Reconstructive Management of Facial Gunshot Wounds

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1 Introduction

Firearm-related facial injuries are caused by a wide variety of weapons and projectiles in military and civilian populations [1]. The type and extent of treatment required should be based on an understanding of the various mechanisms contributing to tissue damage and wound assessment.

The kinetic energy (E = 1/2 mass × v^2) of the penetrating projectile defines its ability to disrupt and displace tissue. The actual tissue damage is determined by the mode of energy release during the projectile-tissue interaction and the biologic characteristics of the tissues involved and the distance to the target. Certain projectile factors, such as caliber, configuration, construction, stability, and velocity, greatly influence the rate of energy transfer to the tissues along the wound track. As the velocity of the projectile significantly impacts the energy transferred, GSWs have been classically divided into low-velocity injuries (<300 m/s) caused by handguns (except Magnum loads), and high-velocity injuries (>300 m/s) caused by rifles, and shotgun blasts.

In high-energy GSWs, two zones of tissue damage can be identified, the permanent cavity created by the passage of the bullet and a potential area of contused tissue surrounding it, produced mainly by temporary cavitation which is a manifestation of effective high-energy transfer to tissue [2, 3].

The gunshot injuries may involve various parts in the face and have also been classified according to the involved anatomic areas [4]. They can be associated with serious ocular and brain injuries that require urgent neurosurgical and ophthalmologic interventions. Self-inflicted GSWs typically involve the lower half and anterior portion of the face that includes the mandible, maxilla, nose, and anterior cranial base.

In general, high-velocity and high-energy injuries result in more severe facial destruction compared to the low-velocity and low-energy-type injuries. Thus, facial GSWs may range from minor soft tissue injuries and/or bone fractures to devastating soft tissue and bone destruction and defects. The management depends on the type and location of the injury. Table 1 shows patient demographics, type of weapon involved, associated injuries, and reconstructive procedures. The following cases demonstrate the reconstructive surgical approach in various facial gunshot wound scenarios.

1.1 Case 1

A 58-year-old male sustained facial GSWs with an unknown handgun (Figs. 1, 2, 3, 4, and 5). After initial management and stabilization,

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Table 1 Patient demographics, type of weapon involved, associated injuries, and reconstructive procedures

Patients	*n* = 29
M:F ratio	5:1
Age range	14–77 years
Average age	36.1 years
Self-inflicted	*n* = 13
Assault	*n* = 16
Permanent brain injury	*n* = 4
Bilateral blindness	*n* = 2
Unilateral blindness	*n* = 4
Handguns	*n* = 15
357 Magnum handgun	*n* = 2
Shotgun 12-gauge	*n* = 6
High-powered rifle	*n* = 4
Unknown	*n* = 2
Anterior skull base reconstruction	*n* = 5
ORIF of mandible fracture	*n* = 6
ORIF of midface fracture	*n* = 8
ORIF of orbital fracture	*n* = 9
Tongue repair	*n* = 8
Facial nerve sural nerve grafting	*n* = 1
Free fibula osteocutaneous flap (mandible and floor of the mouth: 10, maxilla/palate: 2)	*n* = 12
Free radial forearm flap (lower lip: 3, palate 3, nose:3, cheek:1)	*n* = 10
Free anterolateral thigh flap (lower lip/chin)	*n* = 1
Free rectus abdominis flap (midface)	*n* = 1
Free dorsalis pedis flap (lower lip)	*n* = 1
Free gracilis muscle flap (lower lip)	*n* = 5
Pedicled pectoralis major myocutaneous flap (floor of the mouth/chin and mandibular plate coverage)	*n* = 2
Maximum number of free flap in one patient	*n* = 4

patient underwent left frontotemporoparietal craniotomy, evacuation of subdural hematoma and debridement of GSW to left frontal lobe, frontal sinus cranialization (Fig. 6), rigid fixation of the anterior table of the frontal sinus, dura repair with pericranial graft, and temporalis muscle to skull base (Fig. 7). In the same operative setting, he also underwent adequate but limited debridement of soft tissue injuries, and primary repair of floor of the mouth, tongue and submental wounds, intraoperative maxillomandibular wire fixation, and open reduction and internal rigid fixation (ORIF) of mandible fractures (Fig. 8).

