

Splitting and Splaying Apart of the Craniomaxillofacial Skeleton by Medially Directed Disruptive Forces of Unusual Etiologies- A Case Series

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Abstract

Introduction: Extreme forces directed towards the centre of the facial region can produce devastating injuries, with disruption of the mandible, maxilla and naso-orbito-ethmoid complex, with or without frontal bone involvement. The magnitude and trajectory of the force and nature of the impacting object, dictate the degree of displacement and comminution of the craniomaxillofacial skeletal components, as well as the extent of soft tissue loss sustained. **Diagnosis & Challenges:** To elucidate various challenges faced in the management of four cases of extreme craniomaxillofacial injuries, caused by centrally directed forces of rather unusual etiologies, namely, a traversing bullet, a bamboo rod, a heavy iron cattle tethering peg and a metal electrical pole. In each of the cases, the force of impact resulted in splitting and splaying apart of the facial skeleton, with a resultant increase in its transverse width, and an ensuing severe facial deformity and functional debility. **Rationale & Interventions:** A 'Bottom-up, Outside-in' surgical sequence was employed to carry out reduction, fixation and reconstruction of the deranged maxillofacial skeletal architecture and restoration of the soft tissue morphology. **Outcomes & Lessons:** The transverse dimensions of the flared out facial frames could be re-established and restored to their pre-trauma status successfully in all the cases, thereby achieving excellent esthetic and functional outcomes. Despite the extensive and serious nature of the injuries sustained, gross residual craniofacial defects, deformities and asymmetries, as well as debilitating functional deficits, could be effectively and successfully averted.

Keywords: Bottom-up, outside-in approach, gunshot wound, pan-facial fracture, secondary reconstruction, sequencing of repair, transverse facial width, vertical and anteroposterior facial projection

INTRODUCTION

Craniomaxillofacial skeleton, in addition to being the structural framework of the head and face, also houses and protects vital anatomical structures in this region, such as upper airway, anterior brain, eyes and visual pathways, neurovascular passages, and oral-pharyngeal mechanisms for speech, chewing, and swallowing.^[1,2]

Multiple fractures disrupting the integrity of the craniomaxillofacial skeleton are often complex and challenging to treat. The problem is further compounded when there is caused a severe disarray in the anatomy, morphology, dimensions, inter-relations, and relative positions of the constituent components of the facial skeleton, leading to extreme facial deformities and debilitating functional deficits. Such esthetic distortions and functional defects not only can have a profound impact upon the quality of life of the patients

but can also deeply affect their psychological state, often limiting social rehabilitation and making them social outcasts. This psychosocial impact upon an individual's life can be mitigated if timely and effective surgical care is instituted, employing a judiciously planned treatment approach and a precisely executed operative procedure.

In cases of severe injuries causing multiple, displaced, and comminuted fractures of the craniofacial skeleton, restoration

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of the original facial architecture is often difficult, owing to the extreme degree of fragmentation, with loss of reference segments that could guide the facial reconstruction.^[3] Increase in the transverse facial width following multiple facial fractures can result from two possible reasons. The first is fracture comminution of the zygomaticomaxillary complex, with collapse of the arch and inferolateral displacement of the body of the zygoma. This results in loss of anteroposterior projection of the mid-face as well as its widening.^[4]

The second possible reason for transverse facial widening is medially/centrally directed impacts, which cause splitting of the mandible, maxilla, naso-orbito-ethmoidal (NOE) complex, and frontal bone (in various combinations), at the midline or close to it, resulting in a splaying apart of the two facial halves, as was the case in the four patients described in this study. The peculiar pattern of injuries sustained in these four patients resulted from medially directed high-intensity forces of unusual etiologies, namely a traversing bullet, a bamboo rod, a heavy iron cattle tethering peg, and a metal electrical pole. The trajectory of the force of impact produced “central” or “midline” pan-facial fractures in three cases and “central” maxillomandibular fractures in one case, with splaying and flaring apart of the two halves of the facial skeleton.

Management of these extreme injuries was challenging as it necessitated and entailed an ideal and effective restoration of both, form and function of the craniomaxillofacial complex. Restoration of facial appearance, harmony, and symmetry to the premorbid condition was imperative, as was restoration of various functions such as vision, olfaction, breathing, occlusion, mastication, deglutition, speech, and articulation. Residual facial deformities and debilitating functional deficits are unacceptable from the patient’s psychosocial perspective and hence were strived to be averted. All of these cases were treated successfully using the “bottom-up, outside-in” surgical sequence, with effective restoration of the original facial width and projection, as well as an excellent functional rehabilitation. Long-term follow-up evaluation by objective, subjective, and radiographic assessment confirmed stable results.

MATERIALS AND METHODS

Treatment sequence employed in the four cases

A “bottom-up, outside-in” surgical sequence was employed, comprising the following steps [Figure 1].

1. Upper and lower segmental arch bar fixation guided by fracture locations of the maxilla and mandible, respectively
2. Reduction of the symphyseal fracture, correction of the flared out angles, and restoration of normal “horseshoe” shape of the mandible
3. Repair and structural realignment of the split palate
4. Correction of the mid-face impaction using Rowe’s disimpaction forceps
5. Maxillomandibular fixation, with the teeth in ideal centric occlusion with maximum intercuspatation, followed by stable fixation of the mandibular and maxillary fractures

6. Fixation of Le Fort I and II level fractures of the maxilla (fixation at the pyriform rims and at the anterior alveolar base across midline)
7. Fixation at the zygomatic buttresses, thereby restoring the integrity of the lateral maxillofacial buttresses
8. Reduction and fixation of fractures of the zygoma, infraorbital rim, and orbital floor
9. Reduction and fixation of the frontal bone fracture
10. Reduction and fixation of the bilateral nasomaxillary and frontonasal suture regions, thereby reconstructing the medial naso-fronto-maxillary buttress, accompanied by medial canthopexy if required.

CASE REPORTS

Case 1

A 31-year-old patient sustained severe pan-facial injuries when his motorbike skidded off the road and he drove full speed into an electrical pole, which struck him at the center of his face [Figures 1-4]. In addition to multiple abrasions and lacerations, the patient exhibited extreme facial widening, impaction of the mid-face, circumorbital edema, and ecchymosis, producing a classical “panda facies” as well as the typical “dish-face” deformity [Figure 2a-d]. Clinical examination revealed extensively displaced midline fractures of both, the maxilla and the mandible, with splaying apart of the dental arches, a wide mid-palatal split, and overriding segments of the lower arch at the center, with complete derangement of occlusion. There was extensive disruption of the NOE complex with splaying apart of the nasal bones and traumatic telecanthus. The patient was tracheotomized due to severe disruption of the nasal and midline maxillofacial structures, with airway compromise [Figure 2e and f]. Segmental arch bars were fixed in all four quadrants, after taking impressions and preparing models for the fabrication of palatal and lingual splints [Figure 2g and h].

Noncontrast computed tomograms (NCCTs) of the craniomaxillofacial region with three-dimensional (3-D) reformatting showed an unusual fracture pattern caused by the force of the blow. There was splitting of the facial skeleton at the midline and splaying apart of the two halves laterally, resulting in extreme facial widening [Figure 2i]. A Le Fort II level fracture of the maxilla was accompanied by a midline split, i.e., complete separation of the right and left halves, with their lateral rotation and divergence. Comminuted fractures of the frontal bone and the NOE complex were also evident. Overlapping of the fractured edges of the two mandibular segments at the symphysis region with flaring outward of the mandibular angles resulted in a gross widening of the lower half of the face and loss of the normal “U” or “horseshoe” shape of the mandible. Axial sections too showed the midline split of the mandible with outward rotation of the body regions and wide splaying apart of the angle regions bilaterally, converting the normal “horseshoe” shape of the lower jaw into a “V” shape [Figure 2j]. Axial sections of the maxilla showed wide mid-palatal split with the separation of two halves of the maxilla, associated with disruption of the NOE complex [Figure 2k].



