Forensic Science International 266 (2016) 54–62

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

The impact velocity and bone fracture pattern: Forensic perspective

Haim Cohen [a,b,*], Chen Kugel [b,c], Hila May [a], Bahaa Medlej [a], Dan Stein [a], Viviane Slon [a,1], Israel Hershkovitz [a], Tamar Brosh [d]

[a] Department of Anatomy and Anthropology, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv 69978, Israel
[b] National Center of Forensic Medicine, Tel Aviv 61490, Israel
[c] Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv 69978, Israel
[d] Laboratory of Fine Measurements, Dental School of Medicine, Tel-Aviv University, Israel

ARTICLE INFO

Article history:
Received 20 August 2015
Received in revised form 6 February 2016
Accepted 26 April 2016
Available online 7 May 2016

Keywords:
Bone
Fracture
Pattern
Impact
Velocity
Forensic

ABSTRACT

Studies on bone-energy interaction are meager and revealed only a general correlation between the fracture pattern and the mechanism of the insult.

This study has two objectives, to establish a usable fracture analysis method and to reveal the association between the energy of the force and the fracture pattern. Dynatup Model POE 2000 (Instron Co.) low energy pendulum impact machine was utilized to apply impact loading on fresh pig femoral bones ($n = 30$). The bone clamp shaft was adjusted to position the bone for three-point bending with additional bone compression. Three different velocities of the forced applied were carried out. On average, the number, length and the curviness of the fracture lines created under moderate and high-energy impact is significantly higher compared to a low-energy impact. Most fractures lines were located on the impacted aspect in bones subjected to moderate- and high-velocity impact. Four oblique-radial fracture lines running from the point of impact creating a double butterfly pattern were found in bones subjected to moderate and high-velocity impact. Only "false" wedge-shaped (butterfly) fragments were found in the current study. Our results suggest an association between fracture pattern and the velocity of the impact.

1. Introduction

Bone trauma is an important source of information regarding the circumstances that "led" to the death of the victim [1]. Proper fracture interpretation may assist in identifying the location and number of impact sites, establishing the sequence of blows, and determining the characteristics of the object that inflicted the injuries [2,3]. Studies on fracture pattern in the forensic setting are of importance in cases such as homicidal assault, suicide, falls, child abuse, and road traffic accidents. Knowledge on fracture associated with specific modes of trauma can be used to predict the nature of the injury. For example, in cases where homicidal victims and child abuse are suspected, identifying the fracture type may assist in determining the direction of the force and whether the bone was twisted or angulated. In the case of suspected fall, analysis of the fracture pattern may assist in determining the type of fall (simple fall or fall from a height), the surface of the impact, and in some cases, the landing orientation of the victim [4]. Analysis of fracture pattern could also be a useful tool for accident reconstruction purposes [5]. There are a limited number of loading modes to which bone can be subjected, and these results in predictable fracture patterns [6]. These patterns are usually classified into 6 classic types: transverse, oblique or butterfly, spiral, segmental and comminuted. This classification of fracture patterns is derived largely from the medical literature where determination of the stability of the injury, probable extent of associated soft tissue damage, and the prognosis for recovery are the primary motivations [7]. Transverse fracture runs at approximately right angles to the long axis of the long bone [8]. This fracture type can be the result of force producing bending [9] or severe angulations, but not necessarily under compression from the normal weight-bearing functions [7], or the result of force producing tension [10]. Transverse fractures become increasingly more comminuted as a result of direct trauma with progressively greater force. Completed and displaced transverse fractures often

* Corresponding author: Dr. Haim Cohen, Department of Anatomy and Anthropology, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv 69978, Israel. Tel.: +972 3 6409495; fax: +972 3 6408287.
E-mail addresses: haimcoh1@post.tau.ac.il (H. Cohen), chen.kugel@forensic.health.gov.il (C. Kugel), hilamay@gmail.com (H. May), Bahaamedlej@gmail.com (B. Medlej), maadan@gmail.com (D. Stein), slonviviane@gmail.com (V. Slon), anatom2@post.tau.ac.il (I. Hershkovitz), tbrosh@post.tau.ac.il (T. Brosh).
[1] Department of Evolutionary Genetics, Max Planck Institute for Evolutionary Anthropology, 04103 Leipzig, Germany.