Fig. 1 Frontal view of the patient who sustained a submental GSW

Fig. 2 The submental gunshot wound extending to the floor of the mouth created a full-thickness avulsion defect of the anterior tongue

Fig. 3 The full-thickness avulsion defect of the anterior tongue

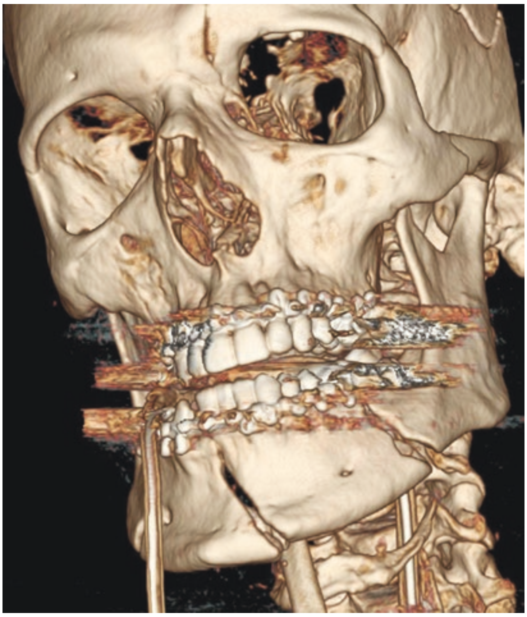

Fig. 4 3D CT (left oblique view) demonstrating the displaced right body and symphyseal mandible fractures

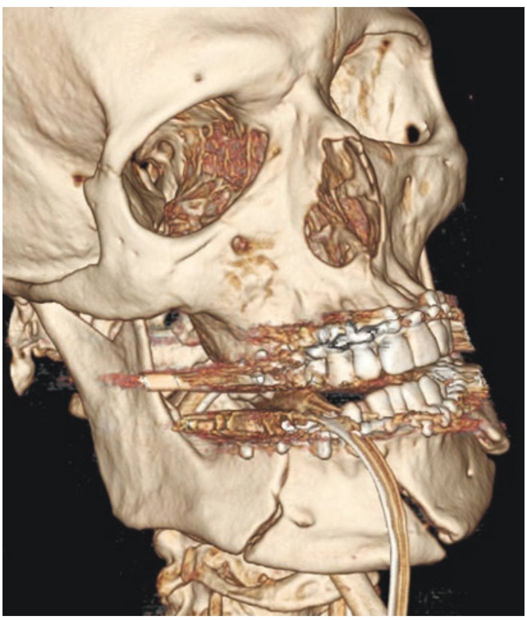

Fig. 5 3D CT (left oblique view) demonstrating the displaced left body and symphyseal mandible fractures

Fig. 6 Cranialization of frontal sinus, intraoperative view

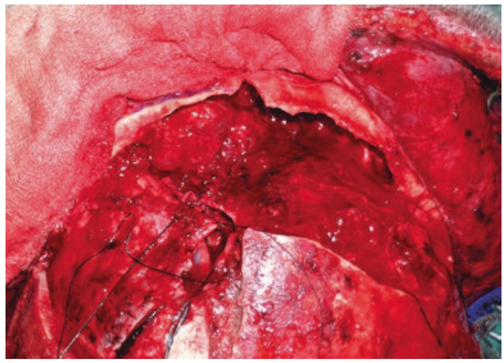

Fig. 7 3D postoperative CT (frontal view, right) and (left oblique view, left) demonstrating the rigid fixation of mandible fractures and craniotomy bone flap fixation

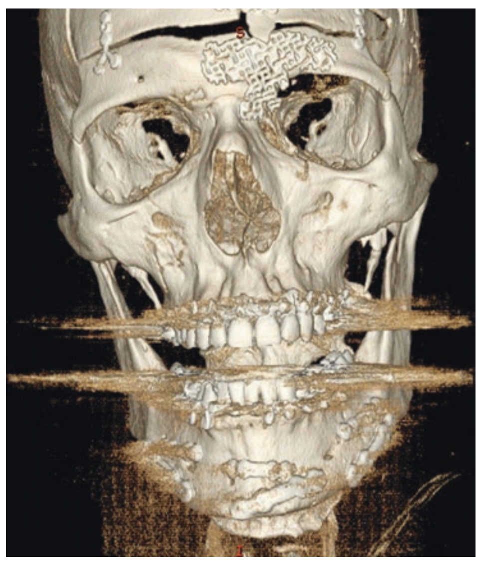

Fig. 8 Intraoperative view: Open reduction and internal fixation of mandible fractures using intraoral approach

1.2 Case 2

A 77-year-old male sustained self-inflicted facial GSWs with an unknown gun. The projectile resulted in an injury splitting his face as it traveled through the soft tissues involving the chin, lower and upper lips as well as the nose with avulsion of nasal soft tissues (Fig. 9). Complex repair was performed after adequate debridement (Fig. 10). Subsequently he received a nasal reconstruction in an elective setting using paramedian forehead flap (Fig. 11).