Figure 1: (Case 1) “Bottom-up, outside-in” sequence, first restoring the occlusal unit, achieving a stable base, followed by reconstruction of rest of the craniomaxillofacial skeleton, correcting its widened transverse dimensions. (A-C) Extreme broadening of the mandibular body corrected by compressing splayed apart of the angle regions, restoring its “horseshoe” contour, followed by stable fixation. (I-O) Disimpaction, reduction, and fixation of the laterally rotated maxillary halves. (P-AF’) Approximation and fixation of comminuted fractures of zygoma, orbital floor and infraorbital rim, frontal bone, and naso-orbito-ethmoidal regions

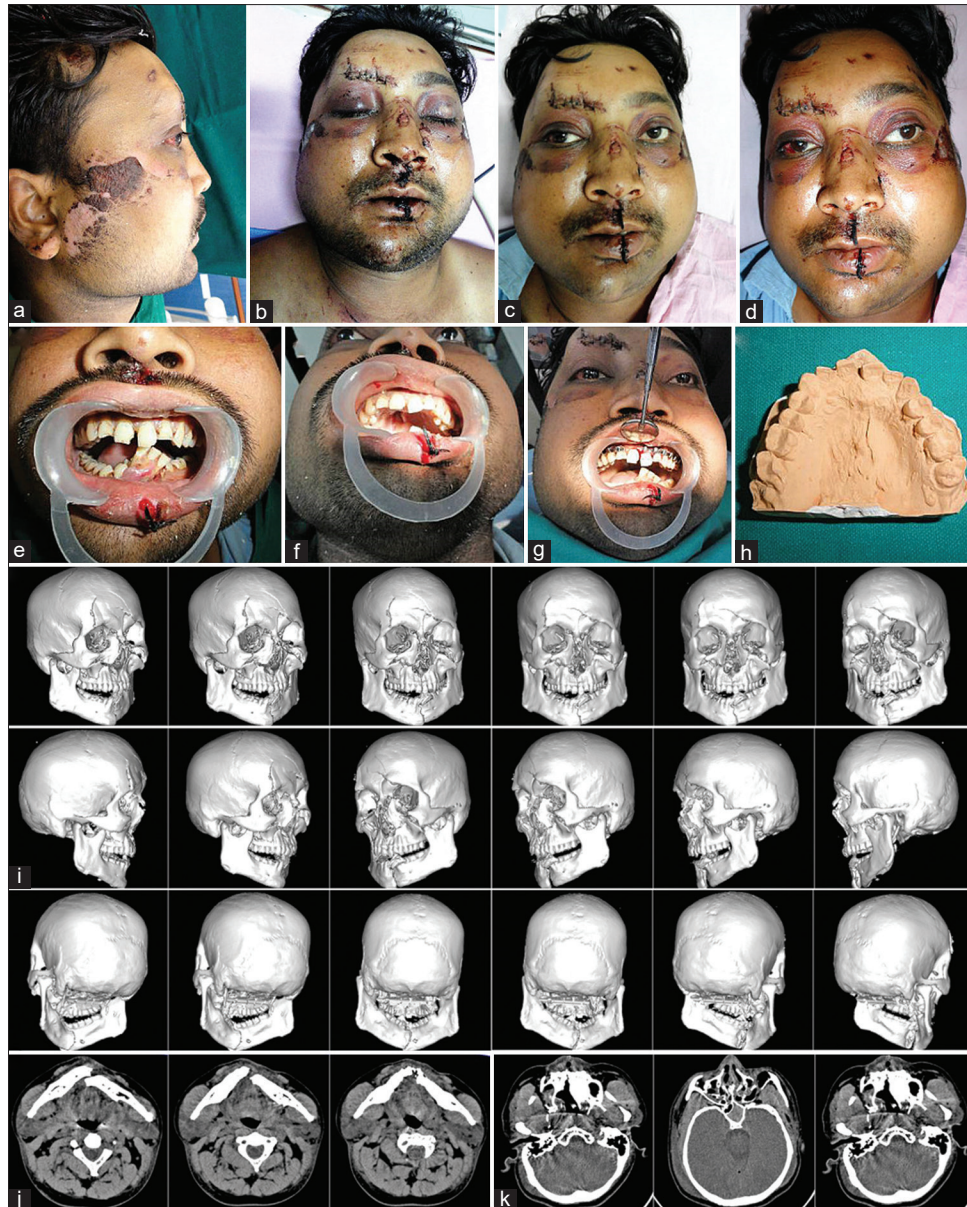


Figure 2: (Case 1) Pan-facial injuries sustained by driving into an electrical pole. (a-h) “Panda facies,” severe facial broadening and flattening of profile, displaced midline fractures of maxilla and mandible with splaying apart of the dental arches and a wide mid-palatal split. (i-i) Noncontrast computed tomogram showing an unusual fracture pattern with splitting the facial skeleton at the midline and flaring of the two halves laterally. Loss of mandibular morphology, separation and lateral rotation of the two halves of the maxilla, comminuted fracture of the frontal bone and naso-orbito-ethmoidal complex

A “bottom-up, outside-in” surgical approach was employed, first restoring the occlusal unit comprising the mandible and maxilla, thereby achieving a stable base, followed by reconstruction of the rest of the craniofacial skeleton, successfully correcting its abnormally widened transverse dimensions [Figure 1]. The displaced midline fracture of the mandibular symphysis with overriding fracture ends was reduced first [Figure 1a and b]. The abnormal widening of the mandibular body was corrected by manually compressing the splayed angle regions bilaterally, thus restoring its “horseshoe” contour. Continuity at the inferior border, as well as the lingual aspect, was carefully checked followed by stable fixation using titanium minibone plates and screws, using occlusion as the guide [Figure 1c-h]. The

fractured and posteriorly impacted maxilla was exposed using a “molar-to-molar” upper vestibular incision. Disimpaction was carried out using Rowe’s disimpaction forceps [Figure 1i and j]. The maxillary midline split was reduced, the two laterally rotated halves brought together into apposition and alignment, teeth were brought into occlusion using the segmental arch bars to guide the final fracture alignment, followed by fixation at the midline at the alveolar base, as well as along both the lateral pyriform rims [Figure 1k-o]. The fractured right and left zygomas and inferiorly displaced orbital floors and infraorbital rims were reduced and fixed using microplates and screws, thus restoring volume and integrity of the orbits [Figure 1p-x]. The comminuted fracture of the frontal bone was then



Figure 3: (Case 1) (a-d) Appearance on the 10th postoperative day showing correction of broadened transverse facial width with restoration of ideal facial symmetry, contour, dimensions, and occlusion. (e-h) Radiographs showing restoration of transverse width of the craniomaxillofacial facial skeleton and good approximation of the fracture fragments. (i-l) 3 months' postoperative appearance showing well-healed operated sites, i.e., normal projection of the face in the anteroposterior, vertical, and transverse dimensions. (m-p) Two-year postoperative photographs confirming stability of results

reduced, re-approximated, and fixed using microplates and screws [Figure 1Y-AA']. The Naso-orbito-ethmoid region was exposed by extending the existing wound laceration. The comminuted fracture fragments were re approximated and fixed using microplates and screws, followed by bilateral medial canthopexy. Nasal packing was carried out, and general anaesthesia (GA) was reversed with the tracheostomy tube retained in place [Figure 1AB'-AD'].

Postoperative recovery was smooth and uneventful with nil complications [Figure 3]. Appearance on the 10th day

following surgery showed successful correction of the broadened transverse facial width with restoration of ideal facial symmetry, contour, and dimensions [Figure 3a-c]. There was achieved successful restoration of occlusion with successful correction of the outward splaying of the displaced quadrants and good healing of all operated sites [Figure 3d]. Postoperative radiographs showed successful restoration of correct transverse width of the craniomaxillofacial facial skeleton, good alignment, and approximation of the fracture fragments of the pan-facial complex with the fixation implants *in situ* [Figure 3e-h]. Three months' postoperative appearance

