The Le Fort system revisited: Trauma velocity predicts the path of Le Fort I fractures through the lateral buttress

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OBJECTIVE: To examine the effect of trauma velocity on the pattern of Le Fort I facial fractures.

METHOD: A retrospective medical record review was conducted on a consecutive cohort of craniofacial traumas surgically treated by a single surgeon between 2007 and 2011 (n=150). Of these cases, 39 Le Fort fractures were identified. Patient demographic information, method of trauma and velocity of impact were reviewed for these cases. Velocity of impact was expressed categorically as either 'high' or 'low': high-velocity fractures were those caused by a fall from >1 story or a motor vehicle collision; low-velocity fractures were the result of assaults with a blunt weapon, closed fist or falls from standing height. The vertical position of each fracture was measured at its point of entry on the lateral buttress and its point of exit on the piriform aperture. To allow for comparison across individuals, values were expressed as ratios based on their location on the face relative to these landmarks. A Wilcoxon rank-sum test was used to compare the fracture heights caused by high- and low-velocity trauma.

RESULTS: The results revealed that high-velocity traumas to the face create Le Fort I fractures at a higher point in the lateral buttress compared with low-velocity traumas. There was no difference between heights at the piriform aperture.

CONCLUSION: High-velocity trauma resulted in higher Le Fort I fracture patterns compared with low-velocity trauma.

Key Words: Craniofacial; Fracture; LeFort; Trauma; Velocity

René Le Fort's seminal classification system for midface fractures has been the standard for >100 years. This system was developed through direct observation, and incorporates what Le Fort described as "great lines of weakness" in the craniofacial skeleton. Through continued surgical experience, our understanding of the horizontal and vertical buttress systems of the face and their importance for successful reconstruction have become more nuanced (1-3). We also know that many facial fractures do not fit Le Fort's classification (1-8). However, Le Fort's system for the classification of facial fractures remains ubiquitous.

The development of a more sophisticated classification system for facial fractures relies on a better understanding of force distribution in the craniofacial skeleton during trauma. The study of long bones provides an example for which strength and failure points in response to compressive, torsional, tensile and shear forces have been studied extensively (9-12). This detailed understanding has enabled the development of model systems for the femur that accurately classify these fractures and improve reconstruction techniques (11). This level of understanding has not, however, been achieved for the face (13).

The bones of the face are more complex than those in the axial skeleton. The craniofacial skeleton distributes forces over a complex series of buttresses, heavily influenced by musculature (1). Because of

Le système de Le Fort revisité : la vitesse du traumatisme prédit le trajet des fractures de Le Fort I dans la structure latérale

OBJECTIF : Examiner l'effet de la vitesse du traumatisme sur le profil des fractures faciales de Le Fort I.

MÉTHODOLOGIE : Les chercheurs ont effectué une analyse rétrospective des dossiers médicaux d'une cohorte consécutive de traumatisés craniofaciaux opérés par un même chirurgien entre 2007 et 2011 (n=150). De ce nombre, ils ont repéré 39 fractures de Le Fort. Ils ont extrait les caractéristiques démographiques des patients, le mode de traumatisme et la vitesse de l'impact, exprimée la vitesse deux catégories : « haute » ou « faible ». Les fractures de haute vitesse étaient causées par des chutes de plus d'un étage ou un accident d'automobile. Les fractures de faible vitesse découlaient d'une agression à l'arme contondante ou au poing fermé ou de chutes à partir de la position debout. La position verticale de chaque fracture était mesurée à son point d'entrée sur la structure latérale et à son point de sortie dans l'orifice piriforme. Aux fins de comparaison, les valeurs étaient exprimées selon le ratio de l'endroit sur le visage par rapport à ces points de repère. Le test de Wilcoxon a été privilégié pour comparer la hauteur des fractures causées par des traumatismes à haute et à faible vitesse.

RÉSULTATS : Les résultats ont démontré que les traumatismes faciaux à haute vitesse créaient des fractures de Le Fort I situées à un point plus élevé de la structure latérale que les traumatismes à faible vitesse. Il n'y avait pas de différences de hauteur à l'orifice piriforme.

