The Benefit of Inevitably Delayed Surgical Intervention Following High-Velocity Maxillofacial War Injuries

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Research article

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Abstract

Background: Over 3200 Syrian patients were admitted and treated at Galilee Medical Center (GMC) over a five-year period (May 2013 - May 2018) since the beginning of the Syrian civil war in 2011. This study compares the number of postoperative complications of patients admitted to the GMC immediately after injury or two to three weeks after initial high-velocity maxillofacial injuries and the potential mechanisms for the variation in complication rates. We describe our experiences, strategies, and resultant treatment approach.

Methods: Retrospective case studies in which the incidence of complications including infection, rejection of hardware, bone or soft tissue grafts, tissue dehiscence, oroantral fistula formation, excessive scarring, and unplanned return to the operating theater were investigated. Patients arriving at the GMC within 24 hours following maxillofacial injury were considered “early” while patients arriving to the GMC within 14-28 days following initial trauma without treatment prior to arrival were considered “late” or “delayed.” Both groups of patients received definitive surgical treatment within 48 hours of admission to our hospital.

Results: Sixty patients suffering from "high-velocity" maxillofacial Syrian civil war-related battlefield injuries were included in this study. The mean age was 26±8 years (range: 9-50) and all except one were male. Post-operative complications in the early group were found to be significantly higher compared to the delayed group ($p = 0.006$).

Conclusions: We discovered that the delayed group of patients, characterized by progressive neovascularization of injured tissue, had better surgical success from rich blood supply that enhances tissue survival. Sustained tissue perfusion to the tissue supports efficient systemic antibiotic delivery, a favorable condition in lowering infection rate and complication. We found that the unintendedly delayed treatment contributed to a critical revascularization period resulting in improved healing and decreased postoperative morbidity and complications.

Background

The Syrian civil war began in 2011. Ongoing violence continues to plague the region and has resulted in hundreds of thousands of people killed or injured (1). These injuries have affected both civilian populations and guerilla warriors, who use modern body armor less frequently than do organized military units. During the war, Syrian healthcare facilities either closed or became only partly functioning (2). Since 2013, Israel has been treating wounded Syrians through programs developed in conjunction with the United Nations. Between 2013 and 2018, over 4700 patients were brought to northern Israeli medical centers, with over 3200 patients referred to the Galilee Medical Center (GMC).

Previous research has been conducted on maxillofacial injuries incurred during wars in Iraq, Afghanistan, and Israel by high-velocity weaponry. Prior studies highlight two primary treatment approaches: either rapid and immediate treatment of these injuries (3, 4) or staged and delayed treatment (5, 6). Similarly, the Syrian civil war presented GMC oral and maxillofacial surgeons with both unique challenges in reconstruction and function restoration to individuals with complex injuries as well as opportunities to further determine and elucidate the mechanisms underlying the timing intervention of greatest benefit to patients.

Weapon injuries are generally categorized as "urban injuries," which are most often inflicted by "low-energy"/"low-velocity" weapons with muzzle velocities between 210 and 600 m/s, or "war injuries," which can be inflicted by either "low-energy"/"low-velocity" or “high-energy"/"high-velocity" weapons (e.g., rifles, machine guns, improvised explosive devices, or missiles). A high-velocity weapon is able to fire a projectile at a velocity of greater than 610 m/s (7).

Ballistic injuries can disrupt soft and/or hard tissues, leading to alarmingly distorted facial features. Such facial deformities obliterate the normal anatomic planes and introduce a unique and challenging dilemma for even the most experienced facial trauma specialists. High-velocity ballistic injuries to the face usually lead to highly comminuted fractures of the facial skeleton and avulsion injuries of facial as well as intraoral soft tissues along the main bullet trajectory. Additional injuries often include secondary, distant fractures caused by propagation of the shock wave (8). At the projectile–tissue interface, injury occurs by either stretch or crush mechanisms. The permanent cavity involves all tissues pushed aside or destroyed during the flight of the projectile and is the location of initial damage. Soft tissue necrosis and small-vessel damage also occur. A projectile striking bone may cause fragmentation of the bullet and/or native bone, forming numerous secondary projectiles, each capable of producing additional wounds, dramatically increasing the size of the permanent cavity (9). The behavior of high-velocity projectiles in tissue is very different from that of low-velocity projectiles and must be taken into consideration when addressing injuries of this nature. Specifically, in low-velocity injuries, the temporary cavity is much smaller, there is less tissue avulsion, and most of the damage is localized to the tissues directly affected or compressed by the projectile. In contrast, high-velocity gunshot wounds are surrounded by a large devitalized area, with temporary damage to the microcirculation of distant soft tissues (7).