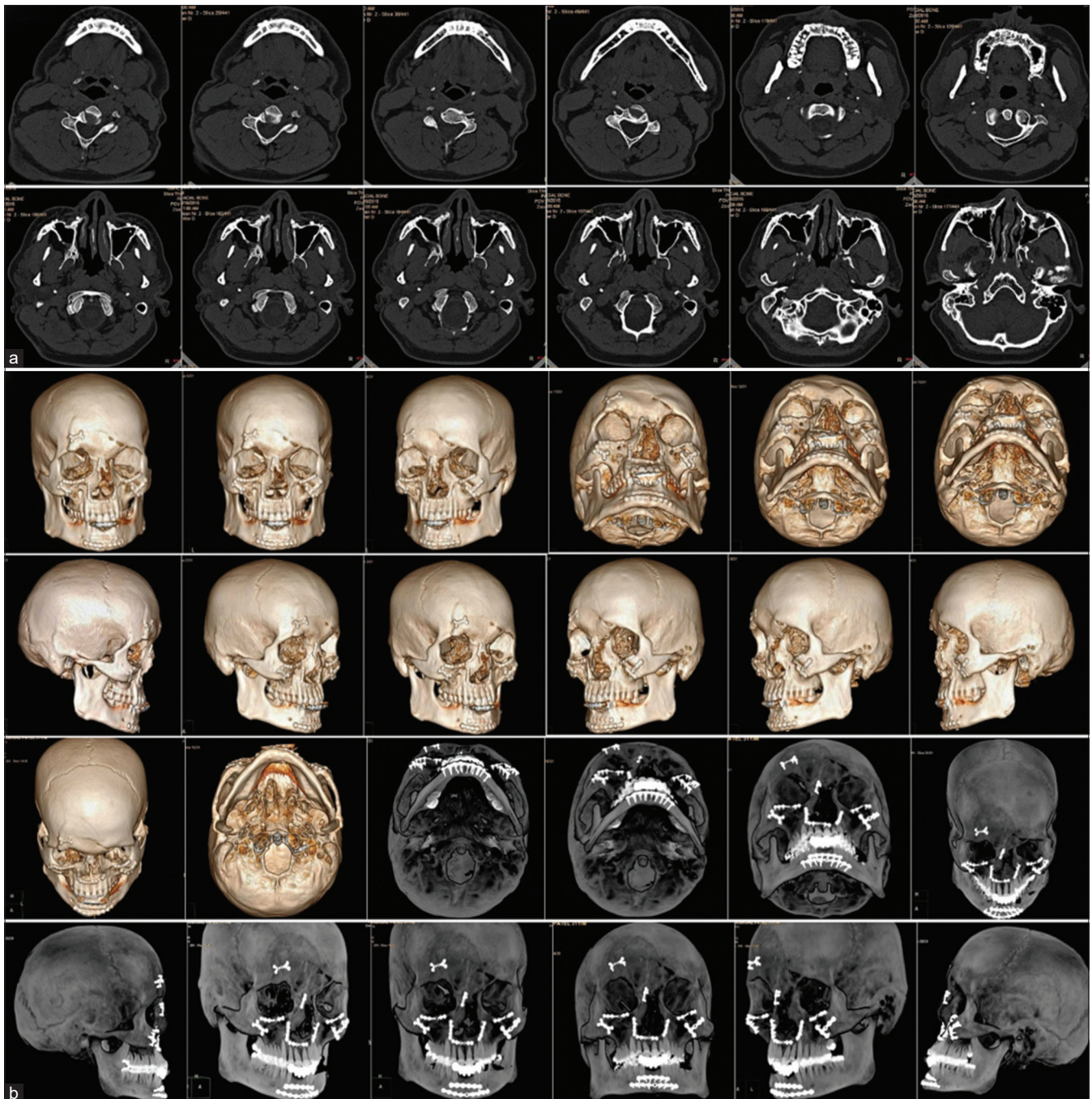


Figure 4: (Case 1) (a) Postoperative noncontrast computed tomogram (axial sections) showing precise reduction and stable fixation of displaced symphyseal fracture, with the achievement of normal “horseshoe” shape of mandibular corpus. Precise alignment of the right and left maxillary halves with approximation at the midline; fixation and bony union of the mid-palatal split and of multiple fracture fragments of the naso-orbito-ethmoidal complex. (b) Three-dimensional images showing restoration of correct craniomaxillofacial skeletal morphology and transverse dimension, which had been grossly deranged by the force of the injury

showed well-healed operated sites, i.e., normal projection of the face in the anteroposterior, vertical, as well as transverse dimensions [Figure 3i-l]. The patient was followed up for 2 years, and there was evidence of good bony union at all the fracture sites with stable results with no residual deformity of functional deficits, thus confirming excellent esthetic and functional outcomes of the “bottom-up and outside-in” surgical management of the extensive pan-facial injuries [Figure 3m-p].

Postoperative NCCT of the craniomaxillofacial region taken a year following surgery showed restoration of continuity of the mandible with precise reduction and stable fixation of the grossly displaced symphyseal fracture, with evidence of bony union [Figure 4a]. Further, appreciable was the achievement of normal “U” or “horseshoe” contour of the mandibular corpus/body following correction of flaring out at the angle regions caused by the force of the

medially directed blow of the injury. Axial sections of the maxilla showed successful reduction, fixation, and bony union of the mid-palatal split; a precise alignment of the right and left halves of the maxilla with approximation at the midline; and stable fixation along the base and lateral borders of the pyriform rims. The reduced and fixed nasal bones retained their morphology with good union of the multiple fracture fragments of the NOE complex. 3-D reformatted images showed restoration of the correct craniomaxillofacial skeletal morphology and shape, in particular, the transverse dimension, which had been grossly increased by the force of the blow which had split the facial skeleton with wide splaying apart of the right and left halves [Figure 4b].

Case 2

A 25-year-old patient sustained grievous craniomaxillofacial injuries from a self-inflicted gunshot wound [Figures 5-7]. There was found a single entry wound of the bullet below the chin and an exit wound just above the nasal bones, shattering the anterior table of the frontal sinus. The bullet had traversed upward disrupting the mandibular symphysis, and then, it had perforated the center of the tongue and shattered the hard palate, anterior maxilla, and the naso-ethmoidal regions, before fragmenting and exiting through the anterior wall of the frontal sinus [Figure 5a-c]. The facial skeleton was thus split at the center all along the line of the upward path of the bullet, with splaying apart of the right and left halves of the craniomaxillofacial region. As the injuries had severely compromised the airway, the patient was immediately tracheotomized, and his general condition stabilized before taking him up for surgery.

NCCT of the craniomaxillofacial region [Figure 5d] revealed mandibular symphyseal fracture with the displacement and distraction of the two halves; a comminuted Le Fort II fracture of the maxilla with a complete paramedian palatal split and splaying apart of the two maxillary halves; anterior maxillary dentoalveolar comminution; fractured nasal bones; and comminution of the anterior table of the frontal sinus.

Open reduction and internal fixation using the “bottom-up, outside-in” approach was carried out [Figure 6]. Split, segmental mandibular and maxillary arch bars were fixed to realign and stabilized the deranged occlusion. After thorough debridement of the wounds and removal of all nonviable tissues including small bony splinters, the severely lacerated and profusely bleeding tongue, which had been perforated by the traversing bullet, was sutured in three layers [Figure 6a and b]. The two separated and distracted halves of the mandible were reduced and brought into alignment by manual manipulation, the displaced symphyseal fracture was re-approximated, the distracted right and left halves of the maxilla were reduced, and the upper and lower teeth were brought into occlusion using Maxillomandibular fixation (MMF). The symphyseal fracture was fixed first so as to achieve a stable base [Figure 6c-e], followed by fixation of the maxilla at the zygomaticomaxillary buttresses bilaterally [Figure 6f-i]. The palatal split was checked for adequate reduction and coaptation, and torn palatal mucosa was closed with vicryl 3-0 sutures [Figure 6j].

The existing forehead laceration was used to access the frontonasal region, which had been shattered by the exiting bullet. Comminuted fractures of the nasal bones and anterior table of the frontal sinus were reduced, and the frontonasal suture regions re-approximated and fixed using microplates and screws [Figure 6k-m]. A persisting defect at the anterior table of



Figure 5: (a-c) Grievous craniomaxillofacial injuries sustained from a self-inflicted gunshot wound. The bullet entered below the chin and exited just above the nasal bones, disrupting the frontal sinus. (d) Noncontrast computed tomogram revealed a comminuted fracture of the maxilla with a mid-palatal split and splaying apart of the two halves; anterior maxillary dentoalveolar comminution; mandibular symphyseal fracture with displacement and distraction of the two halves; fractured nasal bones and comminution of anterior table of the frontal sinus



Figure 6: (Case 2) (A-J) Lacerated tongue sutured in layers, displaced symphyseal fracture, and outwardly splayed maxillary halves reduced and fixed. (K-N) Comminuted fractures of frontonasal regions re-approximated and fixed using microplates, screws, and titanium mesh. (O-Y) Widening and collapse of nasal bridge and traumatic telecanthus managed by closed medial canthopexy, with the help of two 3-hole microplates to compress the splayed nasal bones together. (Z-AA') Good postoperative recovery, patient de-tracheotomised on the 10th day. (AB') Residual palatal fistula planned for secondary closure

the frontal bone was bridged using a titanium mesh [Figure 6n]. Widening and collapse of the nasal bridge and the traumatic telecanthus were addressed next, by closed medial canthopexy. An 18-gauge needle was inserted percutaneously at the deepest portion of the root of the nose on its lateral aspect and then passed transnasally to the opposite side [Figure 6o-q]. A 26-gauge wire was passed through the lumen of the needle to the other side, and the needle then was withdrawn, leaving the wire in position. The wire was drawn through the middle hole of a 3-hole microplate; the plate was closely adapted against the skin overlying the left nasal bone and then drawn through the lower hole of the same plate [Figure 6r]. The needle was employed once more, penetrating 5–7 mm below the previous site, and the wire was drawn to the opposite side. The same procedure was repeated on the right side and a second 3-hole microplate was adapted on this side, and the wire ends were twisted together over the middle and lower holes of the plate [Figure 6s-v]. These external microplates served to compress the spayed apart of the nasal bones together, thus narrowing of the nasal bridge [Figure 6Z-AA']. Postoperative recovery was good and the patient was de-tracheotomized on the 10th day following surgery [Figure 6w-y]. At the time of discharge, a residual palatal fistula was noted in the midline, measuring 1 cm in diameter, which was planned for secondary closure after 3–6 months [Figure 6AB'].