1.3 Case 3

A 59-year-old male sustained self-inflicted facial wounds with a 45 caliber handgun. Despite the low-velocity and low-energy nature of the projectile, he had extensive soft tissue and bone destruction resulting in both soft tissue and

Fig. 10 Intraoperative view after complex repair following adequate debridement

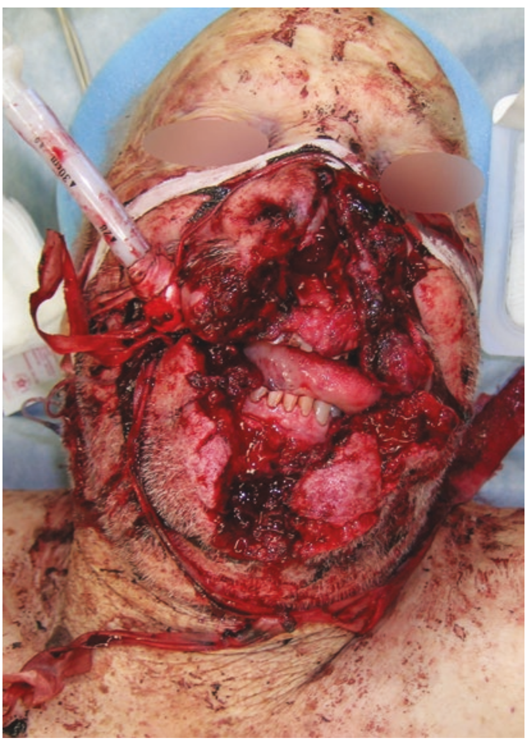

Fig. 9 GSW sustained by self-inflicted injury, splitting the soft tissues with tissue loss involving the chin, lower and upper lips as well as the nose

Fig. 11 First stage paramedian forehead flap for nasal reconstruction

bone defects in the maxilla as well as in the mandible (Fig. 12). 3D CT, remaining teeth and alveolar arches were used for optimal alignment and fixation of the mandible and maxilla. This was accomplished by collaboration and cooperation with maxillofacial surgery prior to surgery. Patient underwent debridement of devitalized tissues, open reduction internal fixation of bilateral orbital fractures, polyethylene implant placement to right orbital medial wall, right canthoplasty with transosseous wiring, and ORIF of nasal fractures. Three days after the initial surgery, he underwent a free osteocutaneous flap for maxilla reconstruction (Figs. 13 and 14), and subsequently in 1 week, another free osteocutaneous flap for mandible reconstruction (Fig. 15). Bilateral Karapandzic flaps were used for lower lip reconstruction at the same stage (Fig. 16). The cutaneous fistula that developed in the lower lip was then reconstructed using radial forearm free flap (Fig. 17). Figure 18 demonstrates postoperative 3D CT after the maxilla and mandible reconstruction using free fibular flaps, and ORIF of midface and orbital fractures.

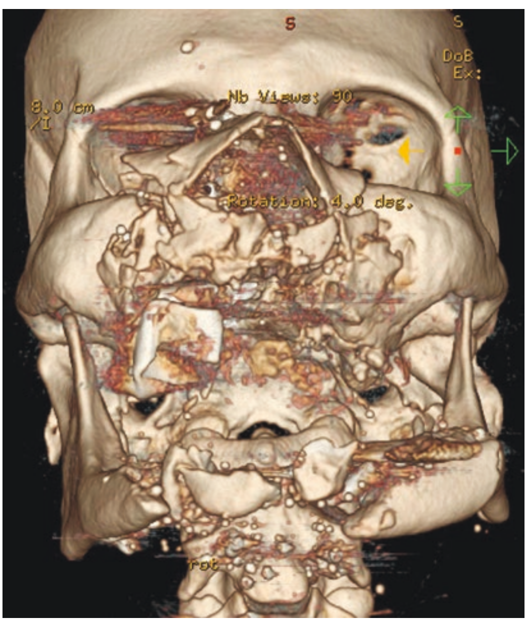

Fig. 12 3D CT (frontal view) demonstrating extensive bone destruction

Fig. 13 Free fibular osteocutaneous flap dissected for maxilla reconstruction

Fig. 14 Free fibular osteocutaneous flap for maxilla reconstruction. Right-sided facial vessels were used as recipient