As mentioned, many authorities advocate a conservative approach for the management of high-energy/high-velocity maxillofacial injuries which consists of, in order, debridement, fracture stabilization, and primary closure, followed by reconstruction of hard tissues and subsequently by correction of residual deformities of the oral cavity (5, 6, 10–16).

Others advocate for the aforementioned procedures to be completed in one stage, rather than in many stages, as well as for open treatment of all involved structures, which is greatly facilitated by the utilization of composite-free tissue transfer that provides intraoral lining, skin cover, and bone support in one step (3, 17–24).

The vascularization of wounded tissue bears a marked impact on this critical revascularization period (CRP), or the time during which blood vessels at the site of injury self-repair, thus improving blood supply to the injured tissue. Tissue regeneration is a complex process that includes numerous biological mechanisms, among them the essential process of angiogenesis. Studies estimate that the physiological growth rate of micro-vessels is not faster than approximately five μm/h (25, 26). Living cells must be within 200 μm of a blood supply in order to acquire sufficient oxygen and nutrients and to remove waste, ensuring long-term survival and functionality (27–29). The pathologic changes of small-vessel injuries, injury mechanisms, and the feasibility for early vessel anastomosis in the maxillofacial region has been described on dogs following high-velocity missile wounds. They found that pathologic changes of the small vessels included microthrombus formation, endothelial loss, breakage in the internal elastic layer, and necrosis. Degeneration of cells was found to end three cm from the wound edge; anastomosis of vessels performed three days after injury provided good short-term patency (8). Moreover, in a mouse arteriovenous loop experimental study, very little angiogenesis or tissue generation occurs at early time-points (between four to seven days) but these repairing mechanisms increase dramatically by 14 days and approximately double between day 14 and day 28 [(30)]. It has been suggested that anastomoses should not be attempted until at least two weeks have elapsed from time of injury (3).

While the timing of intervention and the extent to which each step of treatment is applied may be controversial, we believe that allowing sufficient time for CRP is an imperative step for providing optimal treatment outcomes. The purpose of this study is to compare the peri- and post-operative complication rates of early versus delayed treatment of high-velocity gun shot or artillery-related injuries and to present the experience, strategies, and approach of our level I trauma center in treating severe facial injuries caused by high-velocity weapons.

Methods

This retrospective case series study (NHR 0166 – 17) was approved by the Institutional Review Board (IRB) and the Helsinki committee of the GMC in compliance with the public health regulations and provisions of the current harmonized international guidelines for good clinical practice (ICH-GCP) and in accordance with Helsinki principles.

The medical files of all injured Syrian patients treated at GMC from May 2013 through May 2018 were reviewed. Those maxillofacial injuries classified as high-velocity injuries, e.g., gunshot wounds (GSW) from rifles and machine guns, missile injuries, and improvised explosive device (IED) explosions, were identified.

Data extracted from medical records included age; sex; mechanism, location, and type of injury; interval from injury to admission to GMC; Glasgow Coma Scale (GCS) on arrival; tracheostomy presence; intensive care unit (ICU) admission; and length of ICU stay. Also recorded were date, number, and type of OMFS surgeries performed; complications such as infection, rejection of hardware, bone or soft tissue grafts, oroantral fistula formation; excessive scarring; additional surgeries performed in other departments; and the dates of hospital admission and discharge. Some patients were first admitted to other departments (e.g., orthopedics, neurosurgery intensive care unit) and then transferred to the Oral and Maxillofacial Surgery and ENT departments, or vice versa. Patient medical records lacking any of the afore-mentioned information regarding mechanism and time of injury or containing insufficient data concerning treatment follow-up and/or complications were excluded from our study.

