

Management of High-energy Avulsive Ballistic Facial Injury: A Review of the Literature and Algorithmic Approach

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Background: High-energy avulsive ballistic facial injuries pose one of the most significant reconstructive challenges. We conducted a systematic review of the literature to evaluate management trends and outcomes for the treatment of devastating ballistic facial trauma. Furthermore, we describe the senior author's early and definitive staged reconstructive approach to these challenging patients.

Methods: A Medline search was conducted to include studies that described timing of treatment, interventions, complications, and/or aesthetic outcomes.

Results: Initial query revealed 41 articles, of which 17 articles met inclusion criteria. A single comparative study revealed that early versus delayed management resulted in a decreased incidence of soft-tissue contracture, required fewer total procedures, and resulted in shorter hospitalizations (level 3 evidence). Seven of the 9 studies (78%) that advocated delayed reconstruction were from the Middle East, whereas 5 of the 6 studies (83%) advocating immediate or early definitive reconstruction were from the United States. No study compared debridement timing directly in a head-to-head fashion, nor described flap selection based on defect characteristics.

Conclusions: Existing literature suggests that early and aggressive intervention improves outcomes following avulsive ballistic injuries. Further comparative studies are needed; however, although evidence is limited, the senior author presents a 3-stage reconstructive algorithm advocating early and definitive reconstruction with aesthetic free tissue transfer in an attempt to optimize reconstructive outcomes of these complex injuries. (*Plast Reconstr Surg Glob Open* 2018;6:e1693; doi: 10.1097/GOX.0000000000001693; Published online 19 March 2018.)

INTRODUCTION

"I am eliminating one category of fractures from this study – gunshot wounds... these are veritable explosions in the face and are without surgical interest."

–René Le Fort in Experimental Study of Fractures of the Upper Jaw, 1901

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Over 100 years after René Le Fort's seminal publication,¹ treatment of the ballistic facial trauma patient remains a complex endeavor. Nowhere else is form and function more intimately intertwined. Ballistic injuries are responsible for 2–6% of civilian facial fractures,^{2,3} with 6–81% of these injuries being self-inflicted.^{4–8} Maxillofacial trauma represents 26% of U.S. soldier battlefield injuries in the current Middle Eastern conflict.⁹ With the refinement of craniofacial plating systems and free tissue transfer, the arsenal of tools at our disposal to achieve cosmetically functional outcomes has vastly improved. However, management of these patients remains a complex venture requiring a systematic and multidisciplinary team approach. Evidence on how to best manage ballistic facial injuries remains scarce.

Facial ballistic injury patterns vary widely. High versus low velocity are common terms used to classify ballistic wounds.^{10–12} However, these descriptions do not necessarily translate into clinically observed wounding capacity.¹³ Clark et al.⁵ used the more clinically useful terms avulsive

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and nonavulsive. These 2 types of injuries require significantly different management strategies.

In nonavulsive injuries, fractures tend to be comminuted, but the majority of soft tissue remains—these injuries can usually be managed as blunt facial fractures with overlying lacerations. Avulsive injuries result from higher energy transfer with varying degrees of soft tissue and bone loss—these injuries pose a greater reconstructive challenge and are the focus of this article. Avulsive injuries generally result from close-range shotgun, rifle, and high-powered handguns. Furthermore, analogous to burns, ballistic injuries result in different zones of injury.^{14–16} The area of avulsion represents the area of immediate tissue loss and necrosis. This is surrounded by an area of evolving necrosis, which can further increase in size, should a secondary insult such as infection or hemodynamic compromise occur.

The aim of this study was to systematically review the evidence on how to best manage high-energy avulsive ballistic facial injuries and to describe the senior author's (E.D.R) staged reconstructive approach.

METHODS

A MEDLINE search was conducted through June 30, 2017, using the following terms: “facial ballistic wound/injury” OR “facial gunshot wound/injury” AND “management” OR “treatment” OR “reconstruction.” Articles were reviewed for the following inclusion criteria: (1) human studies; (2) described the treatment of skeletal and soft-tissue ballistic trauma; (3) provided outcomes data related to postoperative complications and/or aesthetic outcomes; and (4) were available in English. Exclusion criteria included (1) publications before 1980; (2) studies not separately reporting outcomes of ballistic trauma patients if other forms of trauma were included; (3) reports with fewer than 5 patients; and (4) letters to the editor, conference abstracts, review articles, and opinions (Fig. 1).

Intervention timing definitions included the following:

- Immediate debridement: debridement performed within 48 hours of injury.
- Immediate definitive reconstruction: segmental buttress bone grafting, local, and/or free tissue transfer performed during initial debridement and fracture fixation.
- Early definitive reconstruction: definitive reconstruction performed during initial admission once wounds stabilized or within 30 days of injury.
- Delayed definitive reconstruction: definitive reconstruction performed greater than 30 days after injury.

Titles, abstracts, and full texts of identified articles were reviewed. Additional articles were selected via review of references of initially identified articles. Extracted variables included study's first author, country of origin, number of patients, patient age, follow-up period, and major findings including complications. Potential study weaknesses were tabulated. Included studies were assigned a

level of evidence using the American Society of Plastic Surgeons Rating Levels of Evidence and Grading Recommendations.¹⁷

RESULTS

Initial query revealed 41 articles, with 17 articles meeting inclusion criteria (Table 1).^{4,5,7,10–12,18–28} Seven of the 9 studies (78%) advocating delayed reconstruction were from the Middle East, whereas 5 of the 6 studies (83%) advocating immediate or early definitive reconstruction were from the United States. Self-inflicted injuries were responsible for 40.3% (241 of 598) of wounds,^{4,5,7,10,12,21,22,24–27} after excluding studies that did not include self-inflicted injuries.

Debridement Timing

No data were available to guide surgical debridement timing.

Definitive Buttress Reconstruction and Timing

Vásconez et al.¹⁰ showed that delayed fracture fixation required twice as many surgical procedures and longer hospitalizations compared with immediate debridement, skeletal fixation, and definitive soft-tissue coverage. In 1 delayed definitive reconstruction study, only 25% of patients returned for reconstruction.²¹

Regarding midface defects, the majority of studies relied on bone grafting^{4,5,7,10–12,23–27} and occasionally rib grafts wrapped in vascularized omentum covered with skin grafts.^{5,7} Mandibular defects were primarily managed with iliac crest grafts and occasionally with fibula osteoseptocutaneous (FOSC)^{5,10,25,26,28} or radial forearm osteoseptocutaneous flaps.²⁵ Outcomes could not be compared between reconstructive flap or graft choice. Furthermore, no study provided details regarding their flap selection approach.

Aesthetic Outcomes

Vásconez et al.¹⁰ reported a decreased incidence of soft-tissue contracture (35% versus 69%) between immediately managed injuries compared with delayed fracture fixation and soft-tissue reconstruction. Three delayed definitive reconstruction studies reported poor cosmesis in 33–50% of patients.^{25,26,28} Aesthetic outcomes were either not reported or uninterpretable in the remainder of studies.