Fig. 15 Free fibular osteocutaneous flap for mandible reconstruction. Left-sided superior thyroid artery and facial vein were used as recipient

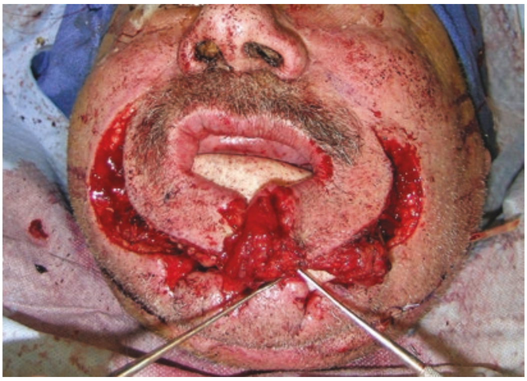

Fig. 16 Lower lip reconstruction using bilateral Karapandzic flaps

Fig. 17 Free radial forearm for reconstruction of orocutaneous fistula that developed at the junction of the lower lip and chin area

1.4 Case 4

A 54-year-old male patient sustained self-inflicted facial wounds with 12-gauge Shotgun. The injury resulted in loss of composite lower lip and the anterior segment of the mandible (Figs. 19, 20, and 21). Patient underwent a staged free osteocutaneous flap for composite mandible reconstruction (Fig. 22) and a free innervated gracilis muscle flap for functional total lower lip reconstruction 1 week thereafter (Fig. 23).

1.5 Case 5

A 46-year-old male patient sustained GSW to the left side of his face with shrapnel pieces

Fig. 18 Postoperative 3D CT (frontal view) demonstrating maxilla and mandible reconstruction using free fibular flaps and open reduction internal fixation of midface and nasal fractures

Fig. 19 Self-inflicted facial GSW that resulted in loss of anterior mandible and total lower lip

entering at the left retroauricular and mastoid area (Fig. 24) with an AR 16. He presented to plastic surgery clinic at 3 weeks after the initial injury that resulted in complex comminuted fractures of the left mandible angle, subcondylar region, and coronoid process. The left facial nerve was also injured. Inability to raise left eyebrow (Fig. 25), loss of eyelid closure (Fig. 26), and asymmetric smile and facial deviation to the

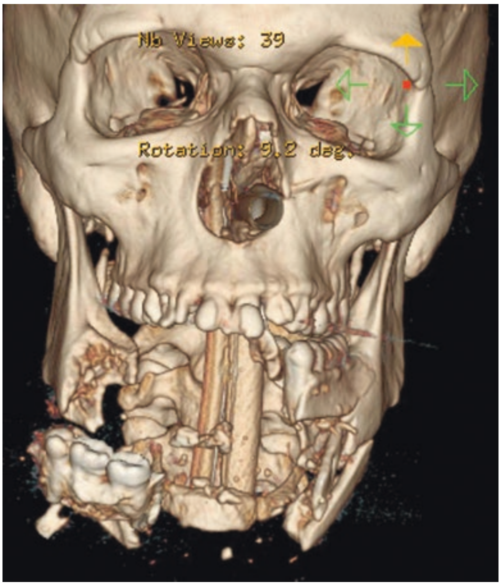

Fig. 20 3D CT demonstrating the extensive bone destruction with mandible defect

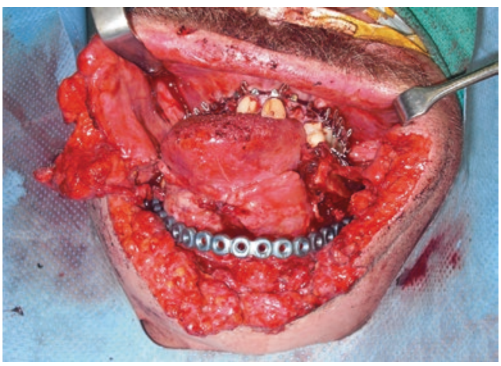

Fig. 21 Mandible reconstruction plate was placed to stabilize the remaining bone

Fig. 22 Mandible reconstruction using free osteocutaneous flap

Fig. 23 The total lip was reconstructed using an innervated gracilis muscle flap. The muscle was resurfaced with a skin graft harvested from the scalp (12 months after reconstruction)