Due to the nature of the presented injuries and the fact that the study population consisted of Syrian nationals, patients could not be invited to return for follow-up care in outpatient clinics. Thus, length of hospital stay represents the total time each patient spent not only in the OMFS department, but at GMC in total.

Patients treated by GMC between May 2013 and May 2018 were divided into two groups: the first group included patients who arrived to GMC within 24 hours of the initial injury while the second group included patients who arrived to the GMC between 14–28 days of injury. This delayed intervention group included patients who had minimal on-site treatment; in other words, debridement of wounds and simplification of fractures with no prior fixation had been performed in Syria. Upon arrival at our hospital, patients of both the early and delayed groups followed the same treatment protocol. Open reduction and internal fixation (ORIF) was conducted, bone defects were reconstructed with grafts, and soft tissue was covered with local flaps at GMC within 48 hours of admission (Fig. 1A). The rates of individual complications, including soft tissue dehiscence and plate or bone exposure, oral-antral fistula, bone graft resorption, infection and non-union of fractures, and numbers of total complications among the delayed versus early intervention groups were analyzed. Each group was further divided into two subgroups according to the site of injury: lower face (mandible) or mid-upper face (maxilla, zygoma, orbits). Analysis of both subgroups combined was also performed.

Statistical analysis was performed with IBM SPSS statistics, version 25. Quantitative data are described by mean and standard deviation, median and range, while qualitative data are described by frequencies and percentages. Quantitative data between the early and delayed groups were compared using independent sample t-test while the qualitative data were compared using Pearson Chi-square test or Fisher's exact test (if expectancy < 5); differences between the two groups were considered significant at p-value < 0.05. Two-sided p-value analyses were also performed.

Results

Over 3200 Syrian patients were admitted and treated at GMC during the period of study, 70% of whom presented with war-related injuries. Head and neck war-related injuries were recorded for 350 patients (11%), 105 (30%) of whom suffered maxillofacial (MF) high-velocity battlefield injuries. Of these patients, 45 were excluded due to lack of follow-up data. All 60 patients included in this analysis were treated by the same team of surgeons at GMC's Department of Oral and Maxillofacial Surgery or Department of Otolaryngology, Head and Neck Surgery. Patients' mean age was 26 ± 8 years (range: 9–50) and all except one were male. Mean hospitalization duration in GMC was 73 ± 16 days (Table 1). Penetrating injuries were presented by 37 patients (62%), while 15 (29%) suffered from perforating injuries. In addition, avulsive injuries were observed in 32 cases (53%). The distribution of the facial fractures by site was as follows: 40 mandibular fractures (39%), 23 maxillary fractures (22%), 19 zygomatic fractures

(18%), 18 orbital fractures (17%), and two Lefort III-type fractures (2%). Of the 40 mandibular fractures, 27 involved more than one fracture site per patient, totaling to 67 mandibular fractures. Of these 67 mandibular fractures, 26 were in the mandible body (39%), 19 were angular fractures (29%), 14 symphysis (20%), seven condylar/subcondylar (10%), and one involving coronoid fractures (2%). Thirty-four of the mandibular fractures were open to the skin, oral cavity, or both (85%). Thirty-one of the mandibular fractures were comminuted (77%). The early group included 25 (42%) patients while 35 (58%) were treated following delayed arrival to our center (Fig. 1).

All patients upon arrival were treated with tetanus prophylaxis and, throughout the course of their stays in the Department of Oral and Maxillofacial Surgery or ENT, received the same antibiotic protocol. Fifty-five were treated three times per day with 1 gram of augmentin (GSK-ISRAEL, LTD) while five patients allergic to penicillin were treated three times per day with 600 mg of clindamycin (Pfizer ISRAEL,LTD). In addition, all patients received the same postoperative treatment, including intravenous (IV) fluid support, steroids (dexamethasone), and the same analgesic drug therapy.

Complications included soft tissue dehiscence and plate or bone exposure, oral-antral fistula, bone graft resorption, infection, and non-union of fractures (Fig. 1B). Sixteen patients (64%) in the early group suffered from complications, while only ten patients (28.5%) in the delayed group suffered complications. When the incidence of each type of complication was compared separately, it was found that the delayed surgical intervention group had fewer complications than the early treated group. Application of the Pearson Chi-Square test to examine the total complication rate for each group revealed that the total complication rate in the early treated group was significantly higher, statistically, compared to the delayed group (p value = 0.006) (Fig. 1B).