DISCUSSION

High-energy avulsive facial ballistic injuries pose a significant reconstructive challenge. While the principles learned from the management of blunt facial fractures^{5,29,30} and oncologic defects^{31–33} have been applied to these injuries, there are important differences requiring a modified approach due to questionable and evolving soft-tissue margin viability, greater bony comminution and devascularization, and bony and ballistic fragment sequestrum.⁵

This systematic review was conducted to determine if there is any objective evidence to guide the management of these complex injuries. Several questions exist, including (1)

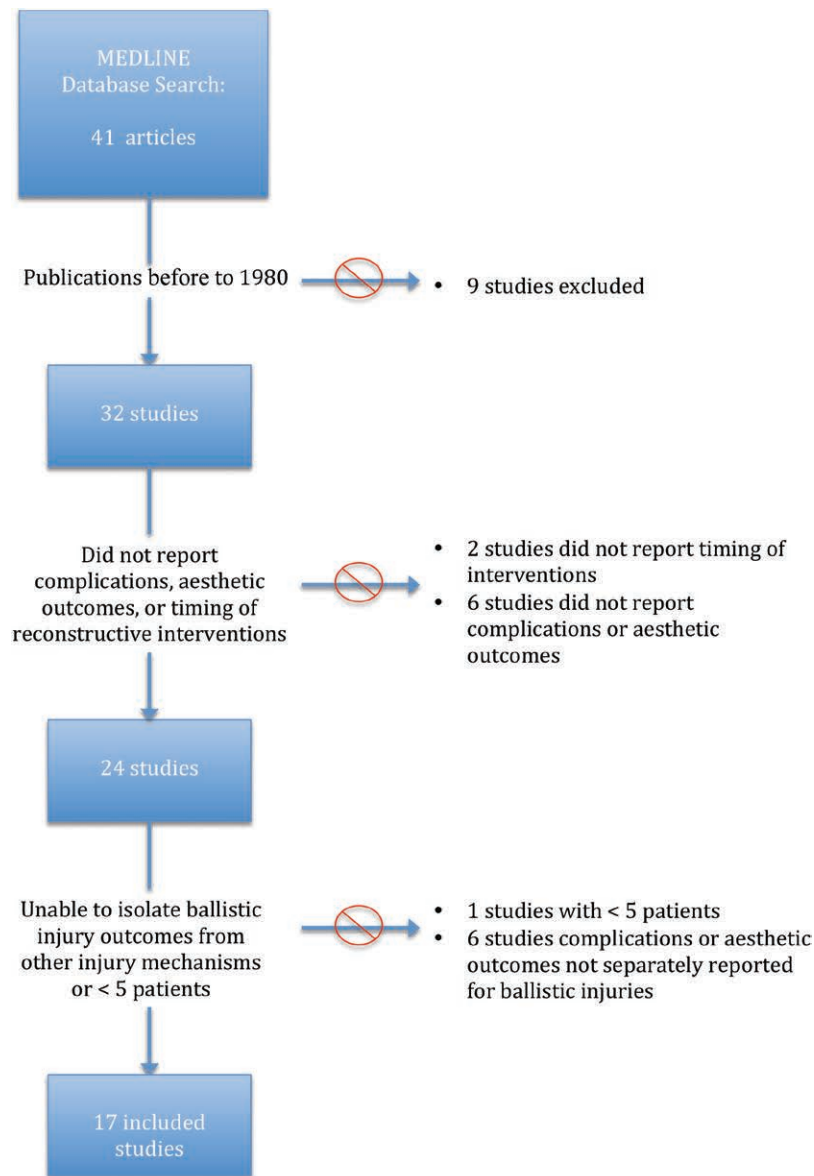


Fig. 1. Systematic review: study selection process.

How soon should initial debridement take place?; (2) When should fractures be fixated?; (3) How and when should segmental buttress and soft-tissue defects be reconstructed?

Level 3 evidence supports immediate debridement and skeletal fixation versus dressing changes and delayed fracture fixation, as the delayed group required twice as many surgical interventions and longer hospitalizations.¹⁰ However, injury severity between these 2 treatment groups was not provided; therefore, it could not be determined if there was a bias for more severely injured patients in the delayed group. There appeared to be an overall higher incidence of infection and fistula with delayed definitive^{12,21–23,26} compared with early definitive reconstruction (Table 1).^{5,11,27} However, these were case series with heterogeneous patient populations; therefore, direct statistical comparisons could not be made.

The majority of studies did not report aesthetic outcomes.^{4,7,10–12,18–22,24,27} Of the few that did,^{5,23,25,26,28} outcomes were subjective and we were unable to compare outcomes. However, 3 delayed reconstruction studies reported poor cosmesis in 33–50% of patients.^{25,26,28} As a substitute for aesthetic outcomes, Váscónez et al.¹⁰ demonstrated a decreased incidence of soft-tissue contracture with immediate debridement and skeletal fixation compared with conservative management. No data exist to guide the optimal timing of free-tissue transfer or how long one can wait until first debridement.

There are several limitations to this study. The retrospective nature of all included studies raises the possibility of complication reporting bias. Many studies suffered from variable or short follow-up. We categorized high-energy avulsive injuries as those where the study authors described segmental composite tissue losses of both bone

Table 1. Systematic Review: Overview of Included Studies

First Author	Year	Country	No. Patients	Mean Age	Follow-up	Level of Evidence	Type of Ballistic Injury	Avulsive Injury (%)	Suicide Attempt (%)	Infection (%)	Fistula Malocclusion (%)	Major Findings	Study Weaknesses
Closed management; minimal debridement													
Dolin et al. ¹⁸	1992	United States	100	28.9	Not reported	IV	98% Handgun 2% Shotgun	—	—	—	—	72% Nonsurgical management, 5% underwent debridement, 23% patients underwent closed reduction, 1% underwent ORIF 2% Incidence of mandible osteomyelitis	Poor follow-up Did not report complications for each treatment group Aesthetic outcomes not assessed
Kihitir et al. ¹⁹	1993	United States	54	27	7 wk mean	IV	100% Handgun	—	None, suicides excluded	—	4%	77% Nonsurgical management, 5% underwent debridement, 13% closed reduction, and 3% underwent ORIF 4% Nonunion, 2% osteomyelitis	Poor follow-up Did not report complications for each treatment group Aesthetic outcomes not assessed
Delayed reconstruction													
Täher ²⁰	1990	Iran	128	16–55	3–36 mo	IV	66% GSW (type not specified) 27% Blast/shrapnel	100%	—	—	—	All patients presented in delayed fashion 3–12 mo after injury with segmental mandibular defects All patients underwent reconstruction with iliac crest grafts and/or corticocancellous bone grafts ± titanium mesh and hydroxyapatite 2% Incidence of reconstruction failure due to infection	Reliability of complication reporting Aesthetic outcomes not assessed
Immediate definitive reconstruction													
Hollier et al. ⁴	2001	United States	84	6–66	Mean 22 wk (1 wk to 29 mo)	IV	Not reported	—	6%	—	—	Advocated for immediate 1-stage debridement, fracture fixation, and free flap soft-tissue coverage if needed 5% Incidence of wound dehiscence	Poor follow-up Type of ballistic injury not specified Reliability of complication reporting Did not report number of patients requiring free tissue transfer

(Continued)

Table 1. (Continued)

