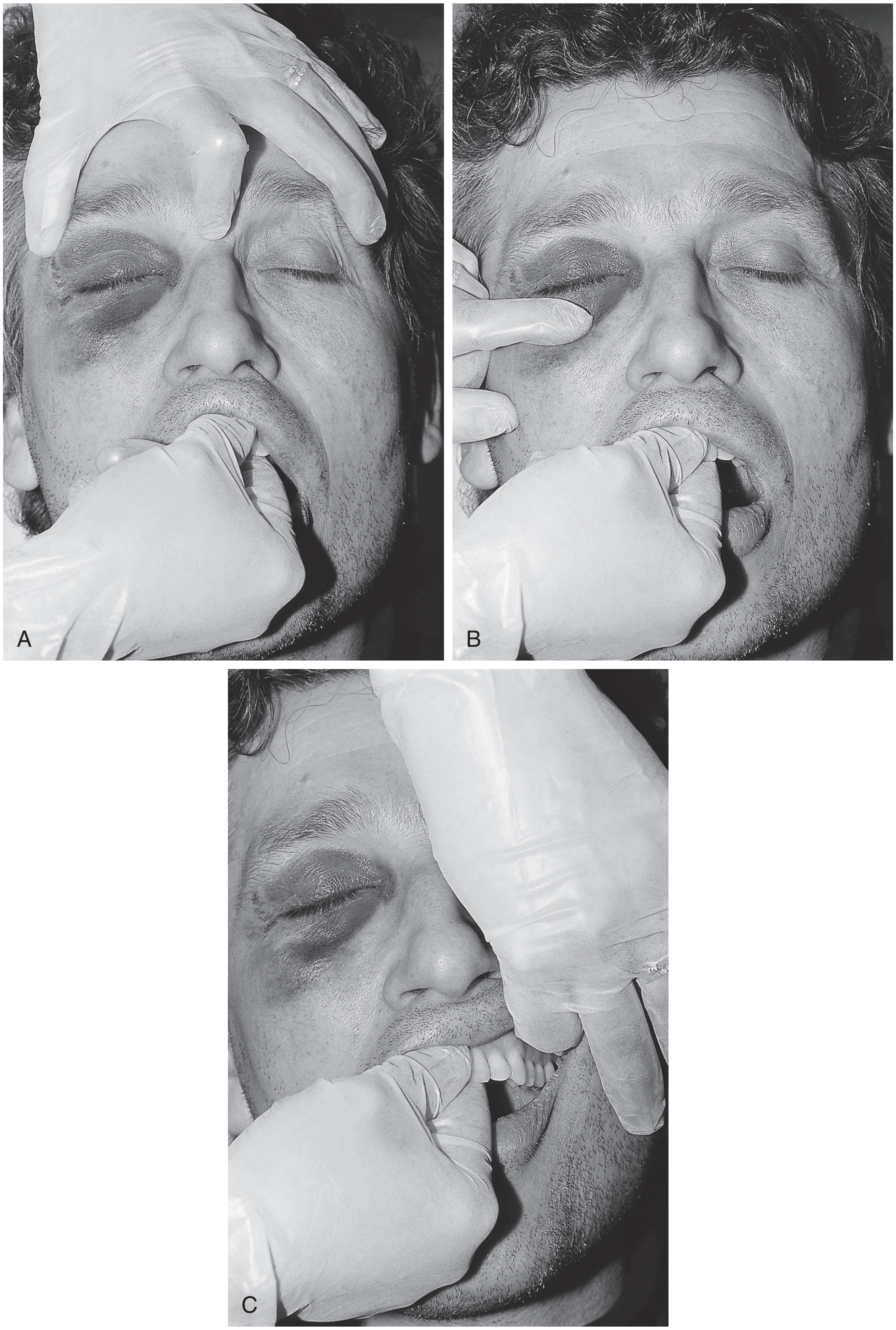

FIG 3-20 Clinical testing of the stability of Le Fort fracture levels. **A,** Le Fort III. **B,** Le Fort II. **C,** Le Fort I. (Courtesy Dr. Juha Paatsama.)

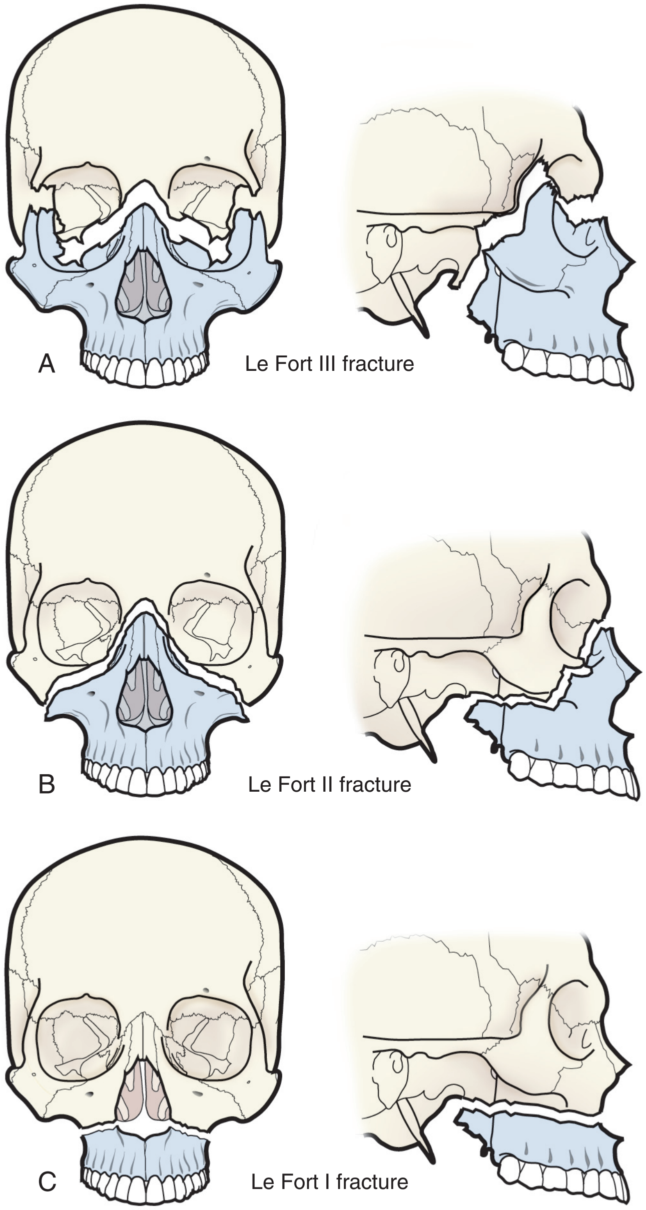

FIG 3-21 Schematic of the Le Fort fracture lines. **A,** Le Fort III. **B,** Le Fort II. **C,** Le Fort I.

most simple, straightforward maxillofacial injuries warrant CT scanning. Maxillofacial imaging should include the whole facial skeleton and be done with fine slices (1 mm) to allow detailed reconstruction of injuries. If old equipment is being used to acquire images that is not capable of gantry tilting and multiplanar reconstruction, coronal CT scans are contraindicated before cervical spine injury has been ruled out (Figure 3-23). If the patient has only isolated facial trauma (e.g., isolated mandibular or zygomaticomalar signs) and is able to fully cooperate with plain x-rays, these may be sufficient; the views that are needed for mandibular imaging are an orthopantomogram (OPG) and a good quality posteroanterior (PA) mandible, which shows the condyles. Isolated zygomaticomalar fractures with no eye signs can be imaged with an occipitomental view. However, if there is any degree of multiple facial bone fractures, eye signs indicative of orbital fractures, comminution, high condylar fractures, nasorbito ethomoidal or craniofacial fracture, then a fine-cut CT with multiplanar reconstruction manipulation and three-dimensional reconstruction capacity should be undertaken.

The detailed radiological examination is discussed in Chapter 13.

CLASSIFICATION OF MAXILLOFACIAL FRACTURES

Several different classifications have been used in the past. Some of these were developed for research purposes only, but some are suitable for clinical work and treatment planning. Whichever classification is used, it should be easily applicable to all fractures and should be used in the primary treatment planning.

Some definitions are required in relation to maxillofacial fractures.

Relation to the Overlying Tissues

The following three terms describe the fracture in relation to the overlying soft tissues:

- *Closed:* The fracture is not situated in the dentate area, and there are no lacerations to the oral mucosa or skin that are in direct contact with the fracture site. A majority of condylar fractures and fractures of the edentulous mandible are closed.
- *Open:* All fractures in the dentate area. Alternatively, there is a laceration in the oral mucosa or overlying skin that is in direct contact with the fracture site in an edentulous area.
- *Complicated:* Open fractures in which a considerable injury or defect exists in the overlying soft tissues. Gunshot injuries and other high-energy injuries usually are complicated open fractures.

Type of Fracture

The fracture itself can be defined as follows:

- Greenstick: A fracture of one cortex while the opposite side of the cortex is bent
- Single: Only one fracture line in the same bone
- Multiple: Two or more fracture lines in the same bone
- Comminuted: Two or more fracture lines that communicate with each other
- Defect: A clear defect in the bony structures
- Infected: An old untreated and/or primarily infected fracture

Also document the course and shape of the fracture line (oblique, transverse, sagittal) and the degree of dislocation, because this influences the treatment decision.

Additional Features of the Fracture

The following additional terms often are used when describing the fracture:

- *Pathological:* A pathological process that involves the bone, predisposing to a spontaneous fracture or fracture caused by a minor trauma. An example is a large dentigenous cyst.
- *Atrophic:* A fracture in atrophic bone, predisposing to a spontaneous fracture or fracture caused by a minor trauma. An example is a fracture in a severely atrophic mandible (height of the mandible in panoramic radiograph less than 10 mm).
- *Impacted:* One fragment firmly impacted into another fragment; for example, in zygomatic complex fractures.