Discussion

To date there is no consensus or well-established protocol for treatment of maxillofacial high-velocity gunshot or artillery-related injuries despite the fact that the timing, sequence, and application of surgical procedures in reconstructing and rehabilitating maxillofacial injuries have been proven to influence the final outcome and aesthetic result (5, 6, 18, 19). In the current study, we focused mainly on the rate of complications, comparing early versus delayed treatments of high-velocity maxillofacial injuries. Sixty patients were treated for maxillofacial high-velocity battlefield injuries, all treated in accordance with AO TRAUMA principles. Overall complication rate was significantly higher in the early as compared to the delayed group (p = 0.006).

Currently, cranio-maxillo-facial (CMF) trauma protocols are based primarily on the experience of treating soldiers injured in Iraq, Afghanistan, and Israel (3, 31–41). Previous studies advocate the aggressive surgical treatment of facial gunshot injuries as early as possible to minimize scarring and contracture of facial soft tissue (3, 14, 20, 34). This approach advocates the early intervention of a multispecialty team integrating plastic surgical techniques, ORIF and miniplate reconstruction of facial fractures, acute bone grafting, and soft tissue reconstruction at the earliest possible opportunity (42). In contrast, the staged, or delayed, treatment approach (5, 6) underscores the importance of staging hard and soft tissue treatment, which to a large degree depends on surgeon judgment, the extent of injury, and the general condition of the patient.

Surgical management of maxillofacial wounds caused by high-velocity weapons generally consists of three stages (5, 6, 18, 35, 36): debridement, fracture stabilization and primary closure; followed first by reconstruction of hard tissues (provided that soft tissue coverage is adequate); then by rehabilitation of the oral vestibule, alveolar ridge and secondary correction of residual deformities. Often, several operations may be required at any of the three stages. Selection of appropriate surgical technique and procedure is important, as improper technique may lead to infection, sequestration, wound dehiscence, graft rejection, or facial deformity, all of which may prolong hospital stay and postoperative morbidity as well as increase treatment costs (5, 18). Simple solitary facial fractures (without extensive soft tissue avulsion or infection) can be reduced, immobilized, and fixed at the time of primary closure using osteosynthesis plating in accordance with AO TRAUMA principles, provided that soft tissue coverage can be obtained and debridement is performed. As for all trauma injuries, bone fragments, especially those attached to the periosteum and muscle, must be located and reduced to ensure periosteal blood supply and tissue attachment during fragment redaction and hardware application. Leaving soft tissue defects open is best avoided since this may result in the extensive scarring of facial tissues and increased infection rate. In contaminated wound debridement, massive irrigation, and loose closure of the locally transferred tissue are required. From both the aesthetic and functional perspectives, local undermining and use of regional soft tissue advancement rotation flaps for primary closure of maxillofacial soft tissue defects have proven beneficial (5, 6, 18, 19).

Preventing infection of hard and soft tissues following high-velocity injuries is crucial; this can be achieved by debridement, irrigation, fixation and immobilization of injured tissues, proper wound closure, and maintenance of clean dressings. Hemodynamics must also be addressed, as oxygen-carrying capacities affect both wound healing and prevention of infection. Here, the use of broad-spectrum antibiotic therapy, which provides aerobic and anaerobic coverage, plays a major role (5, 6, 18, 19).

Conclusions

The Syrian civil war presented Oral and Maxillofacial and ENT surgeons at the GMC with unique challenges in reconstructing and restoring function to wounded patients with complex facial injuries. The unavoidably delayed treatment of Syrian patients who arrived at our center two to four weeks following initial injury highlighted the hidden benefit of physiologic vascular healing prior to planned intervention. Apart from limited, improvised treatment on the battlefield, the patients in the delayed group had no significant prior expert management. The strikingly extensive revascularization of injured tissues during the two to four week period before arrival to GMC is, in our opinion, the foundation for successful surgical intervention in these groups of patients. This principle was found to be especially beneficial in cases that require multidisciplinary intervention of bone grafting and midface reconstruction with advancement and rotational flaps.