First Author	Year	Country	No. Patients	Mean Age	Follow-up	Level of Evidence	Type of Ballistic Injury	Avulsive Injury (%)	Suicide Attempt (%)	Infection (%)	Fistula Malocclusion (%)	Major Findings	Study Weaknesses	
Vásconez et al. ¹⁰	1996	United States	33	31	Not reported	III	73% Shotgun (< 10 feet) 6% Magnum handgun 15% Other handgun 6% Unknown	—	42%	Group 1: 38% Group 2: 30%	—	2 Treatment groups: group 1 (13 patients): debridement and open packing with delayed skeletal fixation and soft-tissue reconstruction versus group 2 (20 patients) immediate debridement, skeletal fixation, and free flap if needed No significant higher infection rate in group 1 (38% versus 30%; $P = 0.31$) Group 1 patients required 3x as many surgical procedures; $P = 0.01$ Longer mean hospitalization in group 1 (43 versus 23 d; $P = 0.02$) Higher rate of soft-tissue contracture in group 1 (69% versus 35%; $P = 0.03$)	Follow-up not reported Did not specify ballistic injury type between groups Group 1 patients were earlier in series Did not report type of free tissue transfer or number of patients requiring free tissue transfer	
Delayed definitive reconstruction; immediate debridement and fracture fixation														
Alper et al. ²¹	1998	Turkey	12	36.5	36.5 d mean	IV	All submental: rifle and shotgun, numbers not specified	100%	100%	17%	25%	42%	Immediate debridement, ORIF, and local flap ± STSG during initial procedure 92% Had mandibular and 92% had maxillary injury Only 3 of 12 patients presented for late reconstruction Performed debridement, ORIF with wiring and local flap closure Cosmetic results not reported but significant soft-tissue contracture seen in case examples	Short follow-up Few patients returned for secondary reconstruction Aesthetic outcome not assessed
Shuck et al. ²²	1980	United States	18	27.9	3 mo to 7 y	IV	33% Handgun (33% avulsive) 56% Rifle (60% avulsive) 11% Shotgun (0% avulsive)	50%	78%	33%	44%	—	Aesthetic outcome not assessed	

(Continued)

Table 1. (Continued)

First Author	Year	Country	No. Patients	Mean Age	Follow-up	Level of Evidence	Type of Ballistic Injury	Avulsive Injury (%)	Suicide Attempt (%)	Infection (%)	Fistula Malocclusion (%)	Major Findings	Study Weaknesses
Motamedi and Behnia ²³	1999	Iran	33	24.2	5.9 y	IV	70% GSW (type not specified) 21% Shrapnel	24%	—	24%	—	Immediate debridement and closed reduction in 45%, open reduction with wire osteosynthesis in 12% Avulsive injuries were secondarily reconstructed with bone grafting and local tissue flaps Reported "acceptable" cosmetic results	Unable to interpret aesthetic results Fistula and malocclusion rates not reported
Yuksel et al. ²⁴	2004	Turkey	14	22	Not reported	IV	All submental: 14 military rifle	100%	100%	—	14%	Immediate debridement and ORIF ± reconstruction plate Primary midface bone grafting, delayed mandibular bone grafting ≥ 3 mo after injury Larger defects left open for delayed future free flap or obturation	Follow-up not reported Minimal complication reporting Aesthetic outcome not assessed
Firat and Geyik ²⁵	2013	Turkey	12	26.2	4.2 y	IV	Not reported	100%	58%	—	—	Immediate debridement and ORIF ± reconstruction plate 6 of 12 patients delayed free flap reconstruction (2 fibula, 4 radial forearm osteocutaneous flap) 6 of 12 delayed mandibular rib or iliac crest bone grafting	Type of ballistic injury not specified Infection, fistula, and malocclusion incidence not reported
Peled et al. ¹²	2012	Israel	9	25.9	Not reported	IV	33% Rifle 66% Shrapnel	100%	0%	22%	—	33% Poor cosmesis 16.7% Nasal collapse Immediate debridement and ORIF ± reconstruction plate Immediate midface bone grafting if sufficient coverage Delayed bone grafts or free vascularized flaps for segmental mandibular defects 11% Late enophthalmos 22% Infection	Follow-up time not reported Fistula and malocclusion rates not reported Aesthetic outcome not assessed Precise timing of definitive reconstruction not reported

(Continued)

Table 1. (Continued)

First Author	Year	Country	No. Patients	Mean Age	Follow-up	Level of Evidence	Type of Ballistic Injury	Avulsive Injury (%)	Suicide Attempt (%)	Infection (%)	Fistula Malocclusion (%)	Major Findings	Study Weaknesses
Sun et al. ²⁶	2012	United States	6	33	4–32 mo	IV	50% Shotgun 33% Handgun 17% Large caliber handgun	100%	88%	16.7%	16.7%	Immediate debridement and ORIF ± reconstruction plate fibula for mandible reconstruction performed an average of 38 d after injury 50% Poor cosmesis 50% Oral incompetence, 33% mandibular plate exposure	Small study size malocclusion rate not reported
Eser et al. ²⁸	2016	Turkey	7	29.1	2.5–5 y	IV	Not reported	100%	—	—	—	Immediate debridement and ORIF ± reconstruction plate Free fibula for mandible reconstruction performed in all patients a minimum of 6 mo after injury 42.9% Poor cosmesis 42.9% Difficulty with speech	Type of ballistic injury not specified Infection, fistula, and malocclusion incidence not reported
Early definitive reconstruction; immediate debridement and fracture fixation													
Clark et al. ⁵	1996	United States	318	Mode of 25 and 55	Not reported	IV	78.5% Handgun 16.7% Shotgun 4.7% Avulsive injuries (type of GSW responsible for avulsive injury not specified)	4.7%	34% Handgun 76% Shotgun	9% Handgun 17% Shotgun 47% Avulsive	—	Immediate debridement and ORIF ± reconstruction plate Immediate midface bone grafting for nonbutress defects if sufficient coverage Mandibular and buttress bone grafting, including rib wrapped in omentum, and composite free flap reconstruction once wound stabilized	Follow-up time not reported Unable to interpret aesthetic results Precise timing of definitive reconstruction not reported
Christensen et al. ¹¹	2015	United States	39	38	Not reported	IV	Not reported	—	—	10%	5%	Immediate debridement and ORIF ± reconstruction plate Free flaps not performed acutely and did not document definitive reconstruction for segmental defects	Follow-up time and fistula rate not reported Definitive reconstruction timing or flap choice not reported Aesthetic outcomes not assessed

(Continued)

Table 1. (Continued)

First Author	Year	Country	No. Patients	Mean Age	Follow-up	Level of Evidence	Type of Ballistic Injury	Avulsive Injury (%)	Suicide Attempt (%)	Infection (%)	Fistula Malocclusion (%)	Major Findings	Study Weaknesses
Glapa et al. ²⁷	2007	South Africa	55	36.2	2.5 y	IV	98% Handgun 2% Shotgun	32.7%	27%	9.1%	7.3%	85% taken to OR the day of injury, remainder taken to OR 1–5 d after injury If soft-tissue envelope intact, patients underwent 1-stage debridement and ORIF/reconstruction (22 of 40) If soft tissue ± bone avulsive injury, underwent serial debridements and ORIF. Bone grafting and soft-tissue coverage once wound stable	Complication rate not stratified between avulsive and nonavulsive wounds Precise definitive reconstruction timing and flap choice not reported Aesthetic outcome not assessed
Gruss et al. ⁷	1991	United States	37	16–66	6 mo to 10 y	IV	27% Rifle 73% Shotgun	100%	81%	—	—	Immediate debridement and ORIF ± reconstruction plate Immediate midface bone grafting for nonbut-tress defects if sufficient coverage Once wound stabilized within 7–10 d, used rib grafts wrapped in omentum for large segmental maxillary defects	Fistula and malocclusion rates not reported Aesthetic outcome not assessed Type of osteocutaneous free flap used not reported