Fig. 24 GSW sustained at the level of left mastoid and retroauricular area

unaffected right side were noted (Fig. 27). The stapedius reflex was intact. Sensation to his ear was not altered. He had normal taste in the anterior 2/3 of his tongue. EMG study showed fibrillation and active denervation in all the facial

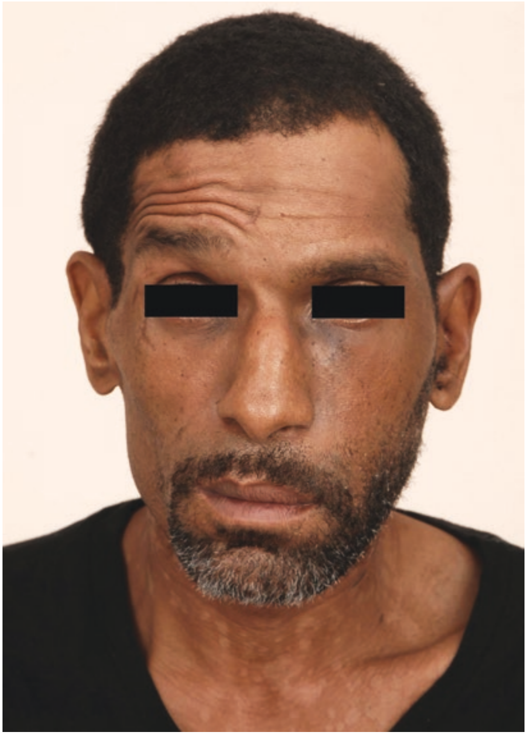

Fig. 25 Facial GSW that resulted in left-sided facial nerve injury. Note inability to raise eyebrow on the left side

Fig. 26 Facial GSW that resulted in left-sided facial nerve injury. Note inability to close the left upper lid

nerve innervated muscles on the left side and voluntary activation in all the muscles except left mentalis muscle. The injury appeared to be in the region of left retromandibular and mastoid area after the nerve exit from the stylomastoid foramen.

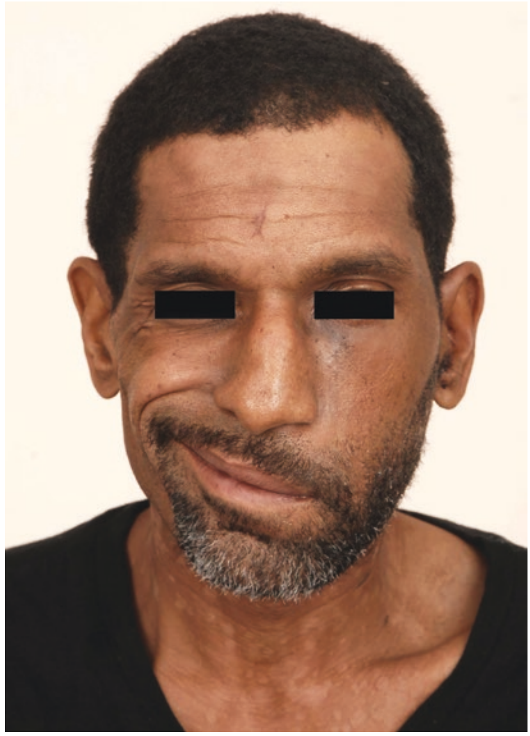

Fig. 27 Facial GSW that resulted in left-sided facial nerve injury. Note deviation of smile to the unaffected side

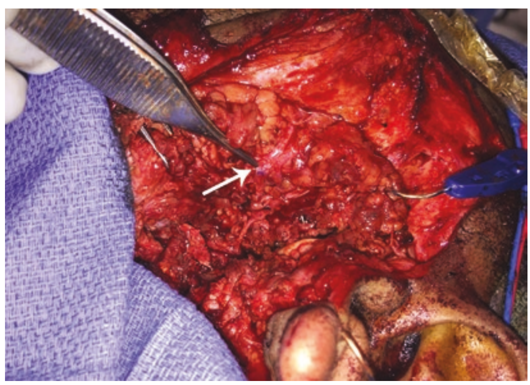

Fig. 28 Facial nerve exploration through preauricular incision. The arrow indicates the level of healthy distal branch where the sural nerve graft will be coapted distally