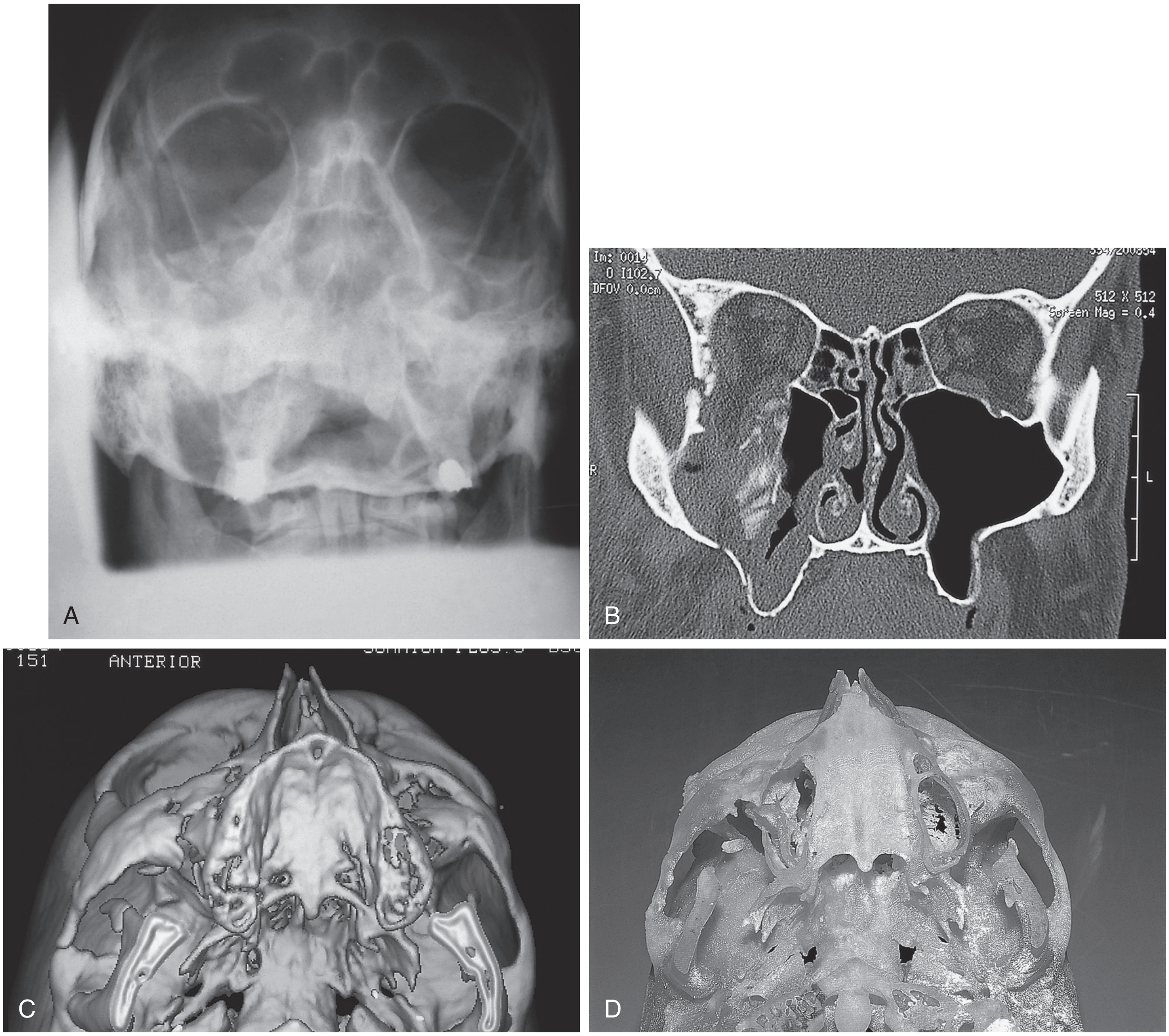

FIG 3-22 Maxillofacial fractures can be evaluated with different imaging methods. A difficult malar fracture is shown in plain film **(A),** computed tomography (CT) **(B),** three-dimensional CT **(C),** and rapid prototype **(D).**

- *Direct/indirect:* The site of initial trauma in relation to the fracture. An example is a blow in the midline that can cause an indirect fracture to the condylar process and a direct fracture in the midline.
- *Blow-out/blow-in:* The orbital roof or lateral or medial wall or floor is fractured away or toward the orbit, with no other rim fractures.

Anatomical Site of the Fracture

One also should consider the anatomical site. Where is the fracture situated? Is it a problem area for reconstruction?

- Midface
  - Frontal bone/frontal sinus (inner table, outer table)
  - Arch
  - Zygomatic complex/malar
  - Orbit—solitary roof, floor, medial or lateral wall, or in combination with NEO or zygomatic complex
  - Nose
  - NEO
- Maxilla (see Figure 3-21)
  - Le Fort I, Le Fort II, Le Fort III, and any combination of these and other fractures
- Mandible (Figure 3-24)
  - Anterior mandible (including median and paramedian): Fracture line anterior to the mental foramen
  - Body: Fracture line posterior to the mental foramen and anterior to the masseter muscle
  - Angle: Fracture line posterior to the anterior part of the masseter muscle and inferior to the mandibular foramen
  - Ramus: Fracture line superior to the foramen mandibularis, not reaching the incisura, or its course runs from inferior to the foramen mandibularis and reaches the incisura
  - Condylar: Fracture line superior and posterior to the mandibular foramen, reaching the incisura
  - Coronoid: Fracture line superior and anterior to the mandibular foramen, reaching the incisura

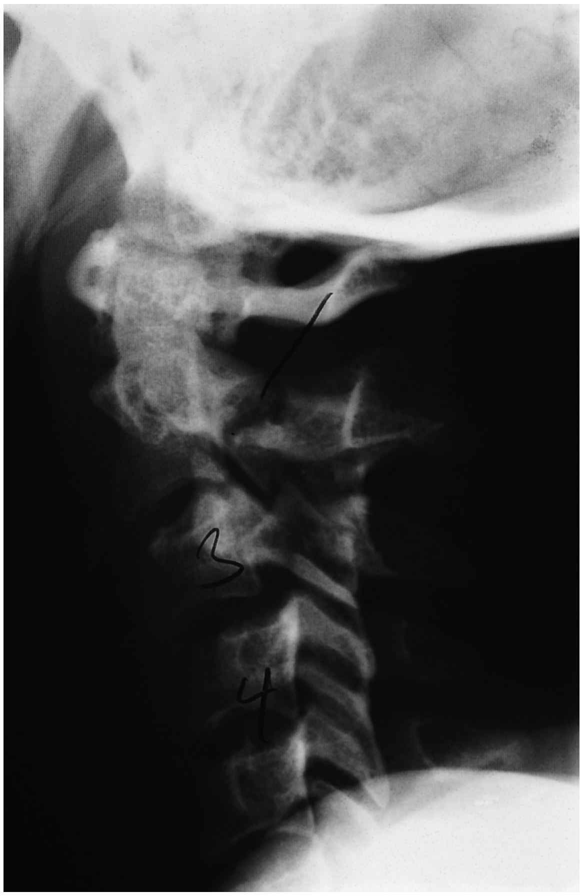

FIG 3-23 Cervical spine injury must be ruled out before coronal computed tomography (CT) is used. A fracture in the C2 can be seen in the plain radiograph.

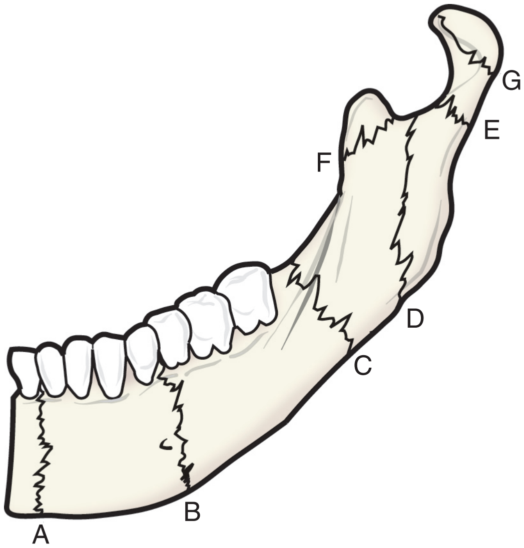

FIG 3-24 Anatomical sites of mandibular fractures. *A,* Anterior mandible (including symphysis and parasymphysis)—fracture line anterior to the mental foramen. *B,* Body—fracture line posterior to the mental foramen and anterior to the masseter muscle. *C,* Angle—fracture line posterior to the anterior part of the masseter muscle and inferior to the mandibular foramen. *D,* Ramus—fracture line superior to foramen mandibularis not reaching the incisura, or its course runs from inferior to foramen mandibularis and reaches the incisura. *E,* Condylar—fracture line superior and posterior to foramen mandibularis, reaching the incisura. *F,* Coronoid-fracture line superior and anterior to foramen mandibularis, reaching the incisura. *G,* Intracapsular—fracture line inside the capsule of the temporomandibular joint.

    - Intracapsular: Fracture line inside the capsule of the temporomandibular joint
- Alveolar process
    - Fracture line within the alveolar process of the mandible or maxilla

SPECIAL CONSIDERATIONS IN MANDIBULAR FRACTURES

To plan treatment, the surgeon must know where the mandibular fracture is situated in relation to the muscles. Muscles may pull the fragments apart, working against the surgeon, or pull them together, thus supporting the treatment (Figure 3-25). Therefore, the question is whether the fracture is favorable or nonfavorable.

Atrophic Mandible

Atrophic mandibular fractures present several problems for several reasons:

- They often occur in older adults with complicated medical histories.
- They often are associated with osteoporosis, which reduces the ability of the bone to hold the fixation devices.
- They often are associated with a poor blood supply to the bone caused by arteriosclerosis to the main nutrient artery.

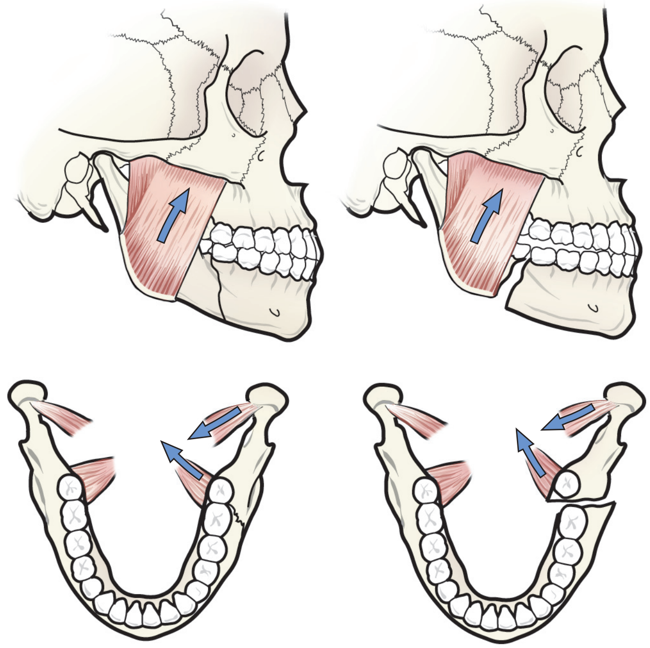

FIG 3-25 The relationship between the pull of the muscles and angulation of the fracture makes the fracture favorable or unfavorable. If the muscle pull "closes" or impacts the fracture, it is a favorable fracture, as shown in the diagrams on the *left.*

TABLE 3-5 **Guidelines for the Use of Antibiotic Treatment in Maxillofacial Trauma***

Diagnosis	Antibiotic	Alternatives
Mild infection in fracture line	Penicillin V ± metronidazole	Macrolides ± metronidazole
Infection and pus in fracture line	Penicillin V or G + metronidazole	Macrolides + metronidazole or clindamycin
Facial skin infection	Flucloxacillin or cephalosporins	Macrolides + metronidazole or clindamycin
Bites	Amoxicillin + clavulanic acid	Macrolides + metronidazole
Pneumonia, aspiration	Penicillin G	Clindamycin or cefoxitin
Pneumonia, post tracheostomy	Cephalosporin, second-generation + metronidazole	Ceftazidime + netilmicin
Cerebrospinal fluid leaks	Penicillin V or G	

*Usually the antibiotic can be given as a perioperative dose.

- Mechanically, the thin bone fragments provide little surface contact for healing or for stability by fixation methods.
- Often at least two fracture lines exist, and the surgeon should search actively for both lines.

Teeth in the Fracture Line

Teeth in the fracture line have been a source of controversy for many years. The presence of lower third molars may double the risk of fracture in the angle of the mandible.[14] Teeth in the fracture line may be seen not only as a source of infection but also as a source of instability if they are removed. According to Ellis, there is an increased risk for postoperative complications when a tooth is present, but the increase is not statistically significant.[15] The consensus seems to suggest that the removal of such teeth is essential only if they are grossly fractured themselves, are obviously infected, or will destabilize the fracture significantly, creating the demand for supplementary fixation methods.

Use of Antibiotics and Antiinflammatory Agents

Principles

The following principles can guide use of antibiotics and antiinflammatory agents.

Presence of infection. The decision to treat a patient with antibiotics is basically easy: The surgeon gives antibiotics to prevent or cure infection. But does the patient have an infection? Is there an increased risk for developing an infection? In most cases, this is based on the patient's general condition and previous illnesses and on clinical diagnosis. Locally there are the classic signs and symptoms of infection, such as pain, swelling, surface erythema, limitation of motion, and an increase in surface temperature. Systemically, the patient has fever, lymphadenopathy, malaise, and a toxic appearance, and laboratory tests show an elevated white blood cell count and C-reactive protein level. In a posttraumatic situation, these are the laboratory parameters one should follow carefully.