It is unfeasible to draw unequivocal conclusions concerning the ideal time for definitive surgical treatment, yet our research findings indicate that delayed treatment, with consideration of CRP, enhances surgical outcomes while simultaneously decreasing postoperative morbidity and complications.

Further substantiation of the value of CRP as a corollary between tissue revascularization and wound healing may be provided by ongoing basic research, that recapitulate the molecular mechanism of injury and healing timelines in humans. Defining the ideal schedule for surgical intervention will greatly assist trauma surgeons in providing optimal patient care.

Abbreviations

ATLS = Advanced Trauma Life Support

CMF = Cranio-Maxillo-Facial

CRP = Critical Revascularization Period

GMC = Galilee Medical Center

MMF = Maxillo-Mandibular Fixation

ENT = Ear Nose and Throat

ORIF = Open Reduction Internal Fixation

Declarations

Availability of data and materials

All data generated or analysed during this study are included in this published article.

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Author information

Authors' contributions

D.O and A.A.D wrote the manuscript with support from S.S., and E.S.
E.Safory and A.A.D. illustrated the working model ‘early’ versus ‘delayed’ surgical treatment intervention

following midface high-velocity injuries. D.O and A.A.D performed data statistical analysis. A.Z., D.O., A.K., L.D., A.A.D., E.Sela. and S.S performed and supervise the patients' surgical treatment and functional rehabilitation. A.Z., D.O. and A.K. performed the ongoing clinical follow-up following the surgical treatment. All authors have read and approved the manuscript.

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Ethics declarations

Ethics approval and consent to participate

No ethical approval was required for this article.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Table

Table 1. Patient demographics, baseline characteristics and treatment course.

	Early Group	Delayed group	Total	P value
Number of patients	25	35	60	
Site of injury Lower face - Comminuted - Mandible body - Angle - Symphysis - Condyle/subcondylar - Coronoid Mid/upper face - Maxilla - Zygoma - Orbit Lower/mid/upper face combination	15 (60%) 10 (40%) 10 (40%) 7 (28%) 5 (20%) 3 (12%) 0 (0%) 14 (56%) 9 (36%) 7 (28%) 7 (28%) 4 (16%)	25 (71.4%) 21 (60%) 16 (45.7%) 12 (34.3%) 9 (25.7%) 4 (11.4%) 1 (2.9%) 20 (57.1%) 14 (40%) 12 (34.3%) 11 (31.4%) 10 (28.6%)	40 (60%) 31 (51.7%) 26 (43.3%) 19 (31.7%) 14 (23.3%) 7 (11.7%) 1 (1.7%) 34 (56.7%) 23 (38.3%) 19 (31.7%) 18 (30%) 14 (23.3%)	*0.412 *0.190 *0.793 *0.779 *0.760 **1.000 **1.000 *1.000 *0.794 *0.779 *1.000 *0.357
Age (yrs), mean ± Std	25 ± 9	26 ± 7	26 ± 8	***0.645
Gender	M(24) (96%) F(1)	M(35) (100%) F(0)	M(59) (98.3%) F(1)	**0.417
Glasgow Coma Scale at arrival, mean ± Std.	9.5 ± 3	9.1 ± 3	9.3 ± 3	*0.613
Interval from injury to admission, (hrs), mean ± Std	16 ± 10	20 ± 8	19 ± 9	***0.105
Intubation or tracheostomy on arrival (%)	10 (40%)	16 (45%)	26 (43%)	*0.793
Intensive care unit admission, n (%)	13 (52%)	20 (57%)	33 (55%)	*0.794
Preoperative time from admission to debridement/simplification (hrs), mean ± Std	2 ± 3	3 ± 3	3 ± 3	***0.208

Table 1. Patient demographics, baseline characteristics and treatment course.