Patient underwent ORIF of mandible fractures and left facial nerve exploration. The facial nerve and its branches were explored (Fig. 28). Distal nerve branches were further explored after superficial parotidectomy. The

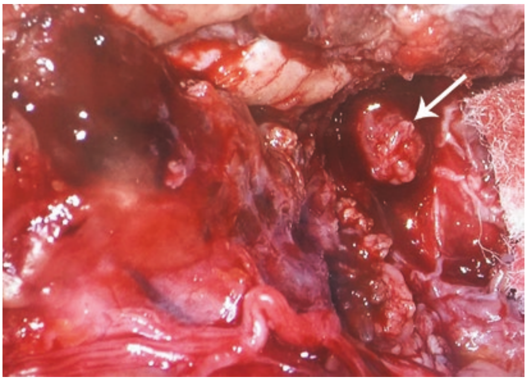

Fig. 29 Facial nerve main trunk was sharply debrided until healthy nerve stump. Proximal facial nerve (close-up view under microscope, arrow) stump 1 cm distal to the stylomastoid foramen

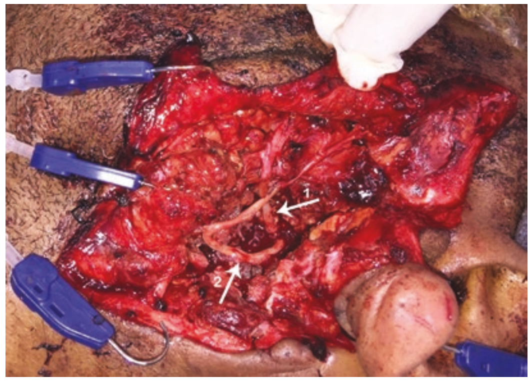

Fig. 31 Two cable nerve grafts were used between the proximal nerve trunk and lower (arrow 1) and upper (arrow 2) divisions of the facial nerve branches distally

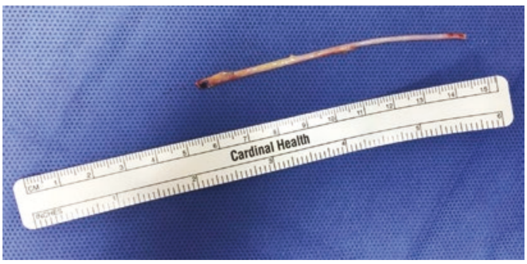

Fig. 30 Sural nerve graft for direct facial nerve grafting

main trunk and its divisions were in continuity but there was no facial nerve activity using nerve stimulator or facial nerve monitoring. The facial nerve main trunk was sharply debrided until healthy nerve fascicles were obtained proximally, 1 cm distal to the stylomastoid foramen (Fig. 29). The damaged nerve branches were sharply excised and direct nerve grafting was performed using two sural nerve cable grafts between the proximal stump and the inferior and superior divisions of the nerve distally (Figs. 30 and 31).

2 Discussion

No two maxillofacial GSWs are the same even if the same type of weapon causes them. In low-energy injuries there is usually limited damage to facial soft tissues and the underlying skeleton. A more straightforward therapeutic approach is required to repair such soft tissue and/or bone injuries using the basic craniofacial principles [5].

On the other hand, high-energy injuries are associated with extensive hard and soft tissue disruption, and are characterized by a surrounding zone of damaged tissue that is prone to progressive necrosis as a result of compromised blood supply and wound sepsis [6]. Current treatment protocols for these injuries emphasize the importance of serial debridement for effective wound control while favoring early definitive reconstruction [7]. Regardless of type of energy and tissue disruption, patients who sustained maxillofacial GSWs require the following:

- Emergency evaluation and management (BLS, ATLS, and trauma center protocols).
- Multidisciplinary approach when and if necessary (neurosurgery, OMFS, plastic and reconstructive surgery, ophthalmology, psychiatry).
- Acute surgical management (adequate debridement, early repair of soft tissue and/or bone injuries).
- Early reconstruction of soft tissue and/or bone defects for optimal functional restoration and appearance.

Multidisciplinary care is required from prehospital admission to discharge [8]. Determination of priorities and orchestration of a surgical plan with other surgical disciplines is mandatory. Neurosurgical and ophthalmologic emergencies have precedence over facial injuries. Patients who sustained GSWs, in particular those with self-inflicted injuries, need immediate psychiatric evaluation and extensive rehabilitation thereafter.