Postoperative NCCT of the craniomaxillofacial region showed complete restoration of the skeletal morphology, with the achievement of ideal transverse dimensions as well as vertical and anteroposterior projections of the facial skeleton. Also evident was the well-aligned and fixed fracture fragments with the implants *in situ* [Figure 7a-d]. The shattered nasal bones were seen to be precisely re-approximated and restored to their original alignment, configuration, and projection.

Other than a persisting palatal defect, there were nil early or late postoperative complications and the patient recovered well [Figure 7]. There was achieved successful reconstruction of the facial anatomy, symmetry, and projection, especially correction of the increased transverse width, which had been caused by the splitting of the facial skeleton by the passing projectile. Scars of tracheostomy and of the entry and exit bullet wounds were still visible at the 5th postoperative month, but with minimal soft tissue contracture and scarring [Figure 7e-h]. There was satisfactory healing of the tongue, with mild scarring and a satisfactory restoration of occlusion and masticatory efficiency [Figure 7i and j]. A large residual palatal defect measuring 2 cm in diameter was observed, causing a wide oronasal communication with nasal regurgitation of orally ingested fluids [Figure 7k and l]. Secondary reconstruction of the palatal defect was carried out, using a robust anteriorly based, dorsal pedicled tongue flap [Figure 7m-s]. The pedicle was cut 14 days after grafting, and there was observed an excellent take of the graft, with successful and complete closure of the palatal defect, with nil donor site morbidity [Figure 7t-x].

Case 3

A 35-year-old male, who was seated next to the driver in a four-wheeler vehicle, was struck at the center of his face by an uprooted, heavy cattle tethering peg, which had swung in on its rope, through the passenger-side window [Figures 8-10]. A bull that had been tethered by the rope to an 18" (25 cm) long, heavy iron peg dug into the ground had crossed to the opposite side of the road, stretching the rope across it at a height of 1 m from the ground. The four-wheeler vehicle had accidentally driven through this stretched rope at a high speed, causing the iron peg to be uprooted from the ground and swing back across, shattering the left (co-passenger side) window of the car and striking the patient on his face. The force of the impact had split the upper and lower lips and shattered both the jaws at the center, with comminution as well as flaring apart of the right and left halves, resulting in severe facial splaying and widening [Figure 7]. Parasymphyseal fracture of the mandible and Le Fort I fracture of the maxilla with a paramedian split and lateral rotation of its right and left halves were accompanied by fracture avulsions of the upper and lower anterior dentoalveolar segments [Figure 8a-f]. Immediate primary soft tissue closure was carried out, and the patient was thereafter planned for surgery under GA for the management of the maxillofacial fractures [Figure 8g-i]. There was considerable widening of the lower half of the face, owing to the splaying outward and apart of the two halves of both, the maxilla and mandible, caused by the force of the medially directed impact by the heavy metal object [Figure 8j-l].

NCCT axial and coronal sections showed a comminuted fracture of the right mandibular parasymphysis, with overriding of the fracture ends and splaying apart of the angle regions, and a mid-palatal split of the maxilla with separation of the two halves [Figure 8m-o]. 3-D reformatted images showed the transverse widening of the maxillofacial skeleton with the lateral and outward rotation of the right and left halves of the maxilla and splaying apart of the mandible brought about by the force of the blow [Figure 8p].

The "bottom-up" surgical sequence was employed to manage the multiple maxillofacial fractures [Figure 9]. Exposure of the grossly displaced and comminuted fracture of the right mandibular parasymphysis was achieved via a submandibular approach. An extreme overriding of the fracture ends at the center with outward rotation and widening of the body region was evident [Figure 9a-d]. The two halves of the mandibular body were reduced and realigned by applying manual pressure against the outwardly splayed angle regions bilaterally, while at the same time disimpacting the overlapping fragments anteriorly. The free triangular fragment of the bone was repositioned, and fixation was carried out using two minibone plates and screws [Figure 9e-h]. The integrity of the mental neurovascular bundle was preserved by careful soft tissue dissection and meticulous bone manipulation. The severely comminuted and disrupted mandibular fracture necessitated two minibone plates for stable fixation and stabilization of the shattered fracture fragments. One long plate was used



Figure 7: (Case 2) (a-d) Postoperative noncontrast computed tomogram showing restoration of ideal skeletal morphology and transverse dimensions. (e-i) 5 months' postoperative appearance showing good restoration of facial esthetics with nil functional deficits. (j) Satisfactory restoration of occlusion and masticatory efficiency. (k and l) A large residual palatal defect causing an oronasal communication, associated with nasal regurgitation. (m-x) Secondary reconstruction using a robust anteriorly based, dorsal pedicled tongue flap, achieving complete closure of the palatal defect, with nil donor site morbidity

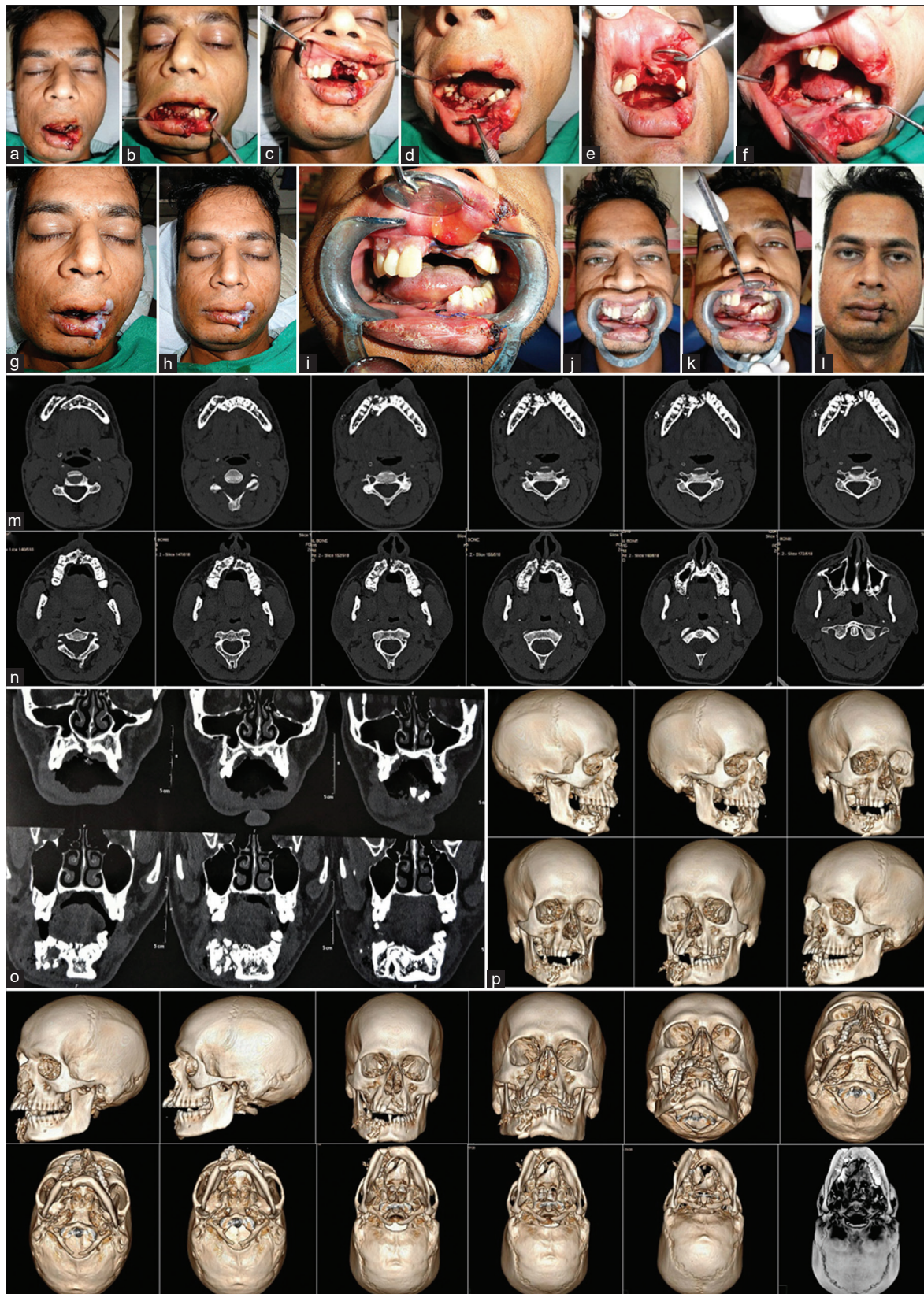


Figure 8: (Case 3) (a-i) Blow from an iron cattle tethering peg, producing lacerations of lips, fracture avulsions of anterior dentoalveolar segments, parasymphysis fracture, and maxillary fracture with a paramedian split. (j-l) Widening of lower half of face from outward splaying of the two halves of maxilla and mandible. (m-p) Noncontrast computed tomogram showing comminuted parasymphiseal fracture, overriding of central fracture ends and flaring out of the angle regions with broadening of the mandibular body; a mid-palatal split with separation of the two halves, producing transverse widening of the maxillofacial skeleton