GSW, gun shot wound; OR = operating room; STSG = split thickness skin graft.

and soft tissue; however, it is difficult to ascertain the consistency of this reporting among studies. Reconstructive interventions also varied, further complicating outcome comparisons. It is interesting to highlight that 78% of studies that advocated delayed definitive reconstruction were from the Middle East.^{12,21,23–25,28} Meanwhile, 83% of studies advocating immediate or early definitive reconstruction were from the United States.^{4,5,7,10,11} This difference may be secondary to surgeon availability, microsurgical expertise, and resource allocation factors.

Ballistic trauma patients tend to be otherwise healthy, with most patients between the ages of 20 to 30 years.^{5,10–12,18,19,21–28} Forty percentage of injuries were self-inflicted; therefore, early psychiatric evaluation should be obtained. Every attempt must be made to achieve aesthetically functional reconstructions to allow patients to pursue fulfilling lives and to optimize their transition back to the workforce. Furthermore, these reconstructions should withstand the test of time, especially given that these patients are expected to achieve otherwise normal life expectancies.

Further comparative studies are needed; however, a randomized trial is not only exceedingly difficult, but arguably unethical. In the senior author's experience, delayed management of avulsive ballistic facial injuries results in poor aesthetic and functional outcomes due to the

untreatable soft-tissue contracture. Delayed reconstruction also risks loss to follow-up—75% of patients did not return for delayed definitive reconstruction in 1 study.²¹ Although there is minimal consensus in the literature, the senior author adheres to the following algorithm (Fig. 2), with an emphasis on 3 key stages:

Stage I: Immediate Debridement and Skeletal Fixation

The distinction is first made between nonavulsive and avulsive facial injuries, with the former mostly being managed as standard blunt facial fractures with overlying lacerations.

Although avulsive injuries may rarely require immediate free tissue transfer, we believe this should be avoided, as tissue margin viability is often in question, thus making it difficult to determine the extent of free tissue transfer requirements and risks placement of the microvascular anastomosis within a highly active zone of injury.

Immediate debridement within the first 48 hours—if hemodynamic or neurologic stability permits—of obviously necrotic tissue is performed. Intraoperative fluorescence angiography can serve as a valuable adjunct to assess adequacy of debridement margins.^{34,35} This serves to dampen the inflammatory response and decrease the probability of infection, which can result in necrosis of potentially salvable tissues. Early tracheostomy and per-

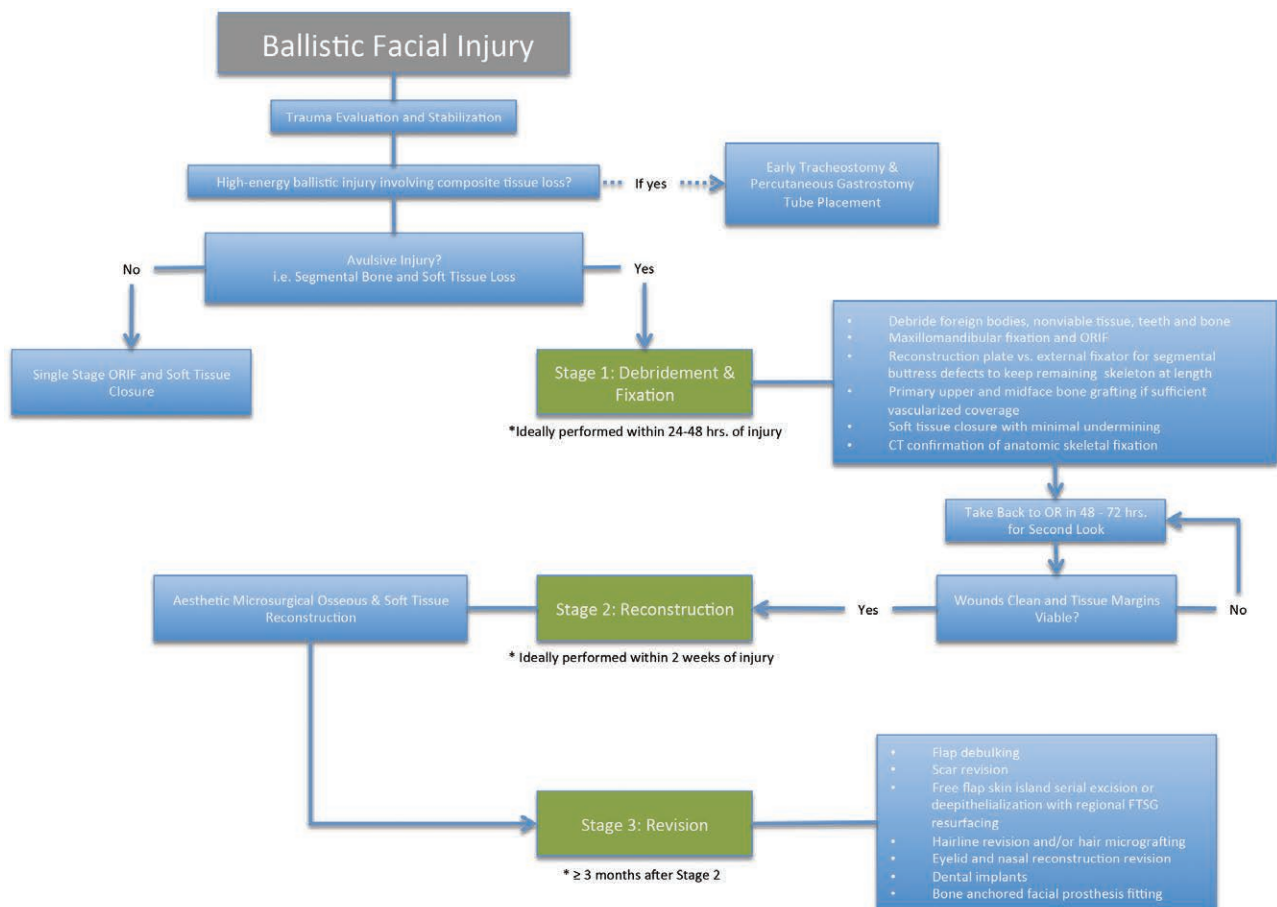


Fig. 2. Ballistic trauma management algorithm. OR= Operating room; FTSG = full thickness skin graft.

cutaneous gastrostomy tube placement is obtained in patients with oral incompetence and comminuted occlusal injuries to facilitate maxillomandibular fixation and early nutrition.