After life-threatening injuries are overcome and stabilization of patient, we prefer to repair and/or reconstruct soft tissue as well as bone defects as early as patient status allows. Delayed repairs are associated with increased wound infection, scarring/contracture, respiratory problems, nutritional derangement, and overall poor functional as well as aesthetic outcomes. Early repair/reconstruction of soft tissue and/or bone injuries/defects provide optimal functional and aesthetic outcome. In complex soft tissue and/or bone destruction, staging of reconstructive procedures may be done to allow excessively long operative hours allowing patient recovery and avoiding surgeon fatigue. The interval between major reconstructive surgeries should be relatively short (preferably few days—1 week) to avoid scar tissue and contracture [9, 10].

Regional and local flaps may be utilized for soft tissue reconstruction but they have limited value in complex facial GSWs with large soft tissue and bone defects. They should be carefully planned as the zone of injury may negate their use. In patients who are not good candidates for free tissue transfer, pectoralis major may be helpful for soft tissue reconstruction in the lower half of the face. Pedicled temporalis muscle flap is useful in palate, maxilla, and midface area. Pedicled trapezius and sternocleidomastoid muscle flaps may be useful in select patients but have limited reach and use in most maxillofacial GSW reconstruction. Bone grafts may be used in relatively small bone defects (less than 5 cm) as long as adequate bone debridement and stable soft tissue coverage can be achieved.

When free tissue transfer is indicated, the flap choice should be based on patient comorbidities, potential flap donor site morbidity, type and extent of tissue loss. Goals should include functional reconstruction as well as restoration of acceptable and satisfactory appearance. Complex facial defects with significant amount of soft tissue and bone loss may require more than one free tissue transfer. While the face does have robust vascular supply through enormous amount of vascular connections among main branches of the external carotid artery feeding the face, a careful planning is mandatory for recipient site selection. This selection should be carefully made not to jeopardize the vascularity of the face as well as of the previously transferred flap(s).

Our choice for bone defects (more than 5 cm) in the setting of GSWs with inadequate soft tissue coverage is vascularized bone flaps. The free fibular flap is the preferred vascularized flap for mandible and/or maxilla reconstruction. Scapular flap is a viable option for maxilla or mandible reconstruction but the need for patient repositioning poses a significant disadvantage in these complex cases. Iliac bone flap may be used for osteocutaneous defects following maxillofacial GSW, but donor site morbidity and relatively rigid skin paddle make this option less favorable.

Use of virtual surgical planning may be useful for complex maxillofacial reconstruction, in particular with more than one simultaneous free flaps to be performed reliably and successfully. The use of prefabricated jigs and pre-contoured plates eases osteocutaneous flap molding and inset, allowing for a more complex procedure to be successful [11, 12]. Virtual planning and intraoperative imaging in management of ballistic mandibular and maxillary injuries are helpful but are not absolutely necessary to obtain good outcomes. In most level I trauma centers in the USA, these sophisticated options are not available.

In patients with total full-thickness lower lip defects, our choice is innervated gracilis muscle flap. The cutaneous coverage may be provided with the skin paddle or a skin graft harvested from the scalp [13, 14]. Figure 32 summarizes the reconstructive approach in patients undergoing reconstruction for composite mandible defect and functional total lower lip reconstruction in terms of timing and staging these procedures. In the majority of patients with self-inflicted injuries, facial nerve branches remain intact and marginal mandibular nerve may be used to innervate the obturator nerve of the gracilis flap. Our

Reconstructive Surgical Approach	Timing	Procedures
Acute Surgery	within 24 hours	Exploration and debridement of soft tissue and bone, ORIF, stabilization of the mandibular segments with reconstruction plate (MMF to guide proper teeth alignment, if feasible).
Composite Mandibular Defect Reconstruction	within 1 week	Further debridement, adjustment and revision of the mandibular plate (if necessary), fibular osteocutaneous flap *
Functional Lower lip Reconstruction	within 1 week after the fibular transfer	Innervated gracilis muscle flap **
Minor surgeries	2-3 months after the major surgeries	Scar revision, vermilion reconstruction, vermilion tattoo, intraoral flap debulking, dental rehabilitation

ORIF: Open reduction and internal fixation, MMF: Maxillo-mandibular using Erich Arch bars and interdental wiring. ** The gracilis muscle was harvested from the thigh ipsilateral to the selected facial vessels. * This was contralateral to the site used for fibular transfer.