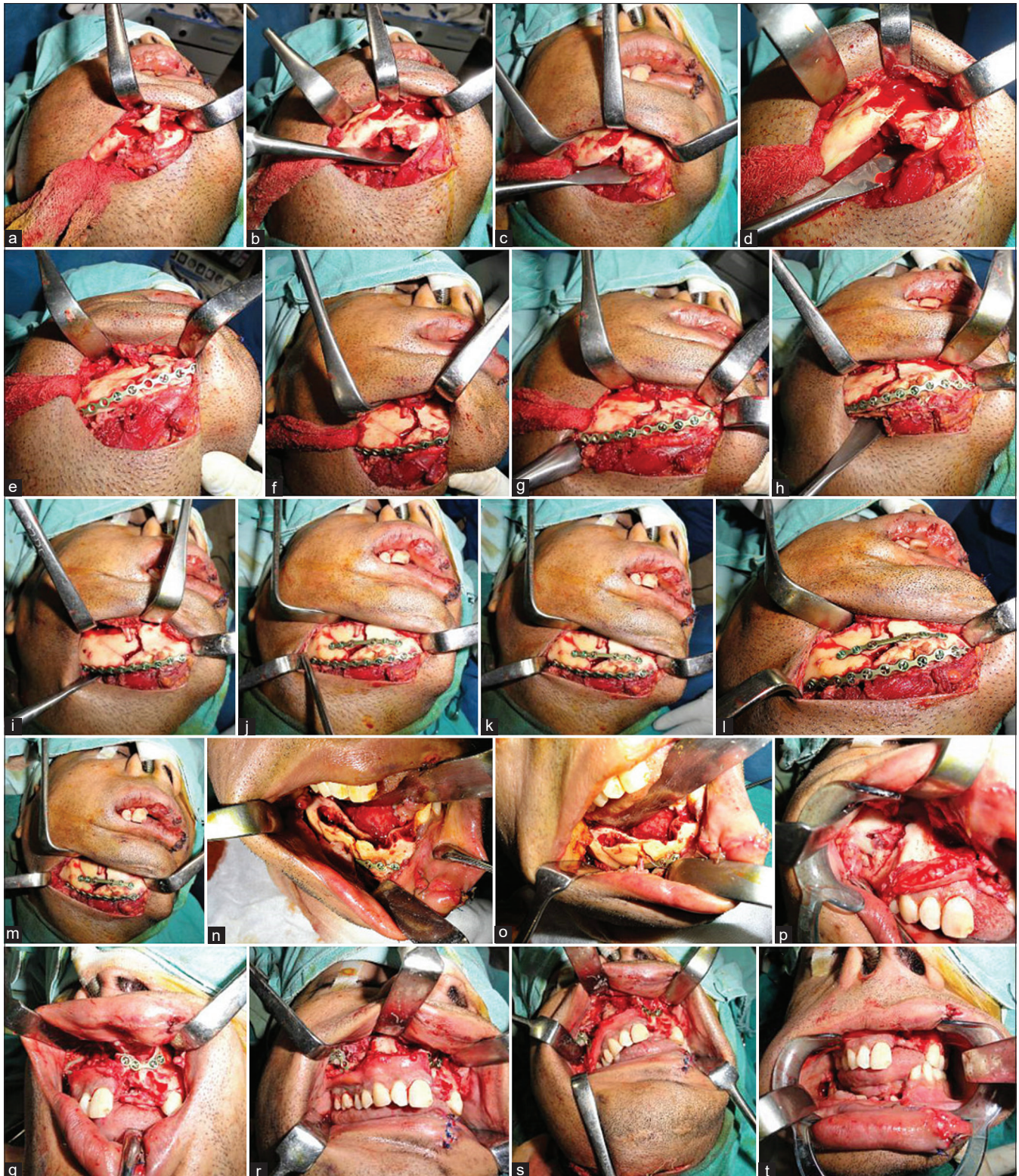


Figure 9: (Case 3) (a-d) Exposure of displaced and comminuted parasymphiseal fracture. (e-m) Pressure applied against flared out angle regions bilaterally, disimpacting the overlapping fragments anteriorly, followed by fixation. (n and o) Precise realignment and reconstruction of the disrupted alveolar process of mandible confirmed intraorally. (p-s) Laterally rotated right and left maxillary halves reduced, brought into apposition closing the palatal split, followed by fixation. (t) Restoration of correct maxillary and mandibular alveolar arch morphology and dimensions, occlusion, and interarch relationships

to stabilize the inferior border and another one was placed along its lateral surface, bridging the multiple fragments

[Figure 9i-m]. Precise realignment and reconstruction of the disrupted alveolar process of the mandible were confirmed

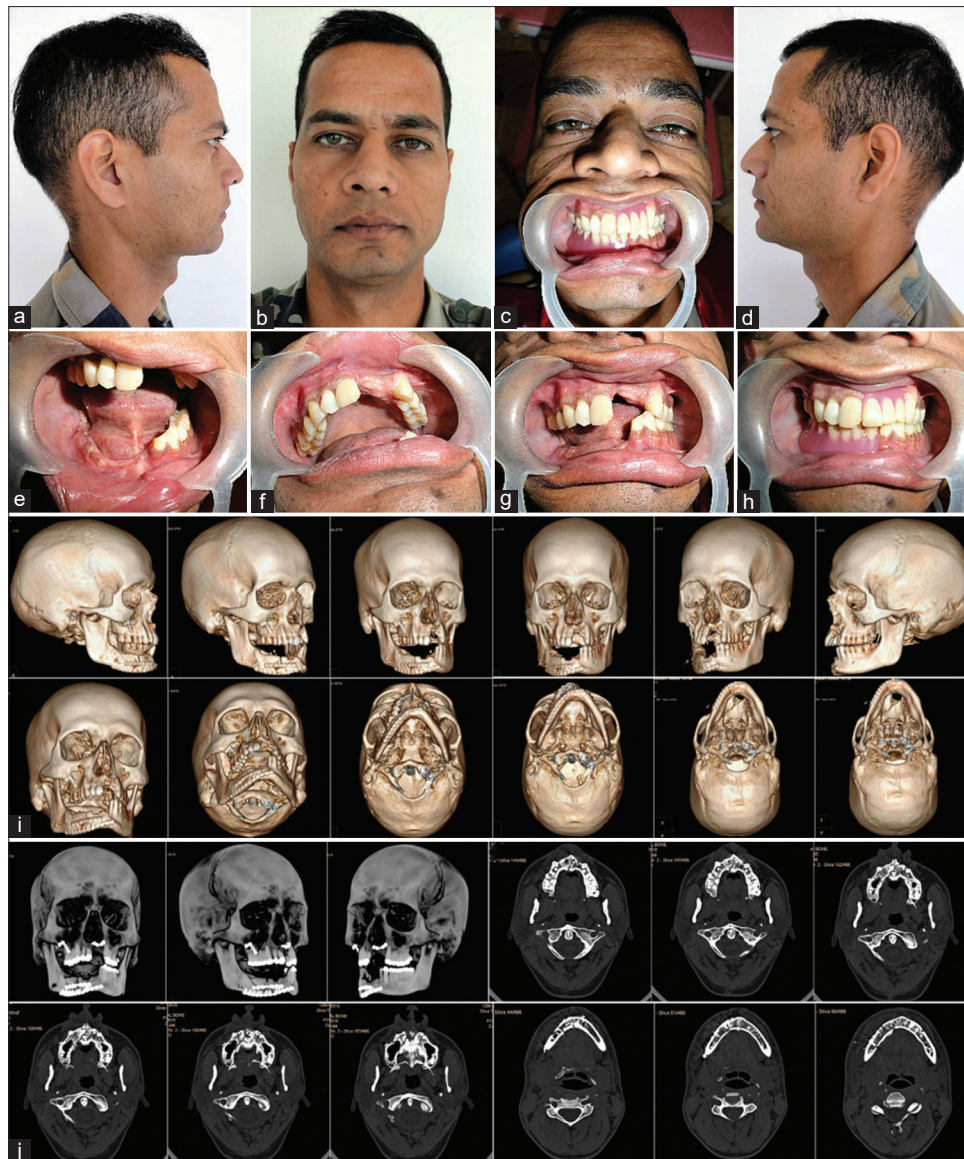


Figure 10: (Case 3) (a-d) 3 months' postoperative appearance showing correction of widened maxillofacial region and achievement of good esthetic and functional outcomes. (e-h) Patient rehabilitated with removable partial dentures, with restoration of good masticatory efficiency. (i) Non contrast computed tomogram showing re-establishment of pre-trauma status of transverse maxillofacial dimensions. (j) Precise restoration of mandibular and maxillary continuity and integrity, with restoration of the "horseshoe" shape of the mandible and complete closure of the maxillary mid palatal split