CONCLUSION : Les traumatismes à haute vitesse entraînaient des profils de fractures de Le Fort I situées à un point plus élevé que les traumatismes à faible vitesse.

its complexity, several groups have taken a reductionist approach to studying the face and have focused on individual components in isolation (14-16). These studies also fail to capture the complexity of the facial buttress system. Moreover, when the response of the complete skull to trauma has been studied, it has been to a bare skull or model, which ignores the contribution of the musculature to force distribution (14,17,18). Improved understanding of the response of the intact face to stress is required to develop a better classification system for facial fractures and to improve reconstructive techniques.

Much has changed since Le Fort's original descriptions; most craniofacial trauma now results from high-velocity motor vehicle collisions, often involving young males (2,3,17,19). This change in trauma mechanism and velocity may explain why many fractures observed today do not fit Le Fort's classification. An investigation of the relationship between velocity and fracture pattern in the facial bones would contribute to our understanding of the key concepts of force conduction, stress, tensile strength and failure point as they relate to the loadbearing buttress system in the craniofacial skeleton. The purpose of the present study was to investigate the role of trauma velocity on the pattern of fractures across the lateral and medial buttress of the face. We hypothesized that high-velocity impacts will result in fractures through the lateral and medial buttress that are along a higher plane than lower-velocity impacts.

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Figure 1 Anterior (A) and lateral (B) views of a Le Fort I fracture (red). Fracture location was expressed as a ratio according to vertical position in the piriform aperture (A) or the lateral buttress (B). Horizontal lines drawn from its apex and base defined the piriform aperture (A). The inferior limit of the lateral buttress was defined by drawing a horizontal line from that intersected the maxillary insertion of the second incisor. The superior limit was defined by a horizontal line across the superior aspect of the zygomatic arch (B)

METHODS

A retrospective medical record review of all facial fractures surgically treated by a single surgeon between 2007 and 2011 was performed with the approval of the London Health Sciences Research Ethics Board (London, Ontario). Detailed patient demographic information, including age, previous injury, the nature of the causative trauma and velocity of the impact, were collected for each patient with a fracture. Patients with panfacial or multiple facial fractures were excluded from the study.

Velocity was expressed categorically, as either 'high' or 'low'. For the purposes of the present study, fractures were classified as 'high velocity' if they resulted from a fall from >1 story or high-speed motor vehicle collisions. 'Low-velocity' fractures were those resulting from assaults with a blunt weapon, closed fist or falls from standing height.

Patients with Le Fort I fractures were selected for the present study. For the purposes of the present study, a Le Fort I fracture was defined as any fracture that started at the pterygoid plate, traversed the lateral and medial buttress, and exited at the piriform aperture (Figure 1). For each unilateral Le Fort I fracture, computed tomography images were used to map each fracture's point of entry on the pterygoid plate, position on the lateral buttress and their point of exit on the piriform aperture. To control for differences in individual anatomy, the locations of these points were expressed as ratios comparing their vertical distance from the top and bottom of the piriform aperture or lateral buttress, respectively. The piriform aperture was easily defined using horizontal lines drawn from its base and apex, while the limits of the lateral buttress were defined by drawing horizontal lines from the maxillary insertion point of the

TABLE 1
Fractures encountered*

Fracture type	n
Zygoma	44
Le Fort I	39
Orbit/orbitomax	17
Nasoorbitoethmoid	17
Frontal sinus	10
Mandible	7
Le Fort II	7
Isolated maxillary	4
Le Fort III	4
Total	150

*Number and type of craniofacial fractures surgically treated between 2007 and 2011 by a single surgeon in a tertiary trauma centre

second incisor, and another from the top of the zygomatic arch (Figure 1A).

To enable comparison among subjects while controlling for variations in head size, these limits were used to express fracture locations at the piriform aperture and lateral buttress as ratios of distance from lower limit/distance from upper limit. Here, a location at top of the lateral buttress or piriform aperture would be represented by a ratio of infinity, whereas a point at the bottom would be assigned a score of 0. Thus, a higher ratio indicates a higher relative fracture location. The relative height of fractures at the pterygoid plate was calculated in a similar way in which, again, locations were expressed as ratios of location relative to the upper and lower limits of the pterygoid.