State of host defense. Host defense mechanisms are the most important factor in the final outcome of bacterial infection. If these are impaired, infection may result from a minor bacterial exposure. In acute trauma, impairment occurs in shock because of the physiological depression of host defense mechanisms. A number of diseases have the same effect: malnutrition resulting from alcoholism, malignant diseases, human immunodeficiency virus infection, diabetes, immunosuppressive therapy, and many more.

Surgical drainage and incision. An established principle of the treatment of infections is to achieve drainage. The basic principle is to drain pus from tissue spaces and to insert drains to release pressure. After maxillofacial trauma, these procedures seldom are needed if the operative treatment is started within the first 24 to 48 hours.

Choosing the appropriate antibiotic. Prophylactic administration of antibiotics and antiseptic mouthrinse should be started as soon as possible, taking into account the oral microbiota. In general, most patients can be treated successfully with penicillin. In patients with poor oral hygiene and delayed treatment, metronidazole should be added (Table 3-5).

The identity of a pathogen most often is based on empirical knowledge of the clinical presentation of the infection. Laboratory investigation includes cultures from pus, blood, or tissue samples. Initial therapy is instituted with a fair degree of reliability if clinical signs and symptoms of infection are present and are judged correctly.

Systemically Effective Corticosteroids

The maxillofacial region is highly vascularized, which means that many principles of flap design, graft placement, and the prevention of hematoma formation in other anatomical sites may be modified in head and neck procedures. Nevertheless, systemically effective corticosteroids commonly are used during and after maxillofacial surgery to reduce edema. If the patient has an active peptic ulcer or a recent history of fungal or mycobacterial disease, corticosteroids are contraindicated. Diabetes is a relative contraindication, and the raised glucose levels usually are controlled with modified medication. The maximal effect is achieved if the treatment is started 30 to 40 minutes before surgery and is continued for 48 to 72 hours to minimize unwanted side effects. Several regimens are possible, and one widely used is that recommended by Roser and Hupp: 125 mg methylprednisolone sodium succinate every 4 hours during surgery and every 6 hours postoperatively until a total of six doses have been administered.[16] At the time of the last dose, one 40-mg dose of methylprednisolone acetate is given intramuscularly to reduce rebound edema. This type of treatment usually is limited to major trauma and to late reconstructions when the patient is expected to stay in the hospital for several days.

IMAGING FOR MANDIBULAR FRACTURES

If the mandible is the only site that signs and symptoms suggest fractures may be present at, then plain views may suffice. These should be an OPG and PA mandible that must show the whole of the condyles and lower border of the mandible. If there is any suggestion of high condylar (above the neck) fractures or comminution of any of the fracture lines, then further delineation of the fracture pattern is advised with a fine cut CT.

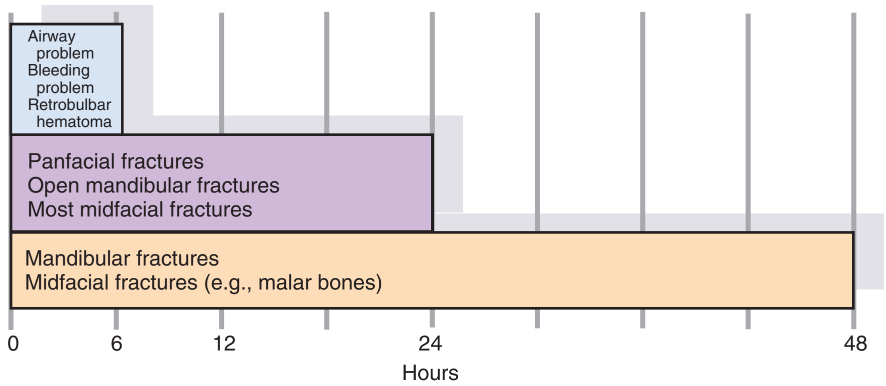

FIG 3-26 Timing of surgery in maxillofacial trauma.

SURGICAL PLANNING FOR FACIAL FRACTURES

Preliminary Treatment Planning in Midface, Zygomatic Complex, and Orbital Fractures

Imaging

In order to plan the treatment of midfacial fractures that involve any fracture pattern apart from a non-comminuted isolated zygomaticomalar fracture that does not have accompanying eye signs, a fine cut CT is required and the images need to be reviewed on a computer capable of multiplanar and three-dimensional reconstruction of the data to plan the required surgery.

The images must be viewed in all three (axial, coronal, and sagittal) planes and the individual fracture lines and resultant fracture fragments identified and considered in the treatment planning. Particular attention must be made to note if there is any (1) orbital floor and/or medial wall component; (2) nasorbito ethmoidal involvement, and if so if the bone that the medial canthus is attached to is displaced and also the size of the fragment of bone that the canthus is attached to; (3) orbital roof fractures and the degree of displacement; (4) frontal sinus fracture and if present whether it is an isolated anterior wall fracture or if the posterior wall is involved and the degree of displacement of any fracture; (5) any fracture at the root of the temporal process of zygomatic arch and the degree of displacement; (6) presence of orbital rim fractures; (7) degree of comminution of the maxilla; (8) any fracture of the palatal aspect of the maxillae, and (9) presence of any dentoalveolar fracture.

Having viewed the fractures in detail in all three planes, it is often useful to get an overview of the fracture pattern using a three-dimensional reconstruction of the data.

The midface is a complex three-dimensional structure, and in general all fractures must be reduced and stabilized. Although, in the past, attempts were made to extend the principles of mandibular trauma treatment to the midface (that is, relying on maxillomandibular fixation), the results were generally poor. Today it is acceptable to stabilize midface fractures with rigid fixation, and the details of the precise methods are covered elsewhere. The principle is to expose the fractures and to reduce and stabilize them. The aim of this chapter is to provide the logical approach to the process.

Midfacial and panfacial fractures are always a challenge to the surgeon. Recreating the facial functions and esthetics requires all the components of midfacial and mandibular surgery. Of great importance is a three-dimensional view of the traumatized structures, because in these patients the preliminary treatment plan also should be considered the final treatment plan; late reconstructions are difficult, and the results are seldom esthetically and functionally satisfactory.[17]

Gruss and colleagues have stressed the importance of establishing the correct reduction on the zygomatic arches and then moving centrally, reconstructing the rest of the midface.[18] Although it is true that poor results may follow if this step is neglected, it is essential that all displaced fractures be reduced, and the zygomatic arches are no more important than any other structure, even though they are responsible for the projection of the midface.

Timing of Surgery

Emergencies involving midfacial and panfacial fractures require immediate surgery (Figure 3-26). These include airway problems, uncontrollable bleeding, and danger to vision (retrobulbar hematoma, compression of the optic nerve, and penetrating eye injuries). If no such medical emergencies are present, all preoperative examinations and consultations can be carried out. The timing of treatment will then depend on what maxillofacial treatment is required and the presence of other non-maxillofacial injuries and treatment requirements for them. If there are only maxillofacial injuries with no cranial component and no other anatomical region with injuries, then timing of treatment is influenced by the presence of mandibular fractures. Treatment of any mandibular fractures should ideally be undertaken within 24 hours. If there are midface fractures also present with no overlying soft tissue lacerations, there are two options for the midface fractures: (1) treatment at the same time as the mandibular fractures, or (2) treatment of the midfacial fractures at a second operative procedure, which would usually be at around day 5 to 10, post injury. Which of these options is the best is likely to be determined by the capacity to get all preoperative assessments done prior to fixing the mandible (e.g., ophthalmic/orthoptic investigations) and by the degree of swelling and extent to which it will affect the intraoperative ability to access the fractures and assess the reduction of them. If there are soft tissue injuries overlying the midfacial fractures that should not be left to day 5 to 10 post injury and these soft tissue injuries provide ideal access to underlying fractures, then the fractures should be reduced and fixed prior to the soft tissue injury, and this will necessitate early treatment of the underlying facial fractures. If only midface injuries are present, then the

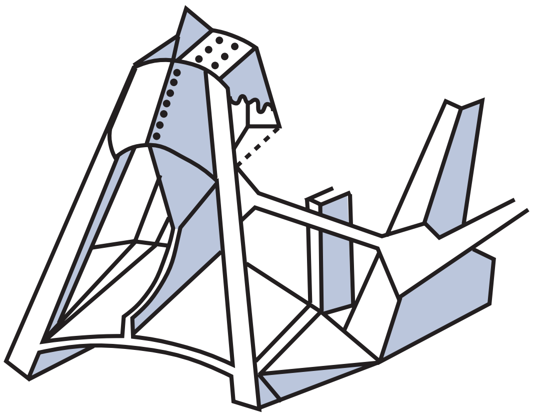

FIG 3-27 Load-bearing areas of the midface.

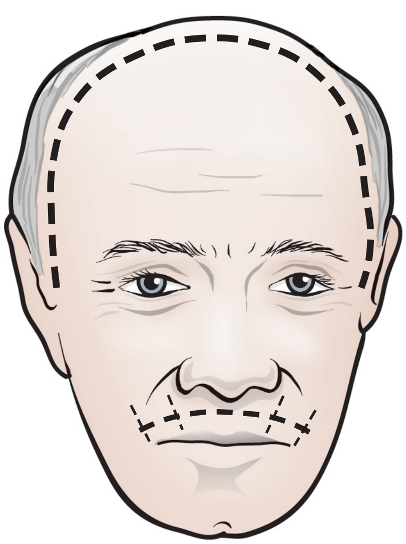

FIG 3-28 Possible skin and mucosal incisions to reach midfacial fracture sites. Preexisting lacerations also should be taken into account.

timing of treatment is determined by consideration of the same things—that is, the need to treat any overlying soft tissue injury, requirement and time taken for preoperative investigations (e.g., ophthalmic, degree of swelling), and treatment may be early within 48 hours or delayed to day 5 to 10 post injury.

In the patient with trauma to other anatomical regions of the body beyond the head and neck, the aforementioned options for management of maxillofacial injuries are still relevant, but timing of treatment might be delayed because of treatment to, or impact of, those other injuries on the patient. To meet these goals, patients with polytrauma and panfacial injury should ideally be treated in a trauma center where teams consisting of specialists in all the necessary fields are available. Treatment of maxillofacial injuries not involving other anatomical regions can be undertaken in specialist maxillofacial units beyond major trauma centers.

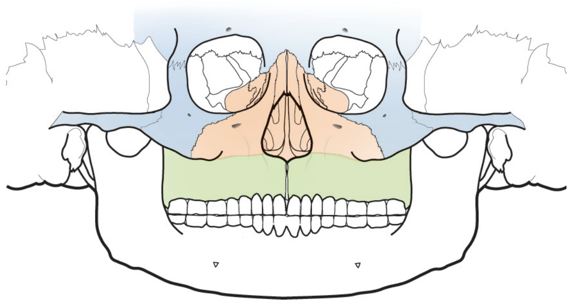

FIG 3-29 Midfacial reconstruction protocol.

Surgical Plan

Complex midfacial fracture treatment should begin with reconstruction of the load-bearing structures of the facial skeleton (Figure 3-27), starting peripherally and moving centrally. This is essential, because these strong bony structures are ideal for the placement of the plates. They have been defined as being the areas that take up the masticatory and functional forces and have the necessary thickness to carry the plates.

Primary bone grafting may be necessary in recreating the facial skeleton. Because a coronal incision is often used in these patients with complex fractures, the natural place to harvest the bone is the cranium. Primary bone grafts are used most often to achieve proper nasal projection, globe position, and stability at the fracture sites. Bone grafts also promote osteogenesis, which allows the use of smaller plates.