http://dx.doi.org/10.1016/j.forsciint.2016.04.035
0379-0738/

result from mechanisms of high energy, such as injuries involving encounters with cars or falls from significant heights [9]. Oblique fractures run diagonally across the diaphysis with short blunt fractures usually ending at a 45° angle with no vertical segment [8,10]. An oblique fracture usually results from the combination of angulation and axial compressive forces of moderate intensity [7] or a combination of torsion and bending (when bending is the dominant loading) [11]. The fracture morphology reflects the predominant loading type (a long oblique is common when torsion is the predominant force or short oblique when the predominant force is bending or compression) [9]. The more common patterns are oblique transverse and butterfly fractures (or indirect wedge-shaped fractures) where the initial fracture is perpendicular to the long axis (representing the failure in tension), while the latter portion is oblique (representing the compression failure). Oblique-transverse and butterfly fractures are commonly seen in the lower extremities when the thigh or calf receives a lateral blow involving weight, as in the case of pedestrians injured by automobiles [10]. Butterfly fractures usually occur at low speed of impact. At higher speeds of impact, "dynamic" noncharacteristic transverse or multifragment fractures are usually observed [4]. Few words about Butterfly fracture are due here as this type of fracture is commonly used in forensic cases for establishing the position of a pedestrian in relation to a motor vehicle [15]. The mechanism of this fracture was the subject matter of Messerer's study in the late 19th century [16]. The rules put forward by him concerning the location of the base of the wedge (from the impact side) and its apex (according to the force direction) has become, from the early 60th of the previous century, a 'standards' in forensic medicine and is treated almost dogmatically both in the literature (especially textbooks) and in practice [15,22–25]. This is surprising considering the growing evidence to suggest the presence of a reversed phenomenon, i.e., the apex and not the base is directed toward the impact site ("false butterfly fracture"), in some of the cases. For example: Spitz and Russell [12] in their study on pedestrian leg impact found that in some cases, even a "false" wedge-shaped fragment may be seen. This observation was repeated by other studies [4,13,14,20]. Rich [4] claimed that a typical bending fracture (Messerer's wedge) can indicates the direction of impact only when the bone was bent at the moment of impact [4]. Already in 1963 Patscheider proved experimentally the possibility of the occurrence of "false" indirect wedge-shaped tibial and femoral fractures by hitting rigidly fixed human and animal bones with weighted pendulum [18]. On 1999 Teresinski and Mydro examined 14 femurs with wedge-shaped fractures following pedestrians' car accidents to evaluate the evidential value of wedge-shaped fractures: in only 50% of the cases a "true" wedge fractures ("Messerer's fractures") were found, 21% of the cases manifested "false" wedge fractures and the rest had the wedge at the impact side [15]. Spiral fractures are caused by rotational forces on the bone [7] or a combination of torsion and bending (when torsion is the dominant loading) [4]. These fractures tend to be the result of low-velocity forces [7] and were produced only from torsional loading in experimental testing of human cadaver long bones [5]. Torsion creates a state of pure shear between parallel transverse planes. In other planes (at other angles with respect to the longitudinal axis), tensile and compressive stresses are present, and they become maximum at a 45° angle to the longitudinal axis [17]. The fracture has long, sharp, pointed ends and vertical segment, which is the last component to form [10], in contrast to the ends of bones in oblique fractures, which are short, blunt and rounded [4]. The direction of the spiral indicates the direction of the torsional forces [10] and can be used to reconstruct the events that produced the fracture [7]. When multiple fractures leave diaphyseal portions separated from the proximal or the distal ends, the intervening segment is called a segmental fracture. This defect may result from multiple simultaneous fractures as would occur when a bone is hit at two points or by a large surface [7]. A comminuted fracture is one in which more than two fragments are generated [8] and usually results from relatively high levels of force [10]. Such fractures are most common in the lower extremity, which is often weight-bearing at the time of impact by an extraneous object. They are commonly seen in the legs of pedestrians hit by motor vehicles. The ability to distinguish between fracture patterns in bones following an impact at different velocities is extremely important. The need for traffic accident reconstruction is of major importance, since road traffic injuries are the leading cause of death worldwide among young people aged 10–24 years (World Health Organization) [27]. Analyses of the lower-extremity fracture patterns are particularly relevant in car-to-pedestrian impacts, since they reflect the actual location of the pedestrian relative to the vehicle and can shed light on the speed of the car when this is in question. It is well known that the greater the magnitude of the force, the higher its energy content, and hence, the more bone destruction. Conversely, the more complex the fracture pattern the greater the energy needed to produce the fracture [10]. A high-energy direct blow to an adult bone will cause a markedly comminuted fracture [13,29] typically associated with extensive soft tissue injury and indicating a large amount of energy dissipation in conjunction with a rapid loading rate [9,30]. Tissues surrounding bone, including muscle, tendons, ligaments, fat, and skin, can affect the fracture pattern by absorbing some of the load energy and also by creating additional load [6]. Studies on bone-energy interaction revealed only a general correlation between the fracture pattern and the mechanism of the insult [31] (cited from Rich [4]). Attempts to determine the crash speed on the basis of the severity of injuries were reported in a text book however this report has yielded no reliable methods of crash speed determination [32]. Text books on bone trauma mostly describe and define fracture types in relation to the direction of loading and loading type applied [7,8,10,33,34]. Studies on the association between the mechanical properties of the bone and physical injury concentrated mainly on microcracking behavior, their location, initiation and propagation [35–39]. These studies however did not explain the correlation between the macrocracking behavior on a whole bone in relation to different types of force applied. Any attempt to predict the behavior of a skeletal region under loading must reflect both the material properties of the bone in that region and its structure [40]. Although there is a consensus regarding the mechanism that produces certain fracture pattern, there are clearly competing theories in the medical literature in relation to others. In addition, most studies analyzing fracture patterns in 3-point bending did not include additional axial compression loading as when the thigh receives a lateral blow during weight bearing, as in the case of pedestrians injured by vehicles. In addition, the information regarding whether the bones were complete or partial during testing, and the precise site of impact is uncertain. Fracture pattern analysis can be a complicated process especially since in most cases the fracture pattern is far from being classic. The determination of the mechanism that results in particular patterns is better approached through experimentation rather than theorizing. Unfortunately, many unsubstantiated theories have been repeated and referenced for decades. Most studies that looked into the micro-morphology of fractures were performed by engineers who were interested in exploring the mechanical properties of bones. Physicians, on the other hand, were more interested in the macro-morphology of fractures (classification of fracture patterns), where prognosis for recovery and fixation are of major concern. Currently, there is no a single study that has examined, in a comprehensive way, the morphological and metrical characteristics of fractures in regard to the impact energy of the force applied in a forensic perspective, simulating a situation occurring in pedestrian road traffic accidents.