intraorally [Figure 9n and o]. The fractured maxilla was exposed via an intraoral molar-to-molar vestibular incision. The laterally rotated right and left maxillary halves were reduced, brought into apposition with one another, thus closing the palatal split, followed by fixation using one curved miniplate across the midline below the base of the pyriform rims, using occlusion as a guide [Figure 9p-s]. Fixation was also carried out along the zygomaticomaxillary buttress regions bilaterally. Restoration of the correct maxillary and mandibular alveolar arch morphology and dimensions, occlusion, and inter-arch relationships was successfully achieved [Figure 9t].

There was achieved successful restoration of ideal facial width, morphology, contour, and projection, resulting in an excellent esthetic and functional outcome, with nil early or

late complications encountered [Figure 10a-d]. The operated sites healed well with no residual deformity or functional deficits. There was observed excellent intraoral healing with healthy residual alveolar ridges. The patient was rehabilitated with well-fitting upper and lower removable partial dentures, with restoration of ideal occlusion and good masticatory efficiency [Figure 10e-h].

NCCT of the craniomaxillofacial region showed successful correction of the deranged and grossly widened skeletal structure with the re-establishment of pretrauma status of transverse, anteroposterior, and vertical maxillofacial dimensions [Figure 10i]. Precise restoration of mandibular and maxillary continuity and integrity was achieved, with restoration of the normal "U" or "horseshoe" shape of the

mandibular corpus and complete closure of the maxillary mid-palatal split [Figure 10j].

Case 4

A 31-year-old patient sustained pan-facial injuries from a blow with a bamboo stick, at the center of his face, by an assailant [Figure 11 and 12]. The force of the blow across the face produced fractures of the maxilla, mandible, frontal bone, and nasal bones. Splitting and comminution of the bones of the central craniomaxillofacial region resulted in their lateral flaring out, causing an extreme widening of the face [Figure 11a]. This was further compounded by “ballooning” of the face due to severe and widespread edema. NCCT of the craniomaxillofacial region showed a severely comminuted and displaced fracture of the mandibular symphysis, with extensive fragmentation of the dentoalveolar complex [Figure 11b]. There was overriding of the fractured ends at the symphysis, with the splaying and flaring outward of the body and angle regions, causing broadening of the transverse dimension of the lower half of the facial skeleton. Comminuted fracture of the nasomaxillary complex, depressed fracture of the frontal bone, and Le Fort III fracture of the maxilla were also evident. The naso-orbital region was displaced posteriorly, with consequent loss of its sagittal/anterior projection. Axial sections [Figure 11c] showed the symphyseal fracture of the mandible accompanied by a lateral rotation of the body regions and outward flaring of the angle regions bilaterally, distorting its shape from a “horseshoe” to a “V” shape. Maxillary fracture with separation at the nasomaxillary and zygomaticomaxillary buttress regions and a depressed fracture of the frontal bone were also evident.

The pan-facial fractures were effectively managed using the “bottom up-outside in” approach, with excellent restoration of the facial width, height, and projection, to the pretrauma status, resulting in gratifying esthetic and functional outcomes [Figure 12]. Significant improvement in the facial esthetics was observed postoperatively [Figure 12a], both, due to the resolving edema as well as successful surgical correction of the extreme transverse facial widening that had been caused by the trauma. Radiographs showed restoration of an ideal facial skeletal morphology and symmetry and well-aligned pan-facial fracture fragments with the implants *in situ* [Figure 12b]. NCCT of the craniomaxillofacial region showed precise alignment, stable fixation, and establishment of continuity at the various fracture sites and reconstruction of the disrupted craniofacial bones to their proper shape and contour [Figure 12c]. Axial sections showed successful realignment and fixation of the mandible, maxilla, nasomaxillary complex, and calvarial bone [Figure 12d].

DISCUSSION

Impacts from high-energy mechanisms, such as gunshot wounds, road traffic accidents, and blows from heavy objects, can cause extensive craniomaxillofacial injuries including pan-facial fractures, involving multiple axial segments of the

facial skeleton, such as the frontal bone, upper mid-face (NOE region), lower mid-face (zygomatic complex and maxilla), and mandible.^[1] An extended injury may also comminute the palate and dentoalveolar structures and cause loss of hard and soft tissue as well.^[2,3] Management of these severe injuries aims at complete anatomical, esthetic, and functional repair and reconstruction, with restoration of the craniofacial region to its original dimension, form, and function.

Four cases of extreme injuries caused by somewhat unusual modes of trauma, and producing peculiar fracture patterns of the craniomaxillofacial region, have been described. In all these patients, high-intensity forces directed and concentrated toward the center of the face produced splitting of the craniofacial skeleton in the midline or close to it, accompanied by splaying apart of the right and left halves, resulting in an abnormal facial widening.

Immediate management was directed toward life-saving measures such as resuscitation, protection of the compromised airway (tracheostomy was carried out in two patients), and stabilization of the general condition of the patient, as well as urgent diagnostic radiological imaging. This was followed by careful treatment planning on a case-to-case basis, followed by definitive management.

In all these patients, the force of the medially directed impact caused a median or paramedian splitting of the skeletal components of the face, with distraction and splaying apart of the right and left halves, resulting in an increased transverse facial dimension. The distracted segments were successfully reduced and realigned by employing a carefully planned surgical procedure, thereby narrowing the skeletal framework of the face back to its correct dimension and configuration and effectively restoring esthetic harmony and functional integrity.

The basic tenets of treatment of pan-facial fractures are establishing re-approximation, realignment, and fixation of unstable segments to stable regions of the maxillofacial skeleton, while simultaneously restoring ideal interrelations, proportions, and dimensions of the skeletal components of the lower, mid, and upper thirds of the face, along with the restoration of a proper occlusal relationship.^[5]

Development of a step-by-step treatment plan and surgical approach before the surgery, yet keeping it versatile and flexible enough to leave room for intraoperative modifications, “tailoring-in” and fine tuning, depending upon the nuances and specific requirements of each case, aided the efficacious surgical management of these patients. Preoperative planning involved careful observation and assessment of:

1. Location, degree of displacement, and extent of comminution of the fractures
2. Injury to structures in the vicinity of the fractures, such as blood vessels, skin, mucosa, and nerve tissue and to adjacent vital structures such as the globe, airway, and intracranial structures