In the operating room, one should always have the patient's entire face uncovered when treating midfacial (or panfacial) fractures so that the surgeon can evaluate the dimensions of the face. Figure 3-28 shows the skin incisions needed to expose all midfacial fracture areas. When planning the incisions, one should take into account the possible need for bone grafting. Primary bone grafting usually is regarded as necessary in gaps wider than 5 mm.

The building up of the face begins by establishing the anteroposterior dimension by reconstructing the outer facial frame, starting from the stable posterior regions and continuing toward the midline (Figure 3-29). After the frontal bar has been fixed, the reconstruction continues downward, creating the central midface, which can be completed independent of the occlusion. The last step in the reconstruction is the stabilization of the tooth-bearing fragments to establish a proper occlusion.

Table 3-6 shows the overall view of the preliminary treatment plan for panfacial and midfacial fractures. In general, miniplates, microplates, and screws are used for the internal fixation of midfacial fractures. Reconstruction of the orbital floor using autogenous bone grafts, resorbable sheets, or titanium sheets should be completed once the main bony reconstruction is complete. Great care is needed with this reconstruction, because the orbital volume is created by complex shapes. For example, it is easy to ignore the rise in the orbital floor posteriorly and postoperatively to discover that the patient has enophthalmos.

Nasal fractures often can be managed by closed reduction. However, results with manipulation alone can be less than ideal and in panfacial trauma access of other facial fractures may well provide access to nasal fractures; and if so, this should be utilized to allow open reduction and fixation of the nasal component.

Of course, soft tissue reconstruction should be the final step. One must take care to restore all the layers during closure. Often, repositioning of the periosteum may be neglected, which can produce a sagging appearance to the face. Soft tissue lacerations and contusions are common in panfacial trauma. Sometimes soft tissue loss is considerable (e.g., resulting from

TABLE 3-6 Preliminary Treatment Plan in Panfacial and Midfacial Fractures

Type of Fracture	Displacement	Sensory Disturbances	Interference in Occlusion	Interference in Mouth Opening	Preliminary Treatment
Arch	–	–	–	–	Follow-up
Arch	+	–	–	+	Reduction
Zygoma	–	–	–	–	Follow-up
Zygoma	+	–	–	±	Reduction (+ stabilization)
Zygoma	+	+	–	±	Reduction (+ stabilization), orbital floor?
Blow-out/blow-in	+	±	–	–	Reconstruction? Bone graft?
NEO	+	±	–	–	Reduction + stabilization, coronal incision?
Frontal sinus walls	–	–	–	–	Follow-up
Frontal sinus walls	+	–		–	Operate
Nose	–	–	–	–	Follow-up
Nose	+	–	–	–	Reduction + stabilization
Le Fort I to III	–	–	–	–	Follow-up
Le Fort III	+	±	+	±	Reduction + stabilization, coronal incision? IMF
Le Fort II	+	+	+	–	Reduction + stabilization, coronal incision? IMF
Le Fort I	+	–	+	–	Reduction + stabilization, IMF
Panfacial	+	+	+	±	Reduction + stabilization, coronal incision? IMF, bone graft?

IMF, Intermaxillary fixation; *NEO,* nasoethmoid-orbital.

shotgun injury). Such injuries are always managed simultaneously with the reconstruction of the facial skeleton. The greater the soft tissue injury, the more challenging the reconstruction, which can be performed by local or distant flaps or sometimes even free flaps.

Preliminary Treatment Planning in Mandibular Fractures

Indications for Surgical Intervention

Surgery should be undertaken if there is a realistic expectation of improving the patient's immediate condition (e.g., to eliminate pain). The outcome must be predictable, and the risk of significant morbidity and mortality must be absolutely minimal.

A nondisplaced fracture in a healthy, cooperative patient with good oral hygiene can be treated without surgery. Instruct the patient to maintain a soft diet, and follow up properly. Be cautious, however, with bilateral nondisplaced fractures, which often become unstable and start to displace. In such cases, a regular clinical and radiological control for up to 6 weeks is necessary. Condylar fractures in edentulous patients in most cases are best treated with prosthetic rehabilitation when the fracture is stable.

Timing of Surgery

As a general rule, the sooner fractures are reduced and stabilized, the less the chance of infection tracking into the fracture (see Figure 3-26). Naturally, earlier surgery also limits the discomfort of the patient. Late treatments, when the healing process has begun, are associated with poor outcomes, because it is increasingly difficult to reduce the fracture properly. In general, most mandibular fractures in the dentate area should be treated ideally within 24 hours. This also applies if the oral mucosa is lacerated.

Surgical Plan

The preoperative clinical and radiological details should allow the surgeon to start work with a clear plan of action. Before entering the operating room, the surgeon must make a preliminary decision on how to treat the fracture. Today, more and more fractures are being fixed internally to allow immediate function of the temporomandibular joint. Using open reduction and internal fixation without postoperative intermaxillary fixation, one can avoid a number of problems associated with the patient's social life. Many fixation methods are available, but to avoid scarring, use of rigid fixation, normally by intraorally placed miniplates, now is considered the norm for most fractures. The details and indications for each type of fixation are discussed in Chapter 4. In all patients, however, the occlusion is restored by intraoperative intermaxillary fixation, after which repositioning and stabilization of the mandibular fractures can be started—from the largest fragment toward the smallest. Table 3-7 gives an overall view of the preliminary treatment plan.

If the general condition of the patient is unstable (for example, patients with multiple trauma), one should wait until the patient is stable enough for surgery. Otherwise, in mandibular fractures there is no reason to wait, and most fractures can be operated on within 24 hours.

Step-by-Step Operative Management of Panfacial Trauma

Take the following steps in the operative management of panfacial trauma (Figure 3-30):

1. Restore the airway.
   - Tracheostomy, submandibular, or transbuccal intubation
2. Expose all fracture sites by planned incisions (coronal, lower eyelid area, and intraoral) and existing lacerations.
3. Connect the incisions and lacerations by subperiosteal tunneling to facilitate direct visualization of all operative sites.
4. Reposition and stabilize the facial skeleton in the following order, independent of the occlusion:
   - Reconstruct the projection of the face (anteroposterior dimension), starting from the stable posterior area (temporal bone, proximal part of the zygomatic arch) and proceeding along the zygomatic arch to the zygomatic complex.

TABLE 3-7 Preliminary Treatment Plan in Mandibular Fractures

Type of Fracture	Stability	Displacement	Infection	Patient Compliance	Preliminary Treatment
Simple	+	–	–	+	Soft diet
Simple	+	–	±	–	IMF/miniplate*
Simple	–	–	±	±	IMF/miniplate
Open	+	–	–	+	Soft diet + antibiotics
Open	±	–	–	–	IMF/miniplate
Open	+	–	+	+	IMF/miniplate
Open	–	+	±	+	IMF/miniplate
Open	–	+	±	–	Miniplate/macroplate*
Comminuted	–	+	–	±	Miniplate/macroplate
Comminuted	–	+	+	±	Reconstruction plate
Defect	–	+	±	±	Reconstruction plate
Condylar	+	–	–	±	Soft diet
Condylar	–	OPG<10 mm	–	±	IMF
Condylar	–	OPG>10 mm	±	±	Miniplate, lag screw
Bicondylar	–	+	–	±	Miniplate, lag screw

IMF, Intermaxillary fixation; *OPG,* orthopantomogram measurement.
*Microplate: 1 to 1.3; miniplate: 1.5 to 2; macroplate: >2.

- Reconstruct the width of the face (horizontal diameter) across the zygomatic arches by fixing the zygomas to the stable part of the upper facial third (reconstruct the frontozygomatic suture area).
- Recreate the NEO area between the zygomas. The key areas are the orbital floors, the medial canthal ligament area, and the nasal bridge.
- Restore the posterior vertical height of the face by repositioning and fixing the condylar ramus fractures.

5. Restore the occlusion by intraoperative intermaxillary fixation, if possible.
6. Reposition and stabilize the mandibular fractures—from the largest fragment toward the smallest.
7. The final adjustments are performed by gently repositioning the Le Fort I level of the maxilla to the position indicated by the mandible via intermaxillary fixation. This might result in steps and gaps in the Le Fort I level, because all deformations of the fragments cannot be undone. Stabilization of the Le Fort I level is performed by placing the osteosynthesis plates in the load-bearing areas. Gaps greater than 5 mm are best treated by primary bone grafting.
8. Soft tissue management is as follows:
   - Defects (see Chapter 11)
   - Repositioning of the soft tissues to prevent facial sagging
   - Coronal flap repositioning to the temporal muscle fascia, lateral canthal ligament area, and nasofrontal area
   - Wound closure
9. Ensure proper drainage.

FUTURE PERSPECTIVES

Over the past century there have been major achievements in the care of victims of maxillofacial trauma, many of which are not specific to surgery. Discoveries and factors involved in the metabolic response to trauma, the healing of traumatic injury, shock, nutrition, and intensive care are more pertinent to the patient as a whole than to the maxillofacial area in particular.

With respect to maxillofacial trauma, there are certain specific factors that have had a major influence on the outcome of the treatment. One is the step from closed to open reduction of fractures. In the preanesthetic, pre-antiseptic era, a closed reduction was the rule for most fractures. After the introduction of antibiotics, the possibility of surgically opening facial bone fractures increased significantly.

Before surgery, a fracture diagnosis and typing is, however, mandatory. This is especially important with respect to the facial skeleton, where only an exact reduction will result in an optimal functional and esthetic result. The second major advancement was diagnostic imaging, which is one of the most significant achievements in the history of medicine. Plain radiographs added a completely new dimension to the surgeon's diagnostic abilities. The next step was panoramic tomography, which made an exact classification of fractures possible, especially in the mandible.

CT and, later, magnetic resonance imaging (MRI) in turn would revolutionize the diagnosis of midfacial fractures completely. The possibility of exact trauma diagnosis and open fracture reduction were the prerequisites of proper fracture treatment.

The third major step was the introduction of rigid fixation techniques, allowing immediate, pain-free function of the masticatory apparatus.

The oral and maxillofacial surgeon is in a unique position, having the ability to perform surgery transorally, which is to be recommended whenever possible: "There is no scar like no scar." However, severe fractures of the midface require a large exposure, which previously was provided by separate small incisions to the face. Craniofacial principles, including facial degloving, led in the 1980s to the possibility of providing maximal exposure through internal or camouflaged incisions and to performing esthetically acceptable single-stage repair of severe facial fractures.