Fig. 32 The reconstructive approach in patients undergoing reconstruction for composite mandible defect and functional total lower lip reconstruction in terms of timing and staging these procedures

experience using this technique in five patients has been favorable and oral competence was achieved in all patients. However, anterolateral thigh flaps with fascia grafts as well as radial forearm flap with palmaris longus have also been shown to provide satisfactory outcomes [15–19].

GSW patients having evidence of facial nerve injury should be thoroughly assessed to determine the level and the site of injury. Clinical examination should include evaluation of eyelid closure, eyebrow elevation, smile, and lip depressors and elevators. Schirmer test of tearing (to assess lacrimal gland function), taste examination in the anterior two-thirds of the tongue (chorda tympani), salivary flow (chorda tympani), and the sensation of ear (auricular branch) are essential tools to detect the anatomical site of the lesion. Further studies include needle EMG, blink reflex, and audiology (stapedius reflex). In addition, the high spatial resolution of multi-sliced CT and/or MRI is often required to support the clinical level of nerve injury. Presence of motor unit potentials in EMG may predict the recovery. Therefore exploration should be held in such cases, clinical findings during follow-up and repeat electrical assessment (monthly) should dictate the necessity of surgical exploration. Substantial clinical improvement supported by EMG may avoid an unnecessary surgical exploration and intervention. No improvement at the end of the third month by monthly electrical and clinical assessments warrants surgical intervention [20].

Clinical judgment is made based on the clinical findings and diagnostic studies whether facial nerve exploration is required. When the decision is made for exploration, within the first 72 h after the injury, distal nerve branches can still be stimulated, as they have not been yet depleted of neurotransmitters within the nerve terminals. Use of a nerve stimulator and/or intraoperative monitoring of facial nerve branches may assist in rapid and accurate identification of ends of facial nerves during surgical exploration [21, 22].

If the facial nerve injury was caused by a blast injury, the surgeon must be cognizant of nerve injury proximal and distal to the site of transection. The extent of the injury may be difficult to determine even using operating microscope. The repair may be delayed for 3 weeks or until the wound permits. Anatomic exploration of nerve branches and intraoperative judgment using the operating microscope to obtain healthy nerve branches proximally and distally will guide the repair. Intraoperative nerve biopsies may be helpful to identify healthy nerve fascicles. Nerve stimulator and/or facial nerve monitoring are still adjunct tools for assessment of neural function, in particular when the nerve is in continuity.

For injuries past the stylomastoid foramen, proximally a healthy facial nerve trunk may be obtained to source the facial nerve branches. The damaged facial nerve branches distally should be sharply excised and interpositional nerve grafts should be used between the main trunk and two divisions of the facial nerve or the distal facial nerve branches, as needed.

For facial nerve injuries in the temporal bone, where the proximal nerve is not available, cross face nerve grafts (CFNGs) using the sural nerve in single or two stages, which are directed to resume eye closure, smile, and oral competency, may provide satisfactory functional outcomes, when done within 6 months after the onset of injury [23]. For later cases (over 6 months–2½ years), the two-stage "babysitter" procedure can be employed: the first stage involves the use of 40% of the ipsilateral hypoglossal nerve, which provides powerful motor fibers to the affected facial nerve preserving the facial muscle bulk. At the same time, several CFNGs are placed which are connected to selected branches of the unaffected facial nerve. The second stage, usually 9–12 months later, involves secondary microcoaptations between CFNGs and selected distal branches of the affected facial nerve [23].

Treatment of acute facial nerve injury requires a detailed understanding of anatomy, accurate clinical examination, and timely and appropriate diagnostic studies. Reconstruction depends on the extent and timing of injury and availability of the proximal stump.

Most patients with complex maxillofacial ballistic injuries will require revision procedures, as needed for both functional and cosmetic improvement. These include intraoral flap debulking, dental rehabilitation, scar revision, commissuroplasty, lip vermilion reconstruction, additional local, or free flap reconstructions if deemed necessary (Fig. 32).

In conclusion, facial ballistic injuries may result in severe soft tissue and/or bone destruction. Reconstructive management is dependent on the type and amount of tissue destruction and loss. Early reconstruction of soft tissue component and bone defects should be performed for optimal outcome.

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