RESULTS

Between 2007 and 2011, 150 facial fractures were treated surgically. The most common operative fractures were zygomatic fractures (n=44) and unilateral Le Fort I type fractures (n=39). The least common operative fracture type were Le Fort 3 (n=4) and isolated maxillary fractures (n=4).

Of the 150 operative facial fractures, 26% were unilateral Le Fort I type fracture patterns (Table 1). The mean age of the reconstructed patients was 40 years (range 16 to 83 years) and the vast majority (92% [36 of 39]) of patients were male. Four patients were edentulous. Of the 39 Le Fort I fractures identified, 17 resulted from high-velocity trauma and 22 from low-velocity trauma.

All fractures of the pterygoid plate, regardless of velocity category, were found to originate in the proximal (ventral) third. The average point of entry at the lateral buttress and the point of exit at the piriform aperture for high- and low-velocity traumas were compared. These data are presented in Figure 2.

At the piriform aperture, there was no difference in relative fracture height generated from high- (ratio = 0.51, SE = 0.05) and low- (ratio = 0.43, SE = 0.05) velocity traumas (Wilcoxon rank-sum Z = 1.1; P>0.05 [two-tailed]). At the lateral buttress, however, fractures resulting from high-velocity mechanisms were located well above the midpoint (ratio = 0.61, SE = 0.04), while low-velocity fractures were below the midpoint (ratio = 0.34, SE = 0.03). This difference was significant (Wilcoxon rank-sum Z = 3.94; P<0.05 [two-tailed]).

DISCUSSION

Through an analysis of 39 Le Fort I fractures, we demonstrated that the relative height of fractures through the lateral buttress varied according to the velocity of trauma. This suggests that because of the complexity of the craniofacial skeletal and muscular systems, facial traumas of different velocities do not simply generate larger fractures at a given location, similar to that observed in simple long bone systems (2,3), but generate fractures that migrate to specific areas of increased susceptibility. These areas of increased susceptibility were alluded to in Le Fort's original description of the "great lines of weakness". Our study, however, was the first to examine these lines in such detail. Moreover, our data suggest that faces fracture in inherently different patterns with different types of impact.

Figure 2) Trauma velocity predicts the relative height of Le Fort I fractures at the lateral buttress. Mean fracture height at the piriform aperture and the lateral buttress are presented. Error bars represent the standard error of the mean. While there was no difference in relative height between high- and low-velocity fractures at the piriform aperture, there was a significant difference at the lateral buttress. *Statistically significant (ie, $P < 0.05$)

While our data suggest that most Le Fort I fractures result from low-velocity traumas, the proportion of high-velocity traumas is nearly 50%. The majority of the high-velocity traumas we observed were the result of high-speed motor vehicle collisions. The subtle, velocity-dependent fracture patterns we observed may only be apparent now because of the relative increase in high-velocity traumas we observed in our data. Ahmad et al (5) suggested that the modern increase in high-velocity trauma mechanisms requires a new classification system.

There have been several recent attempts to develop more accurate systems for the classification of facial fractures (1,4,7,8,17). For example, Catapano et al (4) developed a novel system for grading the severity of facial fractures. Their goal was to provide a metric for future research regarding socioeconomic impact and the true epidemiology of facial fractures. Other studies, have attempted to control the complexity of studying the face in its entirety by studying components in isolation (14,16) or through model systems (15). The results of the current study are unique because they are the first to result from a detailed

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Figure 3) Trauma velocity changes the path of Le Fort I fractures through the lateral buttress. A schematic representation of fractures resulting from high-velocity (green) and low-velocity (red) facial trauma is shown. Results from the present study indicate that high-velocity trauma generates fractures that cross the lateral buttress higher on the maxilla relative to those generated by low-velocity trauma

analysis of fracture pattern relative to trauma energy. By providing a further understanding of stress and fracture points in the craniofacial skeleton, these results further our goal of achieving a greater understanding of the biomechanics of the face.

Compared with related studies, ours benefits from a relatively large sample size. It is also the first to examine a large number of in vivo Le Fort I fractures in this detail. The present detailed analysis has enabled us to validate a method for mapping fractures on the face based on location relative to common landmarks. This has provided us with a way of describing fractures at a high resolution that controls for individual differences in facial size and shape. This will enable us to compare fractures between individuals, and to expand our analysis to complex fractures in the same systematic way.

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