The future of maxillofacial trauma surgery continues to improve. The capacity to link ever more detailed imaging to computer software programs allows improved preoperative diagnosis, assessment, and treatment planning, with the development potentially of preoperative custom-made implants for orbital reconstruction, which may enable more accurate reconstruction. Intraoperative assessment of fracture reduction and reconstruction is available with intraoperative imaging and navigational techniques or endoscopic assisted visualization of fractures to allow assessment of fracture reduction or orbital

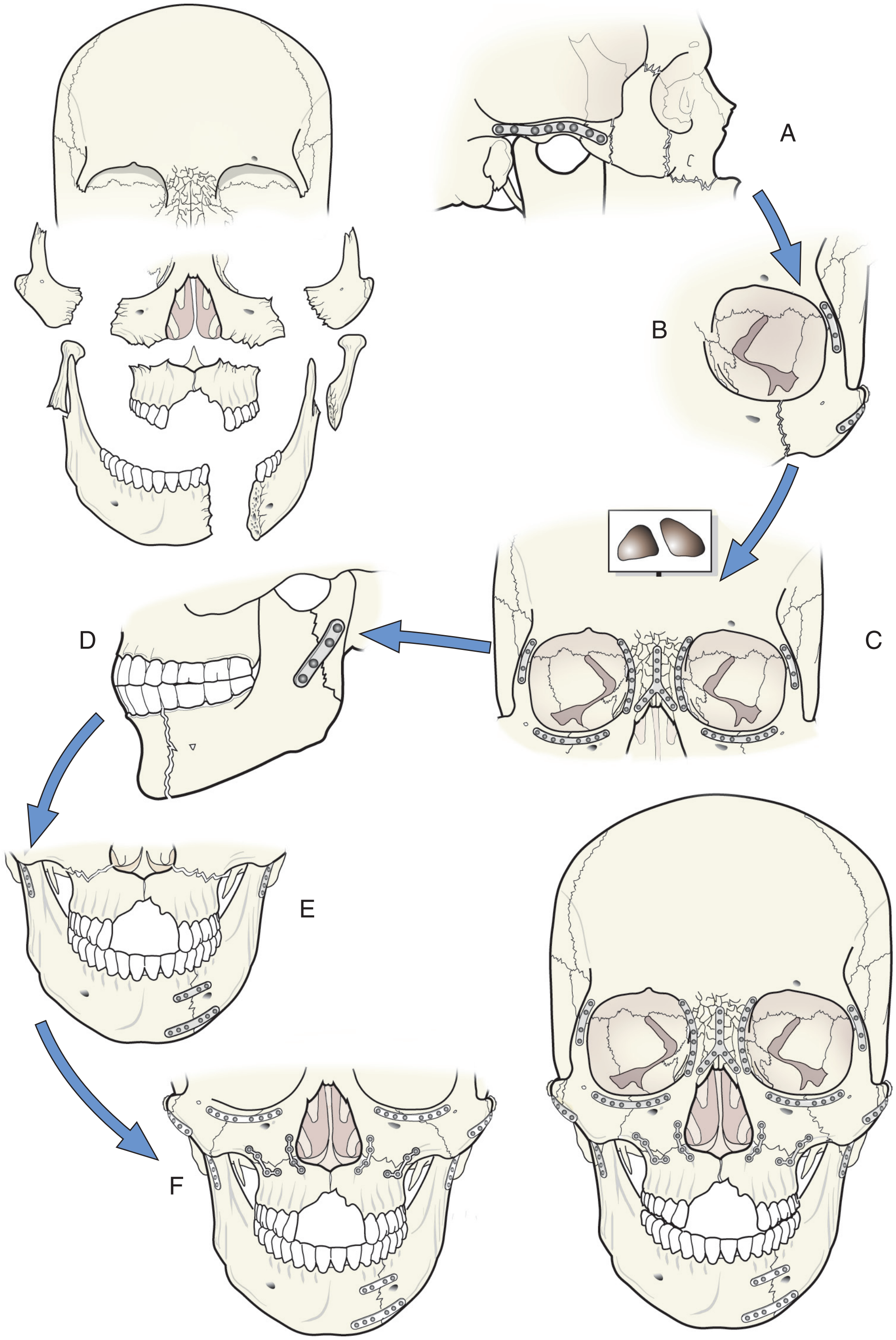

FIG 3-30 Panfacial fracture treatment protocol: Panfacial fracture treatment is based on reconstructing the load-bearing structures of the facial skeleton in a precise and logical manner. *A,* The projection of the midface is created by reconstructing the zygomatic arches, starting from the stable part of the temporal bone. *B,* The zygomas then are fixed to the arches and to the frontal bone to create the final projection of the midface. *C,* The width of the midface is reconstructed by repositioning the central midface (orbits and nose) to its correct position in relation to the zygomas and frontal bone. Concomitantly, canthopexy is fixed adequately, and the frontal bone and sinus fractures are treated. This procedure is carried out independent of the occlusion. *D,* The posterior vertical height of the face is reconstructed by repositioning and fixing the condylar fractures. *E,* Next, intermaxillary fixation is applied, and the mandible is reconstructed. *F,* The final step is to position the Le Fort I level fractures in an easy manner to natural occlusion. Some steps or gaps are acceptable at this level.

reconstruction compared to preoperative predictions, which should allow intraoperative assessments of reductions to be made and, if not ideal, improved immediately rather than at a second procedure.[19]

Diagnosis and Treatment Planning

Today, it is possible to have an exact two- and three-dimensional reproduction of the facial bones. A modern CT scanner provides several images from all possible angles within a few minutes. The information obtained can be transferred via computer and telecommunications, which makes it possible for the surgeon to have a rapid prototype model of the skull before surgery. The operative procedure can be planned thoroughly and the surgery practiced before the actual operation. Telenavigation, which has been used in aviation technology for years, also can be applied to surgery today. The operation can be performed in virtual reality when all information from the preoperative investigations has been collected into a three-dimensional space system. Advances in communication systems and computer technology make it possible for the surgeon to have consultations from any other center in the world, where experts can guide or even execute an operative procedure. Complex fractures can be treated and local professionals assisted by those with greater experience in particular areas. An exact diagnosis is fundamental to the correct treatment procedure.

Exposure

The transoral approach to facial fracture surgery became increasingly common after the availability of antibiotics. Previously, the oral cavity was kept separate from the extraoral areas when operations were performed on both; today, it is possible to work simultaneously within and outside the oral cavity. By combination of transoral vestibular, intranasal, and preseptal transconjunctival incisions, a complete degloving of the midface up to the nasofrontal angle and the zygoma prominence is possible.[20] Incisions in the oral cavity and through the conjunctiva are totally hidden. This also holds for a majority of bicoronal incisions and the face-lift incision. Submandibular or retromandibular incisions seldom are used today and probably will be totally avoidable when surgeons have gained more experience with endoscopic procedures. These procedures have totally changed the approach to several common gastrointestinal and gynecological operations. Although the need for endoscopic procedures is limited in maxillofacial surgery, it will always be an advantage to avoid incisions in the visible facial area. The usefulness of endoscopy varies with the location of craniofacial trauma.[21] Surgeons already have some experience with endoscopic treatment of condylar neck fractures and zygomatic fractures.[22-24] Also, endonasal-transantral endoscopic assistance in the treatment of blow-out fractures will decrease the need for a skin incision in the orbital area.[25] Temporomandibular joint arthroscopy has allowed operative procedures within the joint, not only in the treatment of internal derangements but also in condylar hard and soft tissue trauma. Instruments and equipment technology probably will develop significantly within the next few years.

Fixation Techniques

The development of plate and screw fixation techniques, which were used in orthopedic surgery for many decades before their use in maxillofacial surgery, allowed facial bone fractures to be repaired without supplemental maxillomandibular or skeletal fixation. This was one of the greatest advancements in maxillofacial trauma surgery. The AO school introduced the term *rigid fixation,* by which was meant a fixation strong enough to prevent mobility of bony fragments during active use. In time, this allowed the so-called primary bone healing without callus formation. Bicortical screws and compression and reconstruction plates with lag screw techniques were considered rigid techniques, whereas noncompression and easily bendable miniplates using monocortical screws were seen as semirigid fixation.

Later, special types of miniplates were developed for the fixation of midfacial and cranial fractures. Clearly, infected comminuted and defective mandibular fractures, such as fractures of the severely resorbed mandible, require absolute rigidity for uneventful healing. Yet the majority of fractures heal without absolute rigidity. Currently, surgeons aim for functional stability together with bone healing, not just functional stability per se.[26-27] As a fixation material, pure titanium has completely superseded stainless steel and various alloys. Bioresorbable materials, such as polydioxanone, polyglycolic acid, polylactic acid, and their copolymers, with which a number of fractures and osteotomies can be treated, have been introduced. Bioresorbable lag screws and miniplates and screws currently are being used in some countries.[28-30] Obviously, bioerodable materials into which different chemicals such as enzymes, antibiotics, and bone morphogenetic protein have been added will gain popularity in maxillofacial surgery in the future. The possibility of avoiding a second operation is an obvious advantage against the use of non-resorbable materials. However, problems still remain with respect to the resorption time, which for some of the available materials is too short and for some too long. Therefore, for the surgeon, it is of utmost importance to understand the properties of each bioresorbable material being used. Cooperation with clinicians and polymer chemists will lead to the development of materials that partly will eliminate the need for metallic devices.

Advances in coral chemistry have led to the possibility of treating severe cancellous bone fractures through minimally invasive surgery. A typical example is the tibial plateau fracture, where the marrow can be "filled" with bone cement, allowing immediate function with minimal support from osteosynthesis materials. In the future, several types of resorbable glues that can be applied transorally or endoscopically also may be developed for facial fractures.

PITFALLS

- The maxillofacial surgeon must have all pertinent data before entering the operating room.
- Performing major operations during the nighttime with minimal personnel can be risky.
- One must have enough skill and knowledge to change the preliminary treatment plan during operation, if needed.
- Consultation with other specialists must be sought when appropriate.

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4

Principles of Fracture Management: Reduction, Choice of Fixation, and Timing of Treatment

Wolfgang Puelacher, Christian Puelacher

KEY POINTS

- Coexisting medical problems or concurrent injuries (polytrauma associated with severe injuries to the brain, head and neck, chest, abdominal organs or large vessels, as well as the combination with complicated injuries of the spine and extremities) may delay or hinder definitive repair and consequently make the subsequent treatment of fractures more difficult.
- Insufficient and inadequate preoperative imaging (radiographs, computed tomography [CT] and magnetic resonance imaging [MRI] and sonographic diagnosis) may fail to reveal the type and extent of injuries pattern.
- Inadequate access to and exposure of the facial skeleton may limit success in treatment of skeletal injuries (by limiting direct visualisation of the reduction of the fracture sites).
- Unrecognized soft tissue injuries, including skin, muscles, fat, and nerves, may result in unsatisfactory outcomes.
- Skills of surgeons are crucial in outcomes of clinical treatment of injuries.
- Incompliant patients may refuse or fail to attend for optimal treatment.

The management of craniofacial fractures in relation to the topics reduction, choice of fixation and timing of treatment is described. Subsequent chapters present detailed information about surgical interventions.

INTRODUCTION

Great progress has been made in the last 40 years in craniofacial fracture treatment. Trauma management has evolved toward open reduction and internal fixation (ORIF) rather than closed reduction.[1-4,6-8]

Gross disfigurement and poor functional results, including malocclusion, diplopia, enophthalmus, nasal disfigurement, and nasal obstruction, as well as complications after surgical procedures like chronic infection or pain and restriction of mouth opening, are fortunately rarely seen. Any of these potential complications, however, can cause serious disability for the patient.

In the field of craniomaxillofacial surgery tremendous progress, including greater knowledge and understanding of bone and soft tissue healing, as well as timing of interventions, have been made. Advances in reduction and internal rigid fixation techniques in combination with conventional methods of fracture treatment of the craniofacial skeleton and soft tissue drape have led to improved fracture treatment outcomes.[1,9]

The ultimate goal in advanced clinical and surgical fracture treatment is to restore perfect facial appearance and unimpaired function. Minimizing the risk of suboptimal outcome relies significantly on accurate diagnosis, careful surgical planning and timing of intervention, professional surgery, and attentive follow up (Figure 4-1).[10,11]

FIG 4-1 Significant cosmetic and functional deficits after severe traumatic craniofacial injury.

ETIOLOGY

Performing a treatment evaluation of 10,000 traumatized patients at the craniomaxillofaial unit of the university hospital trauma center in Innsbruck, Austria, revealed fractures of the facial skeleton in 77.5% of the cases, dentoalveolar injuries in 53%, and soft tissue injuries in 62.5%. Out of the 7769 fractures, there were 71.5% fractures of the midface, 24.3% fractures of the mandible, and 4.2% frontobasal fractures. There were 2550 traumatized patients with concomitant injuries: 56.8% with neurological traumata (out of these 60.9% had to be treated by neurosurgery), 11% with injuries of the extremities, 7.7% with chest injuries, 5.4% with injuries of the spinal cord, and 2.2% with abdominal injuries.[12,13]

FROM CLOSED TO OPEN TREATMENT

Closed Reduction and Retention Using Wires and Splints

Closed reduction is considered a "conservative surgical" fracture treatment without visualization of the fracture sites. Accurate reduction relies on fragments fitting together. Anatomical reduction is difficult to achieve with closed methods and only likely if the periosteum is intact. Examples of closed reduction include fixing the teeth of the lower and upper jaw in occlusion (intermaxillary fixation [IMF] or maxillomandibular fixation [MMF]), repositioning of a fractured zygoma, elevation of fractured nasal bones, or using the arch bar to stabilize dentoalveolar fractures.