Next, anatomic skeletal fixation is obtained to prevent soft-tissue contraction over the deformed skeletal framework.^{29,36,37} External lacerations may be useful for access; however, the senior author has low threshold for conversion to larger access aesthetic incisions for anatomic fracture reduction. Denuded comminuted bone segments are debrided. If debrided bone segments are large enough and not significantly contaminated, they may be used as “spare parts” for upper and midface bone grafting. Immediate bone grafting is generally avoided in the mandible due to infection risk from salivary contamination.^{5,7,27} Cranialization should be performed during this initial procedure if there is significant nasal outflow tract disruption, as Bellamy et al.³⁸ demonstrated a decreased incidence of central nervous system infection if performed within 48 hours of injury. Areas of segmental mandibular bone loss are then spanned by locking reconstruction plates, or less preferably, by an external fixator to keep the remaining skeleton in anatomic position.

Even with the most devastating injuries, more soft tissue remains than may be initially apparent. Remaining skin and mucosal edges are approximated with limited and judicious undermining to prevent further ischemic insult. Small areas that cannot be closed are managed with wet to wet dressing changes and secondarily covered during stage 2.

Repeat surgical exploration is performed every 48–72 hours to debride further demarcated nonviable tissue. Anatomic skeletal fixation is confirmed with computed tomography (CT) imaging. This is the last opportunity to adjust any skeletal fixation before proceeding to stage 2. Once the area of soft tissue loss has demarcated and the wound stabilized, ideally within 2 weeks of injury, segmental bone defect reconstruction and definitive soft-tissue coverage, including free tissue transfer, can be obtained.

Stage 2: Aesthetic Free Tissue Transfer

The fusion of craniofacial surgery and microsurgical reconstruction has led to a paradigm shift in the treatment of complex craniofacial defects.³⁹ As our primary organ of social interaction, optimization of facial aesthetic outcomes is paramount.

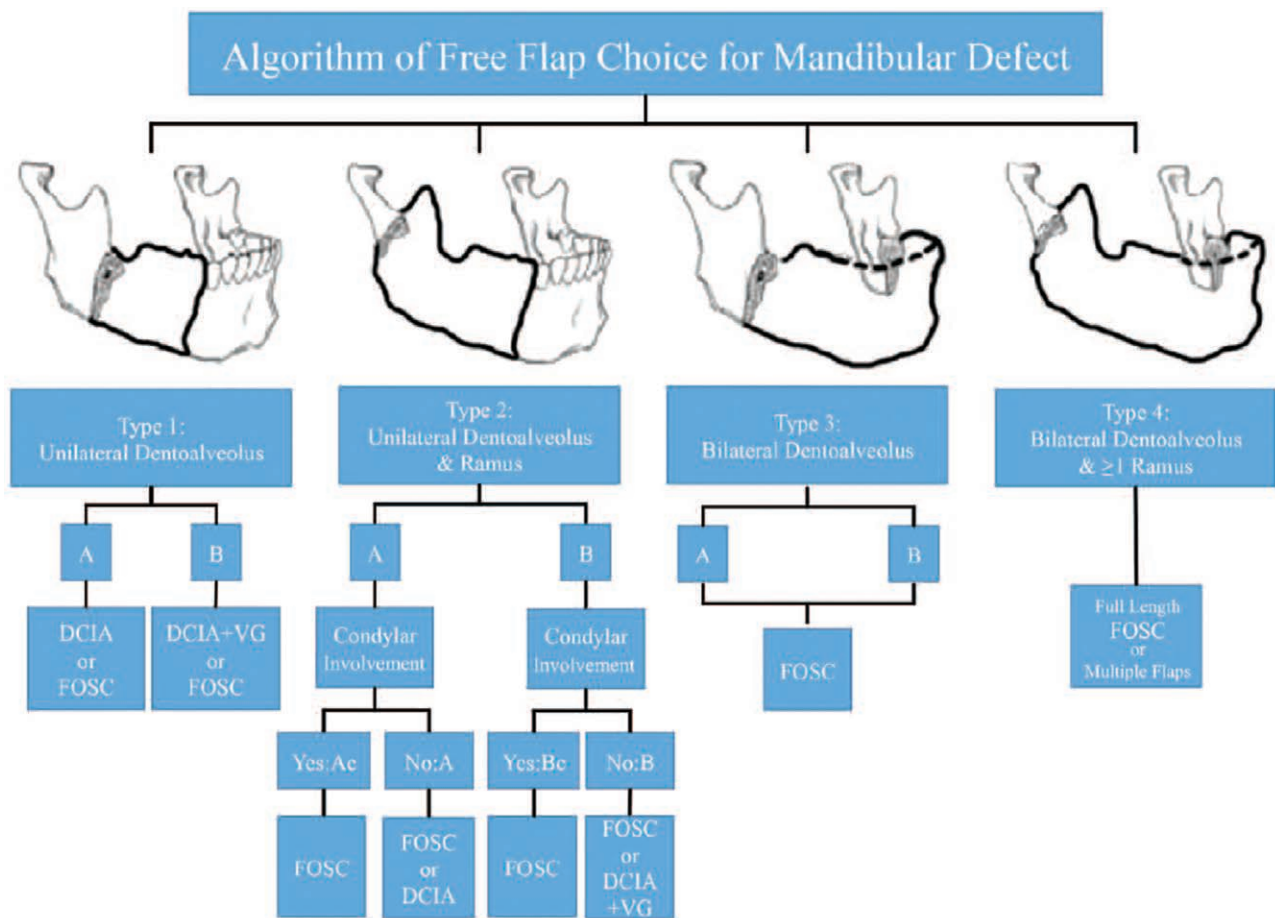


Fig. 3. Mandibular defect management algorithm. A, viable ipsilateral vasculature; B, nonviable ipsilateral vasculature; c, condylar involvement; DCIA, deep circumflex iliac artery (iliac flap); VG, vein graft. (From Schultz BD, Sosin M, Nam A, et al. Classification of mandible defects and algorithm for microvascular reconstruction. *Plast Reconstr Surg.* 2015;135:743e–754 e.) ALT = anterolateral thigh.

The improved reliability of free tissue transfer permits the surgeon proceed confidently in modifying the defect dimensions, if necessary, and thus follow the principles of aesthetic subunit reconstruction.^{32,40–43} Surgical planning is the key to success. Critical concepts include (1) recognition of facial aesthetic unit tissue characteristics; (2) definition of defect boundaries; (3) determination of tissue requirements—that is skin, mucosal lining, volume, and bone³⁰; (4) intervention timing—with early reconstruction to minimize contracture; and (5) recognition of the need for secondary revisions to refine aesthetic subunits and color match.³²

CT scans with 0.75–1.0 mm cuts are obtained for 3-dimensional reconstruction and computerized surgical planning (CSP). Detailed facial anthropometric and cephalometric analysis is performed along with preinjury photographs and dental record evaluation when available. Two millimeter titanium plates are prebent using stereolithographic models and resterilized for operative efficiency.^{44,45} During the procedure, donor vessels are first explored, and the defect margins are confirmed. This ascertains the required skin paddle dimensions and pedicle length. Osteotomies are performed in situ; the segments are partially secured in their correct orientation with miniplates and confirmed on the stereolithographic model before flap procurement to limit ischemia time. The flap is then partially inset with fixation before anastomosis to prevent pedicle avulsion.