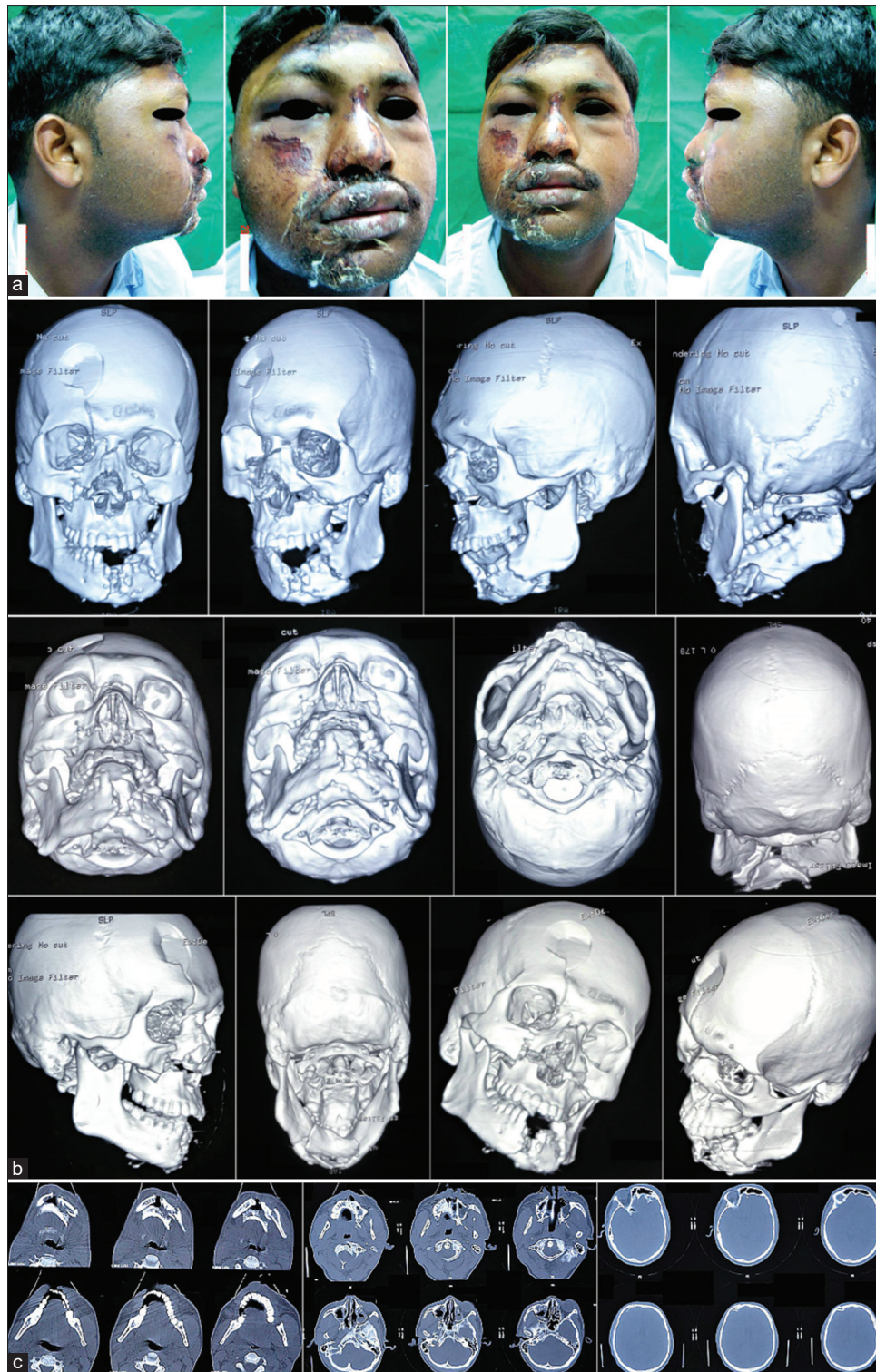


Figure 11: (Case 4) Pan-facial injuries caused by blow on the face with a bamboo stick. (a) Splitting and comminution of bones at the center, with lateral flaring out, producing extreme facial widening. (b) Noncontrast computed tomogram showing comminuted and displaced fracture of mandibular symphysis, with overriding of central fractured ends and flaring outwards of the body and angle regions, comminuted fracture of nasomaxillary complex, frontal bone, and Le Fort III fracture of the maxilla are also evident. (c) Axial sections showing distortion of mandibular shape from “horseshoe” to “V” shape

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| 3. Extent of soft tissue and/or bone loss | 6. Presence and extent of facial deformity and functional deficits |
| 4. Presence of dentoalveolar injury | 7. Concomitant injuries of other parts of the body. |
| 5. Occlusal status and degree of its derangement | |

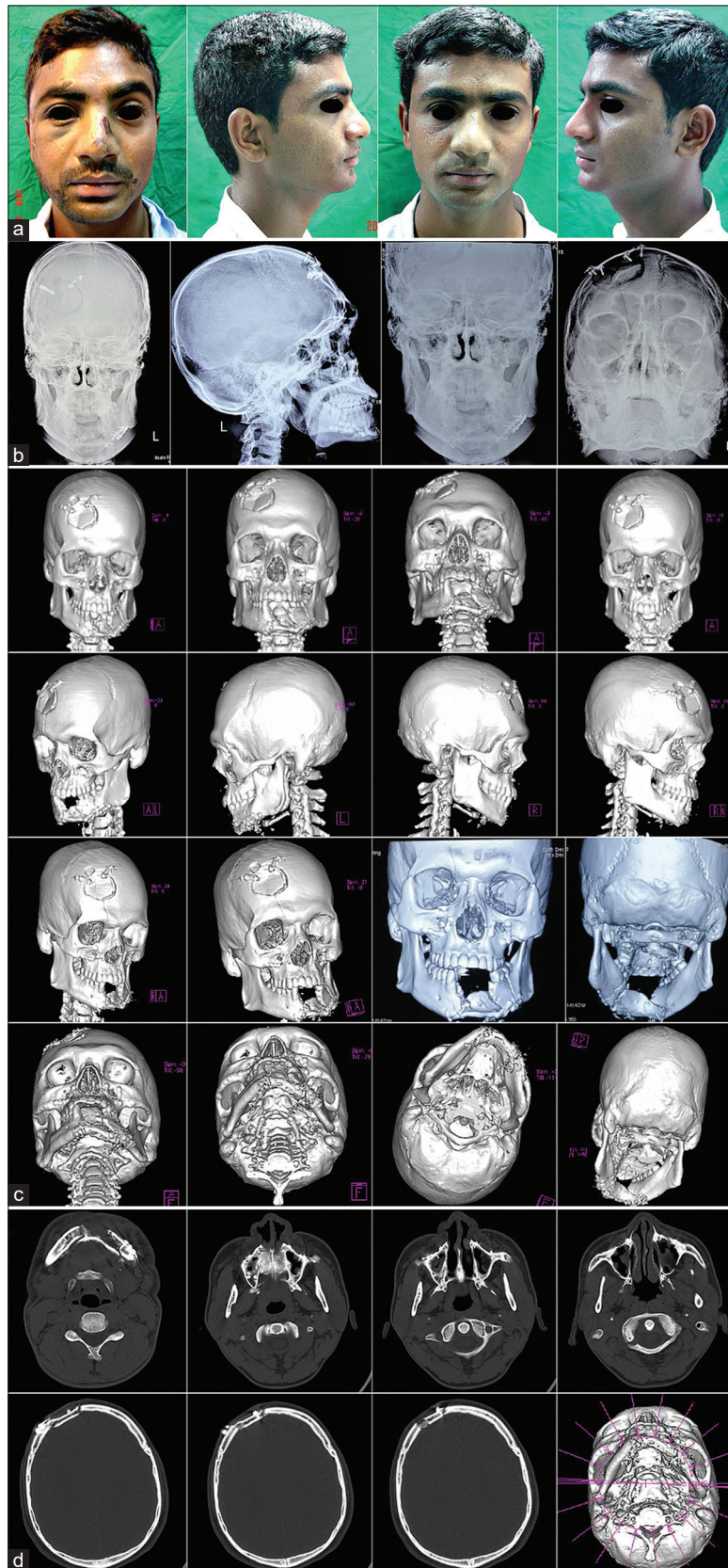


Figure 12: (Case 4) (a) 2 weeks' and 3 months' postoperative appearance showing significant improvement in facial esthetics due to the resolving edema and successful surgical correction of the extreme transverse facial widening that had been caused by the trauma. (b) Radiographs showing restoration of ideal facial skeletal morphology and symmetry and well-aligned pan-facial fracture fragments with the implants *in situ*. (c and d) Noncontrast computed tomogram showing precise alignment, stable fixation and reconstruction of the disrupted craniofacial bones to their proper shape and contour

A choice was made among the following standard, established sequences for pan-facial or multiple fracture reduction and fixation:

1. **Bottom-up (caudal-to-cephalic) approach:** In this approach, the mandible is restored and reconstructed first, which then provides a stable base for repositioning the maxilla, with occlusion serving as the guide.^[6,7] The mandible determines the height of the lower third of the face by the condyle/ramus region and also determines the width and projection by the symphysis/body region. The maxilla too determines the facial width by the palatal region, which, if split and flared out, results in transverse widening. Once the mandible and the maxilla have been repaired, in addition to the restoration of the vertical height and horizontal width, this entire unit will be equivalent to a block that will then be able to articulate and provide stable foundation for the repair of the upper mid-face.^[8] This was the main approach that was employed in all four cases in this study
2. **Outside-in (lateral-to-medial) approach:** As the malar projection and condylar height are the most important determinants of the outer facial contour, this approach advocates pan-facial fracture reduction to begin with the outer bony pillars, such as the zygomatic arch, condylar necks, and the frontal areas, to establish the outer facial frame and to restore the upper facial width and projection and then to address the inner facial frame, such as NOE, maxillary, and mandibular reconstruction.^[9] In the presence of bilateral condylar fractures, these must be addressed first. Medial fractures such as NEO or symphysis and parasymphysis fractures should be followed according to the frame that is decided by projection and height. In all the four cases presented, although there were no condylar processes or zygomatic arch fractures, the body of the zygoma and frontal bone was fractured, and they were addressed before the inner NOE complex
3. **Top-to-bottom (cephalic-to-caudal) approach:** The traditional and older “top-to-bottom” approach advocated pan-facial reconstructions to begin with the reduction of the frontal bone and proceed with the mid-facial bone alignment, using the three buttresses, namely the frontomaxillary, zygomaticomaxillary, and pterygomaxillary buttresses, serving as guides. Using the reconstructed maxillary framework as a template, the lower face was reconstructed last
4. **Inside-out (medial-to-lateral) approach:** This approach is based on the fact that the esthetic core of the face is the NOE region and hence should be considered early in the sequencing of repair, followed by maxillary-mandibular unit and occlusal restoration which is then “built out” from that region^[4]
5. **Occlusion first approach:** This approach focuses on the restoration of the occlusion and occlusal plane, which serves as a solid basis for further reduction, with the initial reduction of larger segments, thereby forming a template, enabling effective reconstruction of the multiple smaller segments involved in the pan-facial fractures.

The most widely favored and employed sequence, ideally suited for most pan-facial fractures, is the “bottom-up, outside-in” approach. Nevertheless, no single sequence can be applied to all cases of pan-facial fractures because of the wide variations in combinations of fracture patterns of the craniomaxillofacial bones.^[4] The standard sequences can be employed in a variety of combinations to best address the individual cases, to restore the craniomaxillofacial architecture.^[8]

In all the four cases described in this study, the contemporary combination “bottom-up, outside-in” approach was found to be the most appropriate and effective sequence to follow and yielded excellent results. The reduction and repair of fractures were begun from the mandible (bottom-up), followed by the maxilla, zygomatico-orbital complex, frontal bone, and finally, the NOE region (outside-in). The mandible being the strongest bone of the maxillofacial skeleton was reconstructed first and restored to its correct transverse width by correcting the symphyseal split and reducing the flaring segments. It was then used as a template against which the rest of the skeleton was realigned and fixed. The restored dentate segment of the mandible allowed occlusion with the upper teeth to guide an ideal maxillary alignment,^[9,10] with reduction the laterally rotated and flared out halves, their re-approximation, and fixation, thus restoring the facial width to normal.

High-resolution computed tomography, sufficient surgical exposure, proper anatomic reduction, stable fixation, and soft tissue suspension are the basic tenets for optimum results and were responsible for the successful results achieved in our cases as well.

A submandibular approach was employed in Cases 1, 3, and 4 for carrying out mandibular repair [Figures 1 and 9], as it provided a wide access to allow ample visibility of the surgical field. The severely comminuted and extensively displaced mandibular fractures necessitated confirmation of precise approximation at the inferior border as well as the lingual cortex, which was more effectively accomplished and verifiable via an extraoral approach. Moreover, forceful manipulation was required to disimpact the centrally overriding fracture ends at the symphysis region, while simultaneously compressing the flared out angle regions bilaterally to achieve the required realignment of the mandible to its correct transverse dimensions and “horseshoe” morphology. Wide contact between the segments from both the labial/buccal and lingual aspects during fixation of mandibular fractures was important because even minimal defects or discrepancies would increase the width of the mandibular arch, resulting in abnormal occlusion with the upper arch, thereby leading to improper management of the maxillary fractures as well.

The area that usually poses the biggest problem with postoperative recovery, leading to unsatisfactory esthetics, is the medial canthal region. Simple external splints do not adequately compress and mold these particular areas. The safest and most effective technique is to use transnasal wires with stiff external splints (in this case, 3-hole microplate) secured to the external

nose (Case 2) [Figure 6p-y]. This allows the nasal bridge to be splinted in the midline, restoring its shape and projection. The superior component of these plates helped compress the medial canthal soft tissue, preventing widening of the soft tissue area, to help keep the medial canthal tendon repair intact, especially as nasal bones fracture had also been treated (Case 2).

In Case 2, disintegration and loss of bone of the central maxilla caused by the traversing bullet resulted in a large residual palatal defect persisting after the pan-facial fracture repair. This defect was reconstructed secondarily, 5 months later, with an excellent functional outcome and rehabilitation. The large oronasal fistula was successfully bridged and closed by a sturdy anteriorly based dorsal pedicled tongue flap [Case 2; Figure 7]. Thus, a hard tissue loss was secondarily reconstructed using a soft tissue flap, with a remarkable functional outcome, despite the fact that the donor site, namely the tongue, itself had been severely damaged at the initial injury by the traversing bullet.

Recent studies have demonstrated the value of oral and dental tissues, such as the periosteum, dental pulp, periodontal ligament, dentin, dental follicles, apical dental papilla, and even periapical cyst tissue, as the valuable potential sources of mesenchymal stem cells (MSCs), with the capability to differentiate toward various cell lineages, including bone, cartilage, muscle, nerve, and adipose tissue.^[11] They may hence possess the capability of contributing toward maxillofacial tissue repair, reconstruction, and regeneration, following extensive, destructive, and even avulsive injuries of this region. Human periapical cyst-derived MSCs possess the classic trilineage differentiation potential into osteogenic, adipogenic, and chondrogenic lineages. They have been reported to retain high proliferative rates and extensive multipotency, which could play a strategic role in bone and dental regeneration, more so, when added to specific scaffolds such as nonvascularized grafts such as the rib graft or iliac crest corticocancellous bone graft. Dental-derived MSCs are currently being tested in preclinical and clinical trials for their ability to foster wound healing and tissue regeneration and in their role as promoters, enhancers, and playmakers of translational regenerative medicine.^[12]

Dental pulp stem cells cultured in 1% concentration of human platelet lysate have been shown to demonstrate enhanced osteogenic and chondrogenic differentiation, with the capability of accelerating *in vivo* healing and tissue regeneration.^[13] Ongoing nanomaterial researches using engineered bioactive nanoparticles within a biomaterial scaffold have shown promise in bone tissue engineering and bone regeneration, with possible applications in the treatment of osteoporosis.^[14] Along similar lines, the use of nanomaterials for the promotion of new bone growth can also be considered for accelerating bone regeneration and repair, in the management of severe maxillofacial trauma. It is also important to employ biomaterials and scaffolds of reasonable impact resistance and of adequate strength^[15] to take on the anticipated loads of the region, such as masticatory stresses.

The facial widening in all the cases presented in this series, resulting from the wide splaying apart of the maxillofacial skeleton, was successfully corrected, resulting in an excellent esthetic outcome. In addition, functional results achieved were gratifying, owing to the efficient management of the grossly deranged occlusion, resulting from the midline disruption of the mandible as well as the maxilla with outward rotation both the jaw halves and all four dental quadrants. Restoration of correct transverse dimensions to the craniomaxillofacial skeleton is crucial to reestablish proper facial width and dental arch relationships, and to thereby restore form and function to the face. In the cases presented, mandibular diastasis reduction was achieved by application of medially directed forces at the mandibular angle and body regions. Similarly, maxillary diastasis reduction and closure of palatal splits was accomplished by disimpaction and manipulation, using Rowe's forceps. This was followed by stable, rigid fixation using minibone plates and screws. An organized and systematic, yet flexible surgical approach, keeping in mind the basic surgical tenets and principles of access, visualization, reduction, alignment, and stable repair of the skeletal components of the fractures, meticulous repositioning, and reconstruction of the soft tissue elements and precise restoration of occlusion, all went a long way toward achieving the final goal.

CONCLUSION

Shattering and splaying apart of the craniofacial skeleton, brought about by high-intensity, centrally directed forces, can be extremely complex, daunting, and challenging to treat. Reconstitution of the skeletal morphology to its original configuration, with simultaneous restoration of the disrupted soft tissues of the region to their original pretrauma status, is essential to achieve good esthetic and stable functional results.

Detailed diagnostic imaging, meticulous treatment planning, judicious application of a surgical protocol which is most ideally suited for each individual case, and keeping the treatment approach flexible and versatile, all contribute toward ensuring the desired outcome. A precisely executed operative procedure, incorporating all the basic tenets of repair and reconstruction of the deranged craniomaxillofacial skeletal and soft tissue components in a systematic and sequential manner, helps minimizing the development of residual deformities and functional deficits.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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