IMF, which is the most commonly used method of closed treatment, relies on the anatomically correct positioning of the teeth to control the reduction; these are then fixed together to reach retention and stabilization of the fracture(s) (Figure 4-2).

FIG 4-2 Intermaxillary fixation (IMF; maxillomandibular fixation [MMF]) using wires and metallic arch bars fixed circumdentally.

In emergency cases, the dental arches can be repositioned and realigned using wires or different types of splints, which may be retained using IMF if the patient is completely awake, nasally intubated, or tracheostomized. Wire ligatures may be used for realignment of the fracture at the dental level, including two teeth on either side of the fracture. Preformed metallic splints can be fixed circumdentally using 0.4 mm wires. Additional stabilization is possible by using interdental application of autopolymerising resin. Direct application of these splints should be performed only for emergency treatment. Optimal fitting of the metal splints to the labial aspect can be reached by pre-bending and prefabrication of the metallic splints using repositioned dental casts, so that only minimal occlusal interference is provided (Figure 4-3).

FIG 4-3 Combination of metallic arch bar at the labial aspect and an acrylic splint at the lingual aspect of the dentition after repositioning of the mandibular fracture using dental model surgery.

For permanent retention, metallic arch bars at the labial aspect of the dentition may be used in combination with an acrylic splint at the lingual aspect or palatinal aspect of the dental arch if the fracture lies within the tooth-bearing area of the mandible respectively of the maxilla.

To generate the prefabricated splints, the dental casts are divided at the fracture site. The intact dentition of the opposite arch bar is used for exact repositioning. The metal arch bar (labial side) and the acrylic splint (lingual side) are made in the dental laboratory. If both the maxilla and mandible show fractures or the dentition is incomplete, only approximative repositioning in comparison to the pretraumatic occlusal relations may be obtained.

Small deviations in the occlusal level may show major gaps at the level of the lower border of the mandible. It is almost impossible to realign bone fragments that are not in direct contact with the dental occlusion.

As a consequence, "conservative" or closed treatment is used for primary fracture stabilization, respectively, in cases where an ORIF cannot be performed in time because of adverse general conditions that allow only for delayed major surgical interventions. In selected cases, when the postoperative radiological assessment shows satisfactory results, the closed

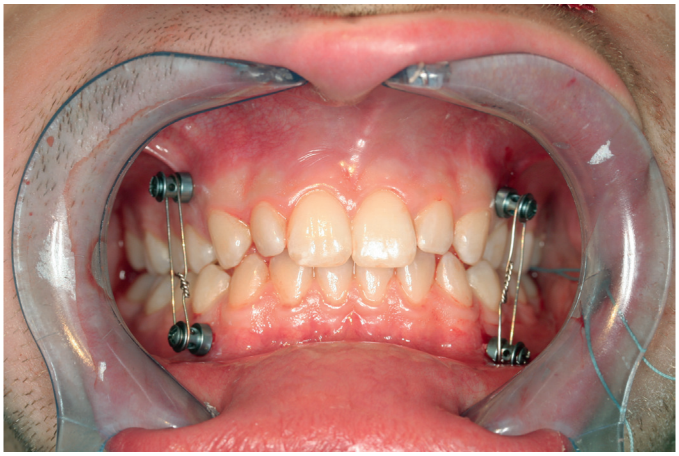

FIG 4-4 Intermaxillary fixation (IMF) using special designed IMF screws and intermaxillary wires.

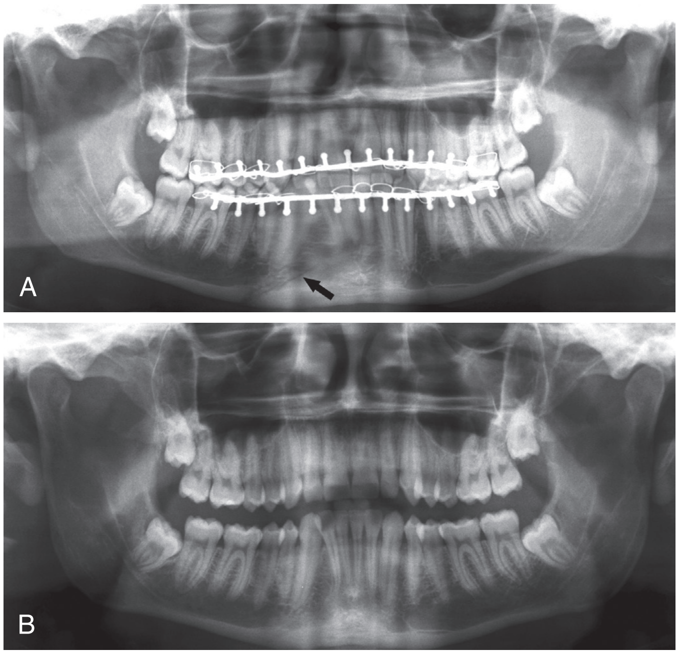

FIG 4-5 **A,** Closed reduction of mandibular body fracture *(arrow).* **B,** Uneventful healing 4 months after closed reduction.

treatment may maintained until bone healing has been achieved (Figure 4-4).

Specially designed IMF screws may be used intraoperatively in order to establish occlusion. They may be left in place temporally for additional application of guiding elastics after surgery. In edentulous patients, dentures may be fixed with miniscrews to both jaws, or circumferential wiring in the mandibular region may be used for retention of dentures. IMF may be used to treat "simple," minimally displaced fractures effectively under local anaesthesia unless contraindications for IMF exist (e.g., epilepsy, chronic respiratory disease, incompliant patient, or chronic alcohol or drug abuse). Generally, the retention should be held for 6 to 8 weeks. Clinical controls are necessary. The patient and the patient's relatives have to be informed about the inconvenience, and they have to be instructed about the risks of IMF.

The aforementioned splints may be fixed together by metallic wires or elastics. One should be aware that the use of elastics may induce orthodontic movements of teeth. The combination of interdental wires and impaired oral hygiene presents a suboptimal therapeutic option concerning the periodontium.

Facial or craniofacial suspension wires are rarely used for retention of facial fractures and may be justified only as preliminary measures in cases of emergency, whereas external fixation as method of "minimally invasive osteosynthesis" still has selected indications in craniofacial trauma surgery (Figure 4-5).

Advantages of Closed Reduction

For emergency care and in situations where limited resources and high workloads are present, the techniques of closed reduction are indicated. Moreover, the use of closed reduction is less expensive. But there are significant "hidden costs." These include the costs of additional patient supervision, as well as delays in returning to daily life activities and work. Possibly these costs can be higher than those of plates and screws.[8]

Disadvantages of Closed Reduction

In cases of fractures of the mandible and the midface, the closed reduction relies on positioning the occluding teeth in a correct way, based on the (wrong) assumption that this will result in precise reduction of the attached bony fragments. There is a necessity to restore the occlusion correctly, but closed reduction provides only a limited control over the final repositioning of the adjacent bone fragment(s). Larger distances from the dental arches may result in more extensive bony gaps. Muscular activity of the masticatory system may also displace bone fragments despite maintaining the apparent therapeutic position of the dental arches. Finally, the bones of the centrolateral midface are not related to the teeth at all.[14]

In certain cases, the alignment of the fractured bone fragments by occlusal guidance may be difficult. Especially in cases of malocclusion, dysgnathia, missing, diseased, or damaged teeth. In these cases, reliability of correct reduction of fractures is very poor. This may result in occlusal disturbances, maxillofacial and orbital disfigurement, as well as disturbance of the temporomandibular joint (TMJ) function.

OPEN REDUCTION AND INTERNAL FIXATION

The Development of Modern Osteosynthesis in Trauma Surgery

Internal rigid fixation and its effect on bone healing have continued to be a constant source of controversy, both in craniomaxillofacial and orthopedic surgery.[15-21] During the last decades, biomechanically tested osteosynthesis materials have become available for fracture stabilization. Today, modern osteosynthesis techniques in combination with advanced anaesthetic skills and principles of infection control enable these surgical interventions to be carried out successfully at very low morbidity.

History

Traumatic injuries have been treated successfully for a long time. In the twentieth century, first reports on stabilization of facial fractures started to appear. Fixation mostly relied on the use of the dentition, using different forms of intermaxillary, intrafacial, and craniofacial fixation. Since the fundamentals of sterility were applied and safe anaesthesia was available, it became possible to develop improved surgical methods of fixation. However, the idea of open reduction and placement of plates and screws was not clinically appreciated.

General acceptance of open reduction and osteosynthesis did not appear in maxillofacial surgery until the 1950s. Although some surgeons continued to avoid open approaches, they increasingly became frustrated by the shortcomings of reduced but unstable fractures, because anatomically reduced fractures would displace if they were not stabilized using osteosynthesis techniques. This is particularly important in the craniomaxillofacial region, where a well-healed but displaced fracture may result in significantly compromised functional and cosmetic results. Such poor outcomes are unacceptable today.

Craniomaxillofacial surgery has undoubtedly benefited from the advances in clinical research carried out in orthopedics, but the transfer of orthopedic concepts and techniques to the face was not directly possible.[22,23] The excellent blood supply to facial bones and overlying soft tissues provides favourable conditions for healing and enables the placement of plates at low morbidity, even in the presence of minor contamination. Degloving injuries of the fractured mandible mostly heal uneventfully compared to the situation in the lower limb, which rarely heal uneventfully after comparable soft tissue injuries.

Principles

The craniofacial skeleton represents a complex anatomical structure supported by three-dimensional bony pillars and bony plates. The nasal maxillofrontal buttress, the zygomaticomaxillary buttress, and the pterygoid-mandibular pillar provide sufficient vertical support and distribute masticatory forces throughout the face into the cranial vault. The alveolar process, hard palate, and periorbital bones create the horizontal support of the facial skeleton. The mandibular bone is connected to the facial skeleton through the TMJ.

The injuries to the facial skeleton and disruptions of the structures have been classified by different authors, but Rene Le-Fort's classification (1869-1951) is mainly used today for midfacial fracture description.[24] Mandibular fractures have been classified by fracture type or by anatomic location.[4] Whichever classification is used, proper reduction, fixation, and stabilization must be the ultimate goal to provide and maintain adequate form and function of the craniomaxillofacial region.[15,17,25]

The effects include:

- Maintaining precise reduction
- Restoring early function at the fracture site and its surrounding muscles and joints, resulting in restoration of normal mastication, mouth opening, swallowing, speech, and facial appearance
- Reducing "healing time"
- Preventing of infection associated with excessive movements
- Avoiding other potentially bulky forms of stabilization (e.g., external fixators)

Effects of Fixation on Fracture Healing

Although rarely seen today, examples of untreated and clinically healed facial fractures, such as minimally displaced midfacial fractures, may still exist. When left without fixation, the risks of shortening of the anterior facial height, for example, and occlusal disturbances exist.

Historically, the work of the AO group* plotted the progress of untreated radius fractures in dogs from initial fracture through to fibrous union. Although it is reasonable to question the relationship between young healthy animals and humans, animal models were used to provide useful data. From the animal work, a better understanding of fracture healing emerged.