Lower Face Reconstruction

Bone grafting can be considered for defects < 5 cm, with iliac crest bone graft being preferred if there is no mucosal tissue loss.^{36,40} Avulsive ballistic trauma often results in composite tissue loss of the lower face, impairing skeletal support, facial height, projection, and oral competence. These complex defects require osteocutaneous microvascular free tissue transfer. Schultz et al.³³ present a systematic algorithm for flap selection based upon anatomic considerations of the defect, with larger defects and those involving the mandibular condyle favoring the FOSC flap, whereas smaller defects can be reconstructed with the deep circumflex iliac artery flap ± vein graft (Fig. 3).

Arguably the greatest limitation of CSP—the inability to account for oncologic margins in the preoperative planning—does not generally apply to trauma, making CSP an even stronger tool in the reconstruction of avulsive ballistic trauma. Head-to-head comparisons of the traditional approach versus CSP have demonstrated improved condyle position, bone-to-bone contact, plate/fibular segment/mandible relationships,⁴⁴ and decreased operative times.⁴⁷ Furthermore, the FOSC flap allows placement of osseointegrative dental implants and ultimately improved rates of overall successful dental rehabilitation.^{48,49}

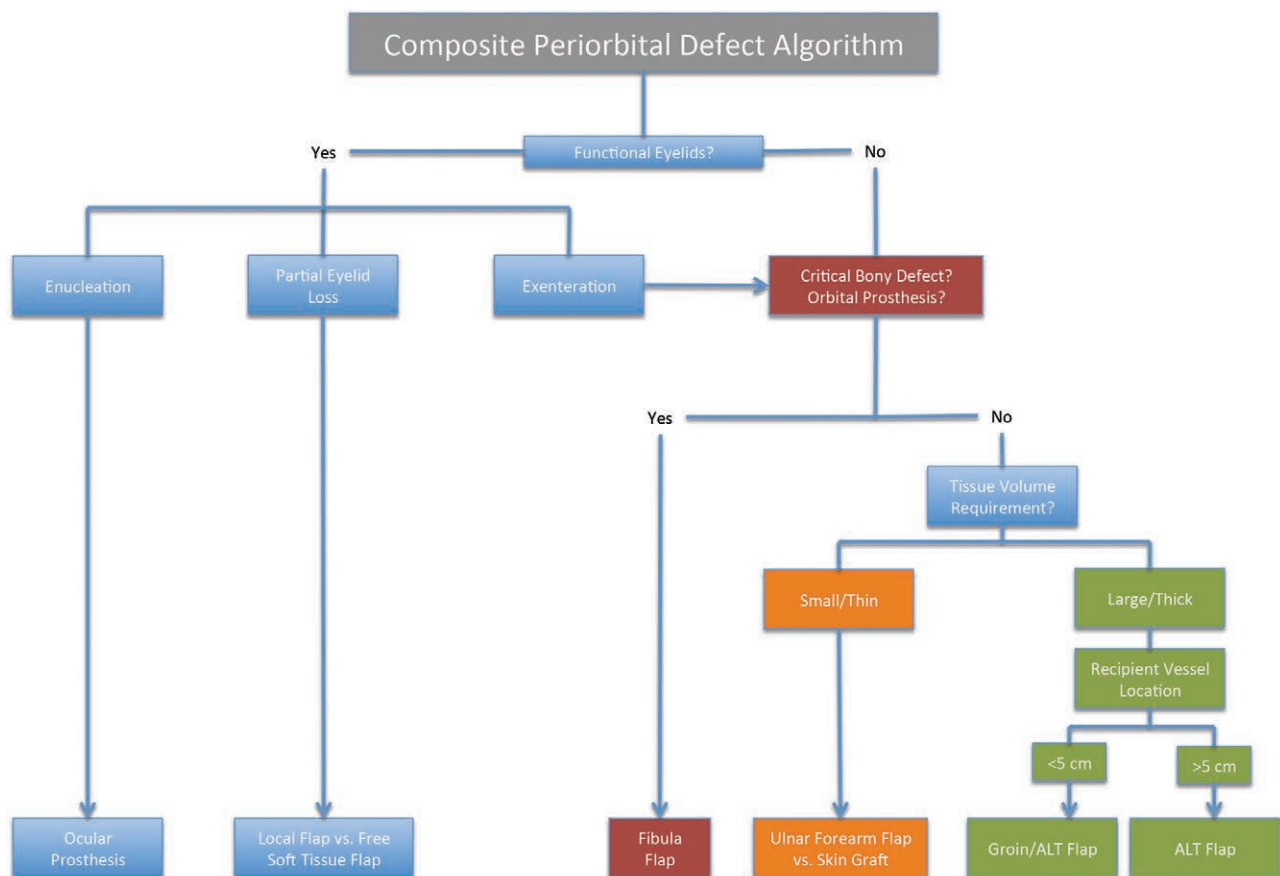


Fig. 4. Periorbital defect management algorithm (Modified from Borsuk DE, Christensen J, Dorafshar AH, et al. Aesthetic microvascular periorbital subunit reconstruction: beyond primary repair. *Plast Reconstr Surg.* 2013;131:337–347.).

Middle Face Reconstruction

Periorbital Defects

Periorbital reconstruction goals include globe protection and positioning. Eyelid defects can be reconstructed with a myriad of local tissue flaps and grafts⁵⁰; however, when local tissues are insufficient, the ulnar forearm, followed by the groin and ALT flap, are our flaps of choice depending on the defect characteristics (Fig. 4).³¹

In cases of globe and periorbital buttress loss, construct compatibility with osseointegrated implant-retained prosthesis significantly improves quality of life.⁵¹ Segmental buttress defects are reconstructed with vascularized osteocutaneous flaps, as bone grafts undergo unpredictable reabsorption and fail to maintain facial projection over time.^{52,53} Buttress reconstruction is also critical for lower lid support and negative vector prevention. The FOSC flap is the flap of choice for midface and periorbital osseous defects as it can be osteotimized to reconstruct multiple buttresses,^{52,54} possesses a long pedicle, and has good bone stock for osseointegrated implants.

Maxillary Defects

Goals include reestablishment of facial projection, dental rehabilitation, vascularized skin and mucosal lining, fistula elimination, oral competence, and aesthetics. Local tissue flaps are used for skin and mucosal lining, but these are often insufficient for devastating avulsive injuries. Bone grafting is reserved for small defects with well-vascularized soft-tissue coverage.^{7,27,55} Larger buttress defects and smaller defects with insufficient lining require composite free tissue transfer. The senior author's algorithm for maxillary defects varies depending on the size of osseous buttress defect, pedicle length, and need for skin and or mucosa lining (Fig. 5).³⁷

Upper Face Reconstruction

Ballistic injuries to the upper third of the face are particularly devastating, with higher mortality rates due to associated brain trauma.³ The author adheres to the 3 aesthetic subunit classification of the forehead.⁴³ The lateral subunit benefits from robust vascularity, skin laxity, and a concave topography that facilitates scar concealment—making it amenable to several reconstructive options. The central and paramedian forehead is aesthetically less forgiving. Great care must be taken to not distort brow symmetry and preserve the hairline when possible, thus, only small defects are amenable to local flap closure and free tissue transfer is more often required for resurfacing. This is especially true in the younger ballistic facial trauma population with less skin laxity.