Additional surgeries, n Orthopedic Neurosurgery Eye and oculoplastic surgery ENT Plastic surgery	23 (92%) 16/51 (31%) 8/51 (15%) 8/51 (15%) 7/51 (13%) 12/51 (23%)	32 (91.4%) 24/74 (32%) 12/74 (16%) 11/74 (15%) 10/74 (13%) 17/74 (23%)	55(91.7%) 40/125 (32%) 20/125 (16%) 19/125 (15%) 17/125 (13%) 29/125 (23%)	*1.000
Mean hospitalization duration in GMC (days), mean ± Std	70 ± 15	74 ± 17	73 ± 16	***0.340
*Chi square test; **Fisher's exact test; ***Independent sample t-test				

Figures

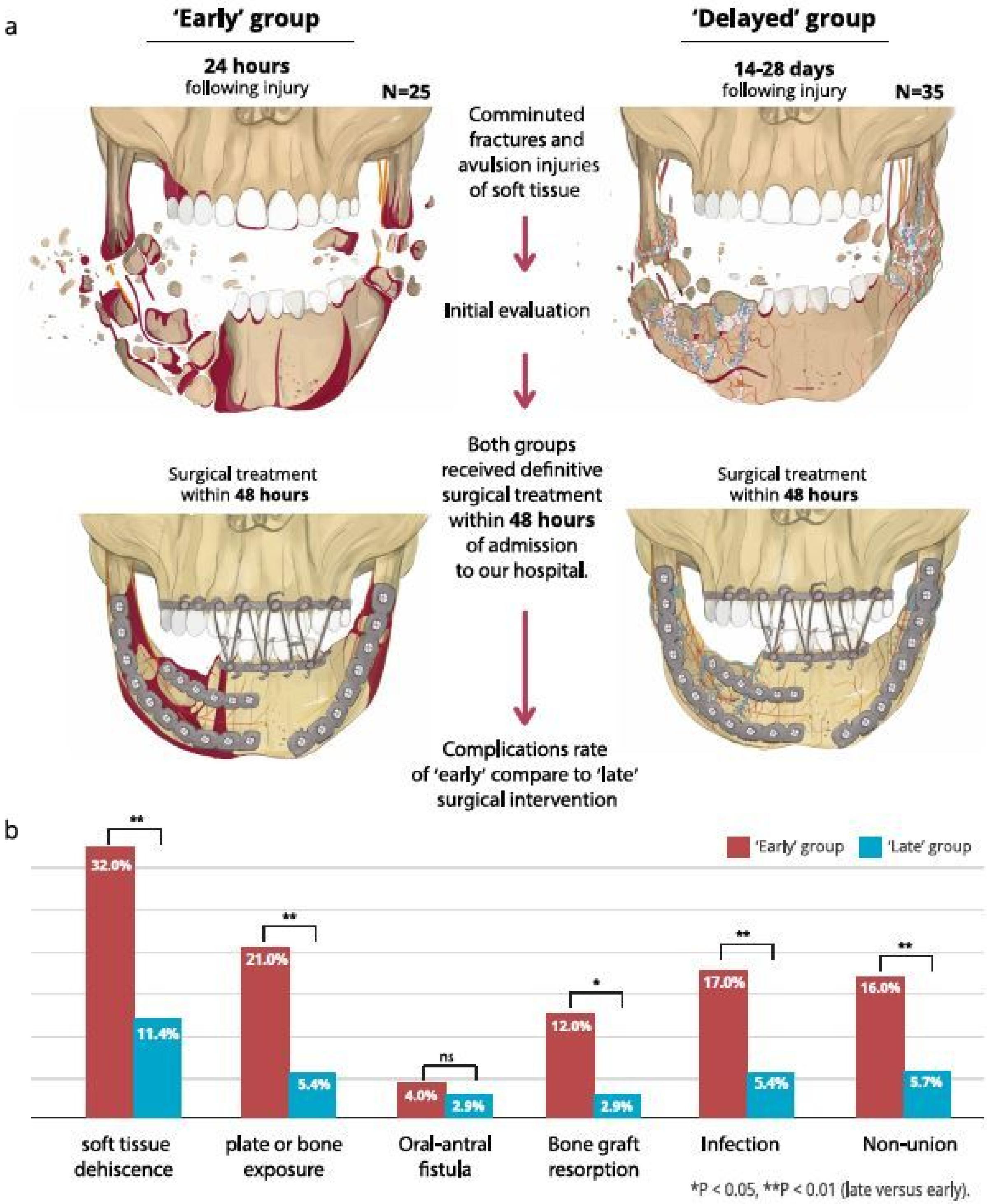

Figure 1

Patient timing of arrival at hospital following "high-velocity" maxillofacial injury and associated rate of post-operative complications