The bone healing process can be divided to direct and indirect processes. *Direct bone healing* was seen to occur in animal experiments when a 1 mm hole was cut into bone. Because of complete stability, immediate growth of bone into hematoma could be observed. This tissue was replaced and remodelled into trabecular bone. No intermediate cartilage bone healing occurred. No callus formation was observed. *Indirect bone healing* classically occurred across a mobile long bone fracture. Initial hematoma formation was followed by the ingrowth of fibrovascular tissue. This regenerative tissue underwent remodelling with proliferative osteoid growth at the periosteal callus formation. Across the fracture, the surrounding tissues provided early stability for osteoid formation. Once united, remodelling of the callus and the osteoid occurred, and the final trabecular bone was produced.

In cases of excessive mobility, incomplete callus proliferation occurred that was unable to stabilize the fracture. This resulted in a nonunion fracture and subsequently in osteomyelitis in a large number of cases. Indirect healing, therefore, became associated with problems of fracture management, including excess of callus formation, infection, prolonged immobilization, prolonged antibiotic regiments, malunion, nonunion, extended hospitalization, secondary surgery to encourage union or to eliminate infection, as well as reoperation for a second time where the generation of a second donor site for bone grafting was necessary.[26]

These potential clinical problems and results were compared with the results of direct bone healing in which osteoid and trabecular bone formation did occur without callus formation. With direct healing, there was perfect reduction, early healing, and early restoration of normal function. Based on the poor experimental result of indirect bone healing, it had been postulated that direct bone healing should be achieved in fracture management. Therefore, engineers were motivated to develop methods of fixation, which produced sufficient stability for direct healing to occur. However, in a biological system in which bone itself demonstrates intrinsic flexibility, absolute rigidity cannot be reached. Moreover, results from long bone fracture healing cannot be directly transferred to the maxillofacial bone with their abundant blood supply and intrinsic healing capacity. Therefore, comparing the results of stability rather than the healing processes themselves does not necessarily lead to instability and failure of fracture healing in facial fractures.

Macroplates for Mandibular Fracture Treatment

The AO group developed prototype systems of compression osteosynthesis, which later were refined.[17] Stability was achieved by pressing the bone ends together. This required open

*Arbeitsgemeinschaft für Osteosynthesfragen, or the Association of the Study of Internal Fixation (ASIF).

reduction, and compression was achieved by the plate. Initial compression loads in maxillofacial plates are in the order of 60 to 80 kPa/cm^2 at the fragment interface. This force, however, drops off with time as bone resorption occurs around the screws and fracture line. As a result, compression falls to about half of this figure at 6 to 8 weeks. Forces may be increased further by preloading the fracture site by applying extrinsic forces to compress the fragments together before performing osteosynthesis using macroplates (Figure 4-6).

Further studies showed that muscle activity, resulting in changing loads across a bone, were found to create change of compression and areas of tension within it. Placing a plate across an area of tension was found to create compressive forces in that zone when the bone was loaded. The anatomical location where the plate is placed depends on the morphology and anatomy of each bone and the type and configuration of the fracture. When the plate is pre-compressed and then fixed along such lines of tension, this may further elevate compression across the fracture site. This principle is known as *dynamic compression* or *dynamic compression osteosynthesis.* In the animal model, this resulted in stabilization of the fracture leading to direct healing, anatomical union, and a rapid return to function. Dynamic compression osteosynthesis has had an enormous impact on orthopedic trauma treatment and has become established practice in many trauma units.

In the facial skeleton, the application of these principles is not straightforward because the mandible presents a complex three-dimensional shape, against which any plate must fit precisely. Moreover, teeth and neurovascular structures may limit plate positioning. Furthermore, the maxilla is largely made of thin bone lamellae, which is incapable of carrying the necessary loads around the screws to apply significant compression.

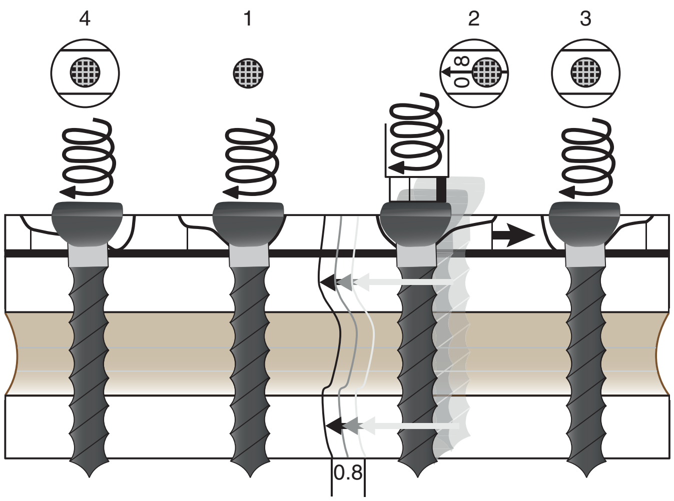

FIG 4-6 The dynamic compression plating acts by transforming the downward force of screw insertion into a longitudinally directed compressive force. This action displaces the screw and its fragment in the direction of the opposite fragment, resulting in static compression between the bone ends (and thus interfragmental compression). *Arrows* indicate the interrelationship between the tension on the plate side and the pressure on the bone side. The circle marked with 0.8 *(2)* is an eccentric drill guide; *0.8* indicates the compressive displacement in millimeters that is produced by the dynamic compression hole of the plate.

Several maxillofacial units (e.g., in the German-speaking countries) introduced dynamic compression plates,[7] but this technique did not become generally accepted. There were problems in applying this technique to the face, including the curvilinear shape of the mandible, which created difficulties for a system designed to provide straight-line compression. The application to the regions of the midface was not possible. The presence of teeth and the inferior alveolar nerve only allowed placement of the compression plates in zones already exposed to compression rather than tension. Extensive compression (e.g., in commuted fractures) resulted in inadequate compression at the upper border and straightening of the natural curvature of the mandible. This has been associated with malocclusion. This was considered inappropriate because the need for precise reduction in the face to establish adequate occlusal function and facial esthetics appeared to be greater than in orthopedic surgery. In addition, skin incisions were required in most cases with scarring and a small risk of damage to the mandibular branch of the facial nerve.

Dynamic compression plating turned out to be a demanding technique in the maxillofacial area. This should not be a reason for not using it, but beyond the aforementioned problems, concerns were raised that the plates were too rigid, inducing delayed healing through stress shielding.[23,27-29] Moreover, augmented contact and pressure from bulky plates compromises the periosteal blood supply. This appears to be particularly important in the older population with a tendency for an atrophic mandible with reduced mandibular height. Finally, plate removal may require a second, extraoral approach.

Another type of macroplates, reconstruction plates, are equally strong and of comparable size but do not provide any compression to the fracture gap. They are used for osteosynthesis in comminuted fractures or in continuity defects (e.g., avulsion injuries, gunshot injuries).

Lag Screws for Mandibular Fracture Treatment

In oblique fractures, compression lag screws (Figure 4-7) are used for stabilization. These are applied without plates, being placed perpendicularly across the fracture line in order to avoid displacing the fragments. To produce compression, the proximal bone hole is oversized so that only the distal fragment is engaged by the screw. Tightening applies sufficient compression and consequently stabilization of the fracture site.

The lag screw technique has proved to be an effective method, which can be employed transorally in a number of cases. This technique appears to be ideal for parasymphyseal and symphyseal fractures, but it becomes technically more difficult in body or angle fractures because the risk of damage to the alveolar inferior nerve increases (see Figure 4-7).[30]

Miniplates for Mandibular Fracture Treatment

A different concept and osteosynthesis system comprised of smaller plates inserted along the lines of tension has been developed and popularized.[2,5,31]

Champy and colleagues developed the technique of Michelet and Moll.[5] He described a technique of monocortical fixation using miniaturized plates applied to the outer cortical surface of the mandible through an intraoral surgical approach. The technical advantages of osteosynthesis using miniplates include the easy adaption of the small plates, the monocortical

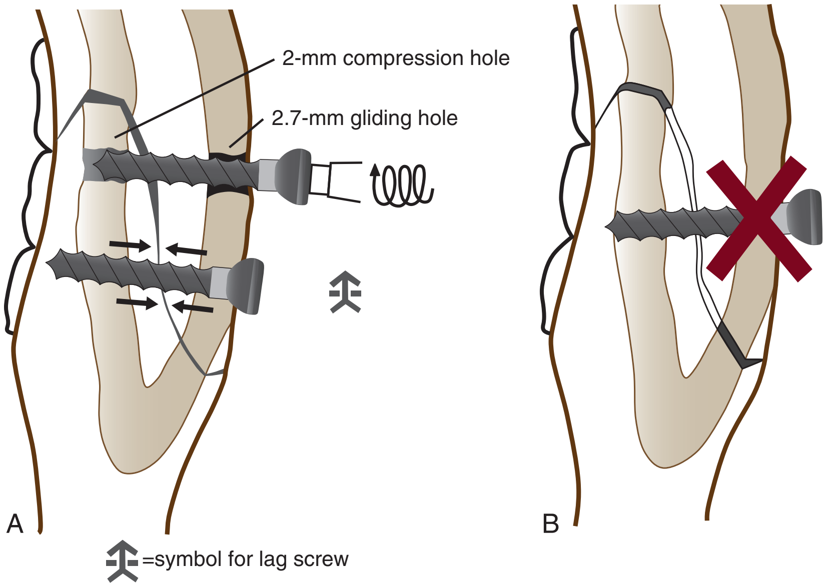

FIG 4-7 **A,** Interfragmental compression is obtained only if the screw glides freely through the near fragment and grips the far fragment. The gliding hole is cut with the 2.7-mm drill bit; the compression (thread) hole is cut with the 2-mm bit and threaded with the 2.7-mm tap. The rounded tip of the screw projects about 2 mm from the bone to ensure that the last thread completely engages the far cortex. **B,** Without a gliding hole, the fragments are transfixed.

application, the intraoral approach, and the functional stability (Figure 4-8).

Miniplates (miniaturized plates) have become the standard method of internal fixation in many units of maxillofacial surgery nowadays. These osteosynthesis techniques, further developed by the Strasbourg Osteosynthesis Research Group (SORG) effectively demonstrated that good results from indirect healing are possible as long as adequate fixation is provided and functional loading is avoided.

Placement of miniplates through an intraoral approach has shown to be a great advantage of this technique that has considerable reduced morbidity compared to plates that aim at direct fracture healing. Although miniplate osteosynthesis was primary directed to the management of mandibular fractures, the principles of osteosynthesis have been applied to the treatment of midfacial fractures, craniofacial surgery, orthognathic surgery, reconstructive bone surgery, and reconstructive preimplantologic surgery. Although, it was not originally recommended by Champy to extend miniplate fixation to treat most facial fractures.[16]

Within the mandible, the miniplate principle involves identifying the lines of tension at the site of the fracture.[32] A plate is then secured along this line across the fracture without compression of the fracture site. Because (nearly) no compression is used, the plate can be anchored using only the outer cortical bone with so-called "monocortical" screws. As a result, plates and monocortical screws can be placed safely in anatomically correct position where they are biomechanically desirable.

Champy and colleagues' studies examined stress loading at different sites of the mandible.[2] In the anterior mandibular region, it appeared more advantageous to use two miniplates, because this is a challenging region due to a combination of sharp curvature of the bone and the muscle attachment with different vectors of action. Posterior to the canine, the mylohyoid muscle pulls medially, whereas anterior to the canine the gonial muscles and digastric muscles tend to pull more posteriorly, resulting in rotational forces.

Additional studies have added further understanding to the miniplate technique. Kroon and colleagues demonstrated that at the angle there are circumstances when tension and compression are reversed.[33] Tams' group, using finite element analysis, documented force vectors within the functioning mandible.[34]

In comminuted or sagittal fractures, the miniplate technique has been modified. In these configurations, the bones do not have secure contact in the areas of compression, the fragments may "slip" past each other, and sufficient tension will not be generated. In comminuted fractures, careful repositioning and fixation of all the fragments is necessary using miniplate technique, whereby smaller bone fragments may become devitalized.