The suprafascial ulnar forearm flap is our preferred option for forehead resurfacing, followed by the suprafascial anterolateral thigh flap.⁴³ Pericranial flaps are often employed for vascularized lining; however, in the event of significant composite tissue loss, the free fibula is the work-horse flap for frontal bandeau reconstruction and watertight separation of the sinuses from the intracranial contents.

Stage 3: Secondary Revisions and Aesthetic Refinement

Cosmesis is further refined with tertiary procedures including debulking, local tissue rearrangements, and serial excision of the free flap skin island or deepithelialization followed by full-thickness skin grafting with supraclavicular or postauricular skin for better color match. Hair micrografting is a valuable adjunct for eyebrow, anterior hairline, and facial hair restoration.⁵⁶

Unfortunately, the avulsive ballistic facial trauma patient may present in delayed fashion after facial skeletal, and

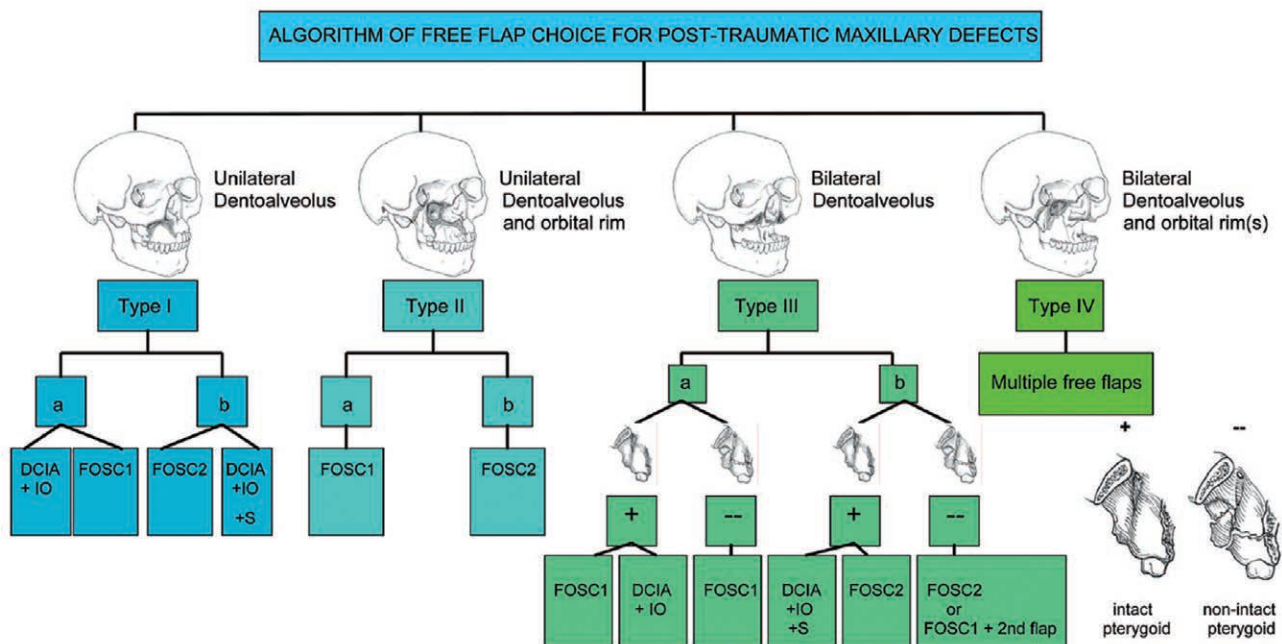


Fig. 5. Maxillary defect management algorithm (From Rodriguez ED, Martin M, Bluebond-Langer R, et al. *Microsurgical reconstruction of post-traumatic high-energy maxillary defects: establishing the effectiveness of early reconstruction. Plast Reconstr Surg.* 2007;120:1035–175.). a, no skin defect; b, skin defect; DCIA, deep circumflex iliac artery (iliac flap); IO, internal oblique muscle; S, skin paddle.



Fig. 6. Case 1. Delayed reconstruction (Fig. 6A reprinted with permission from Sinno S, Rodriguez ED. Nuances and pearls of the free fibula osteoseptocutaneous flap for reconstruction of a high-energy ballistic injury mandible defect. *Plast Reconstr Surg*. 2016;137:280–284. Figs. 6B–G printed with permission and copyright retained by Eduardo D. Rodriguez, MD, DDS).

soft-tissue contraction have taken hold (Fig. 6). The same reconstructive principles outlined above apply. However, cosmetic outcomes are often disappointing in comparison. Noncompliant soft tissues have an increased tendency to contract and collapse, making it difficult to maintain facial projection.⁵⁷ Only in the most severe injuries where autologous tissues options have been exhausted involving central face composite tissue loss (eyelids, nose, and lips)—with the additional requirement of a compliant patient with a good psychosocial support—should facial vascularized composite allotransplantation be considered.^{58,59}

CASE REPORTS

Case 1

Delayed Reconstruction

A 36-year-old male was referred for consideration for facial transplant 7 months after a self-inflicted ballistic injury resulting in composite tissue defects of the midface and lower face (Fig. 6A). Note the contracted soft-tissue envelope with mid-face widening and loss of vertical facial height. CSP was used for mandibular reconstruction using a FOSC flap with intra- and extra-oral skin paddles (Fig. 6B, C). A second FOSC flap to the maxilla—with skin paddles used to resurface the palate and nasal floor—was used during a subsequent procedure (Fig. 6D). Multistage nasal reconstruction was commenced

with an ulnar forearm flap for nasal lining and costochondral rib grafting for structural support. A tissue expander was placed in the left forehead in preparation of a paramedian forehead flap (Fig. 6E). A rotation-advancement upper lip repair was performed to correct the “whistle” deformity, and the external mandibular FOSC flap skin flap was deepithelialized, and hair-bearing chin skin was advanced (Fig. 6F). Dentoalveolar osseointegrated implants were subsequently placed. Finally, the expanded paramedian forehead flap—with additional costochondral grafting for nasal dorsum, sidewall, and tip/columella support—was used for external nasal resurfacing. Figure 6G demonstrates 7-month follow-up after forehead flap inset. Further planned procedures include laser resurfacing and minor tissue rearrangements to optimize cosmesis.

Case Example 2

Early Definitive Reconstruction; Immediate Debridement and Fracture Fixation

A 35-year-old male sustained a self-inflicted gunshot wound to the submental region exiting the nasoorbitoethmoid complex (Fig. 7A, B). After initial trauma evaluation and resuscitation, high-resolution CT imaging demonstrated a comminuted mandibular fracture, avulsive segmental defect of the left maxilla, and bilateral obliteration of the nasoorbitoethmoid complex (Fig. 7C). The day after injury he was taken for initial washout and debridement of devitalized soft tissue and bone, internal skeletal

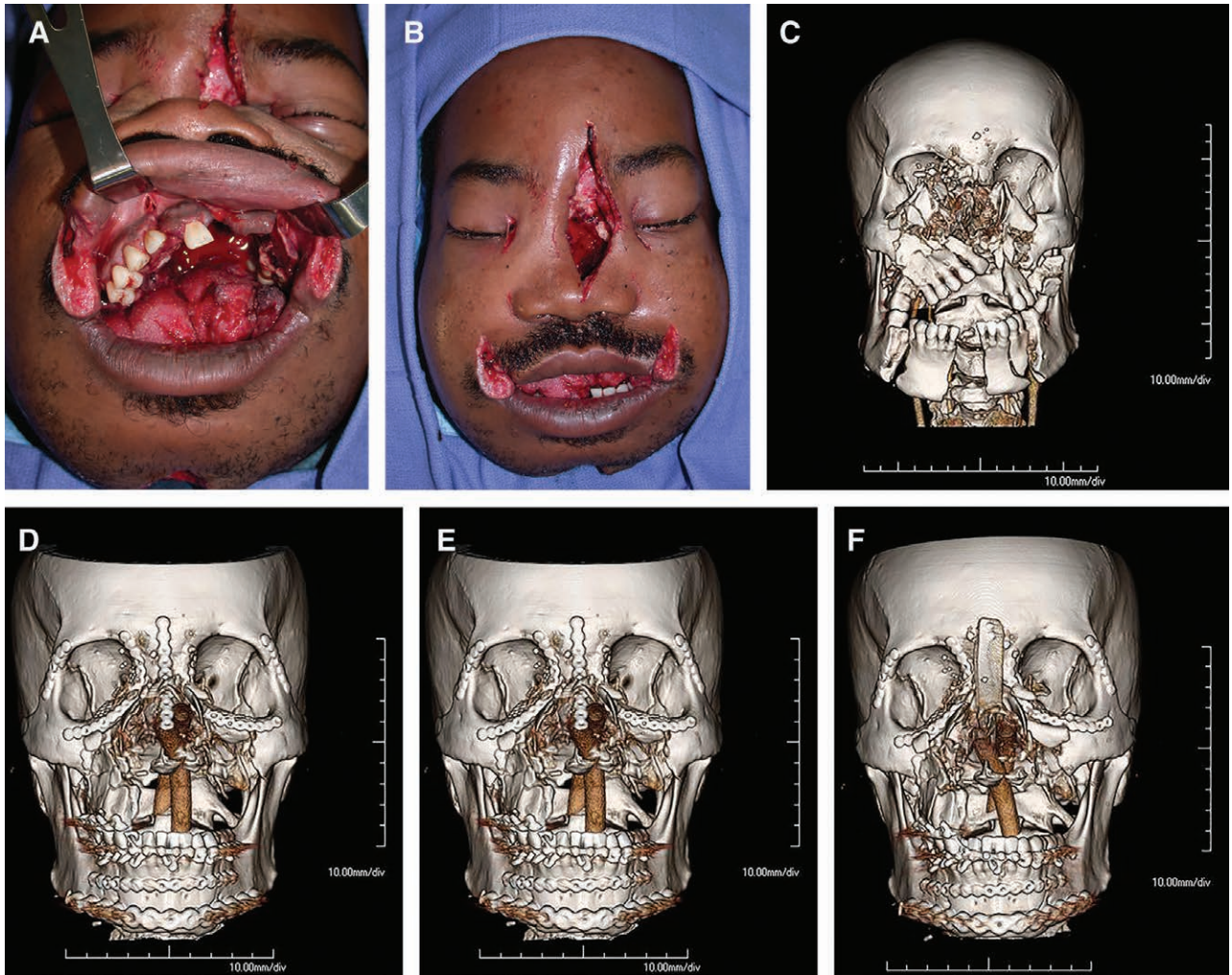


Fig. 7. Case 2. Early definitive reconstruction; immediate debridement and fracture fixation. (Fig. 7A-C reprinted with permission from *Plastic Surgery 3rd Edition* by Neligan PC, Elsevier 2013. Fig. 7D-F printed with permission and copyright retained by Eduardo D. Rodriguez, MD, DDS).

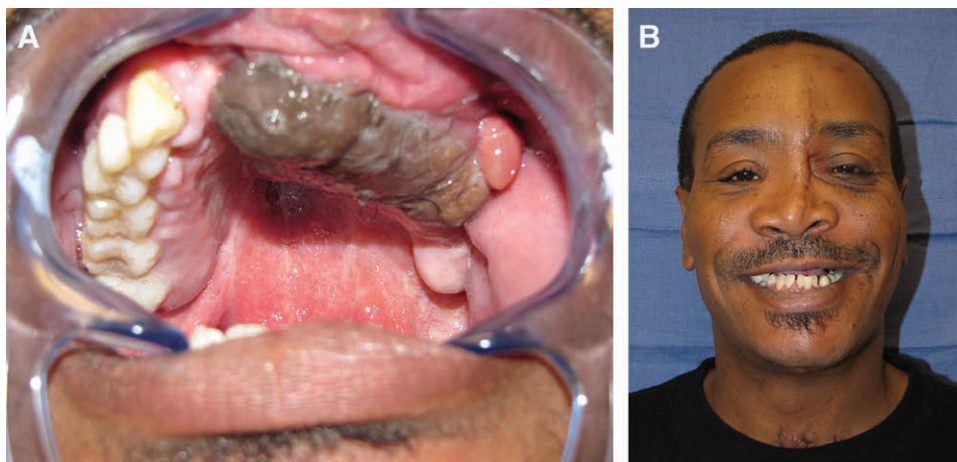


Fig. 8. Images demonstrate his 1-year follow-up after initial injury. In contrast to case 1, note the improved maintenance of facial proportions. (Figures printed with permission and copyright retained by Eduardo D. Rodriguez, MD, DDS).

stabilization, and temporary soft-tissue closure. Of note, debrided bone fragments were used for temporary mid-face bone grafting and nasal trumpets were placed to splint the soft tissues. A tracheostomy and gastric tube were also obtained during this procedure. Post-Open reduction, internal fixation (ORIF) CT demonstrated nonanatomic zygomaticomaxillary widening (Fig. 7D). On postinjury day 4, additional nonviable bone fragments and intraoral lining were debrided. Revision of the prior nonanatomic fracture reduction and a temporary cantilever nasal bone graft was performed during this same procedure to adequately splint the overlying soft-tissue envelope (Fig. 7E). On postinjury day 12, additional areas of demarcated nonviable floor of mouth and palatal lining were debrided. On postinjury day 18—during his initial hospitalization, a free osteoseptocutaneous fibula flap was transferred to his left maxillary defect, using the skin paddle for intraoral lining and the flexor hallucis longus muscle for oronasal fistula closure.

The patient was discharged and subsequently underwent tertiary reconstructive procedures 5 and 12 months after injury including structural rhinoplasty with rib bone and cartilage for nasal sidewall and tip reconstruction, floor of mouth scar release and skin grafting, and LeFort I revision for a posterior cross bite. Figure 8A, B demonstrate his 1-year follow-up after initial injury. In contrast to case 1, note the improved maintenance of facial proportions.

CONCLUSIONS

Existing literature suggests that early aggressive intervention improves reconstructive outcomes after avulsive ballistic injuries. Further comparative studies are needed, however. Although evidence is limited, the senior author presents a 3-stage reconstructive algorithm advocating early definitive reconstruction with aesthetic free tissue transfer in an attempt to optimize reconstructive outcomes of these complex injuries.

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