Because of the simplicity of the miniplate application and its inherent flexibility relatively, quick fixation and reduced risk of malocclusion compared with rigid compression plates is provided.

Locking miniplates have been developed to further enhance stability of fracture treatment and avoid pressure of the underlying bone. The screw head is "locked" to the plate. Until now, there is only minor evidence that this extra stability between miniplate and miniscrew may have a relevant effect on clinical outcome. Advanced technologies in manufacturing provide pre-bent plates and laser-melted plates nowadays (Figure 4-9).

Microplates for Maxillofacial Fracture Treatment

Microplates—even smaller plates than those for the midface—may be used in the repair of naso-orbital–ethmoidal fractures,

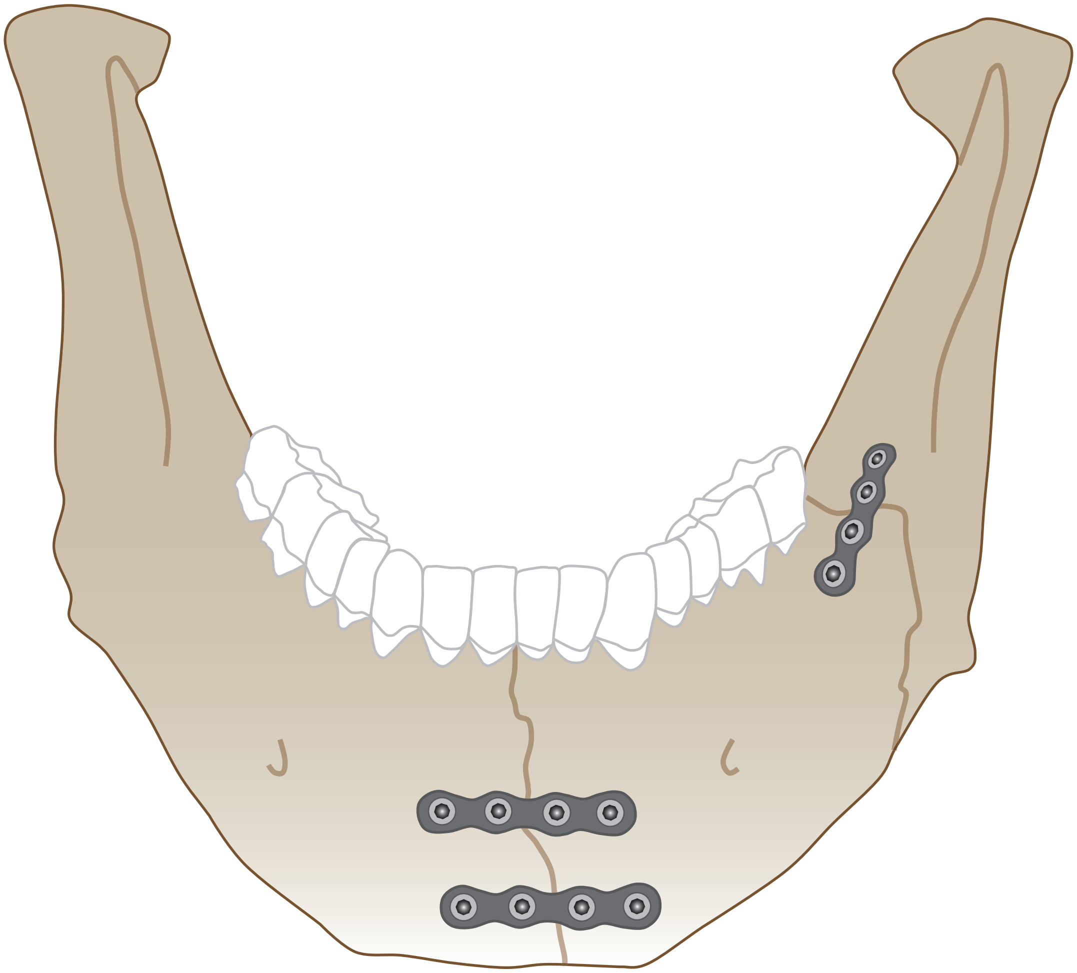

FIG 4-8 The miniplates for mandibular osteosynthesis are placed along lines of tension of the lower jaw.

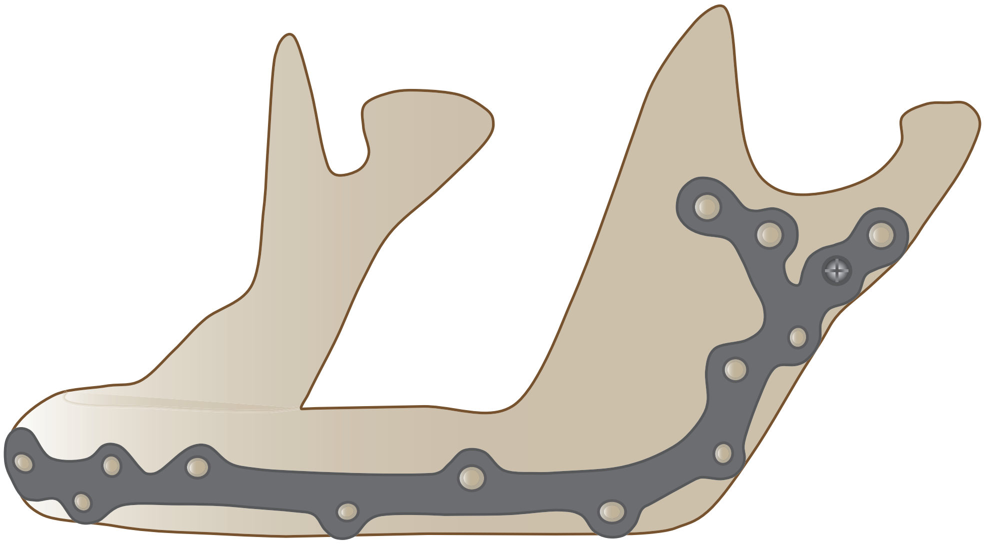

FIG 4-9 Laser-melted individualized plate designed for the mandible.

nasomaxillary fractures, frontal sinus repair, and the bony structures of the alveolar process.

External Fixators

Because of their inherent instability, external fixators enable a degree of micromovement, thereby possibly stimulating bone healing. As a result of these findings, external fixation became more popular. A trend developed in the orthopedic literature toward biological or "semirigid" fixation.[35] Knowing that excessive movement is associated with delayed union or nonunion, the difficulty, therefore, was to achieve the correct degree of stability. However, in maxillofacial fracture treatment, these fixation devices are used in cases of excessive soft tissue trauma or as provisional means of stabilization.

Condylar Fracture Treatment

Although the discussion about the indication for closed treatment in condylar fractures is declining, there is still an argument claiming that good results can be reached using IMF.[36,37] It is argued, that complications are rare and union occurs in nearly all cases, whereby inclusive functional therapy is mandatory. On the contrary, it is claimed that closed reduction is less favourable, because it is frequently associated with poor long-term function, including reduced mouth opening, deviation in opening and occlusal disturbance, TMJ pain and clicking, and consequently arthrosis of the TMJ.

Although the reconstruction of the mandibular anatomy of the TMJ (including hard and soft tissue structures) is an important goal, biology of fracture healing has to be taken into account when dealing with the question of closed versus open treatment of condylar fractures. In adults, severely displaced fractures with condyles out of the fossa show insufficient remodelling. In children, the bone forming and remodelling capacity is significant higher.[38,39] In adults, the spontaneous repositioning of anteriorly and medially dislocated condylar heads cannot be expected, whereas open reduction with anatomically correct position is technically possible in almost all types of fractures. Open reduction and rigid internal fixation of condylar fractures using two triangular positioned miniplates through a retromandibular approach (Figure 4-10) demonstrated that this technique allows for exact reduction of the bony fragment and functional stable results while avoiding the aforementioned long-time functional disturbances.[40] Alternatively, delta-shaped plates can be applied through an enoral approach. Lag screw osteosynthesis shows the advantage of central compression of the fragments and easy removal of the osteosynthesis material[41] (see Figure 4-10).

In surgical treatment of condylar head fractures, not only the reduction of the mandibular capitulum but also repositioning of adjacent tissue (such as, the lateral pterygoid muscle), the TMJ disc and the TMJ capsule is crucial when performing ORIF on these types of fractures.[42]

Facts to consider regarding condylar fracture treatment:

- Patients should have their own choice between closed treatment (rather than closed reduction respectively conservative treatment) and ORIF.
- Closed treatment may still be seen as a method in treatment of children with condylar fractures.
- Pure intracapsular fractures may be treated by closed methods at present. In selected cases, operative open treatment may lead to excellent functional results.
- Functional treatment plays a key role in closed and open treatment.
- Increasing numbers of publications demonstrate excellent outcomes with low morbidity performing ORIF.
- Additional prospective studies are necessary to evaluate treatment outcomes in fractures of the condylar head.

MIDFACIAL FRACTURE TREATMENT

In 1901, René Le Fort described the classical fracture patterns of the midface and determined three main levels of fractures as interruption of buttresses and lamellar bone structures in the midfacial architecture.[24] However, Le Fort's "simple and catchy" classification fails to adequately account for asymmetric fracture patterns and comminuted fractures, as well as concurrent anterior cranial fossa and mandibular fractures.[44]

The midface basically consists of thicker force transmitting regions (bony pillars), which transmit or resist forces to the base of the skull and neurocranium. The bilateral bony pillars are defined as pterygomaxillary, zygomaticomaxillary, and frontomaxillary (nasomaxillary) buttresses. These stronger buttresses exist around highly pneumatized lamellar bony structures (bony plates) of the midface and anterior skull. Comparing the construction of the midface to the architecture of gothic cathedrals, the force transmitting system may be likened to a

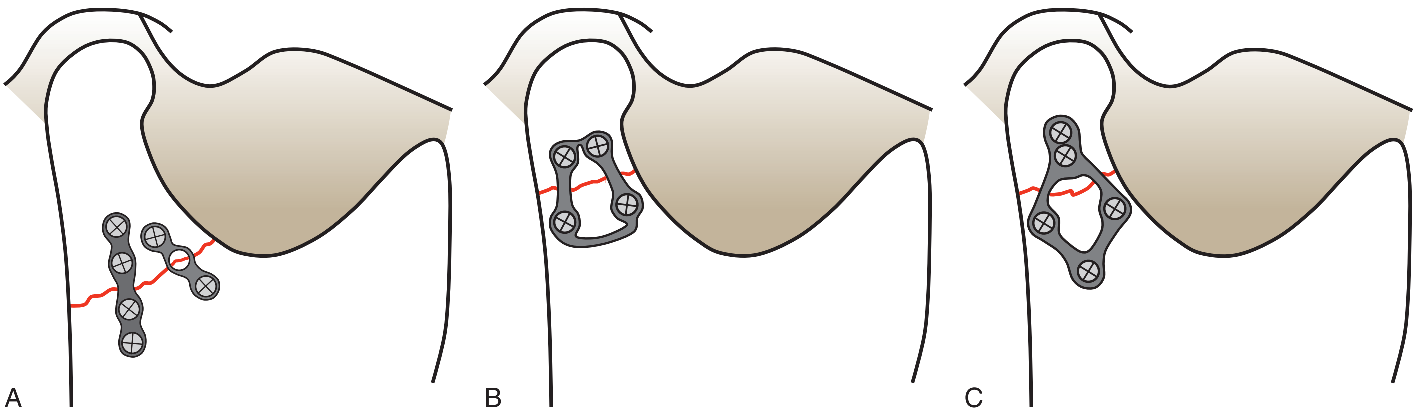

FIG 4-10 Open reduction and internal fixation (ORIF) of condylar fracture can be performed using two triangular positioned miniplates **(A)** or osteosynthesis devices of special design **(B** and **C)**.