PREDICTING ZYGOMA FRACTURES FROM BASEBALL IMPACT

Joseph M. Cormier[1], MS, Joel D. Stitzel[1] , MS, William J. Hurst[1], BS,
David J. Porta[2], PhD; Jeryl Jones[3] DVM, Stefan M. Duma[1] ,PhD

[1]Virginia Tech – Wake Forest Center for Injury Biomechanics
[2]Dept of Biology, Bellarmine University
[3]Dept of Small Animal Clinical Sciences, VMRCVM, Virginia Tech

ABSTRACT

The purpose of this study is to develop injury risk functions that predict zygoma fracture based on baseball type and impact velocity. Zygoma fracture strength data from published experiments were mapped with the force exerted by a baseball on the orbit as a function of ball velocity. Using a normal distribution, zygoma fracture risk functions were developed. Experimental evaluation of these risk functions was performed using six human cadaver tests and two baseballs of different stiffness values. High speed video measured the baseball impact velocity. Post test analysis of the cadaver skulls was performed using CT imaging including three-dimensional reconstruction as well as autopsy. The developed injury risk functions accurately identify the risk of zygoma fracture as a result of baseball impact. The experimental results validated the zygoma risk functions at the lower and upper levels. The injuries observed in the post test analysis included fractures of the zygomatic arch, frontal process and the maxilla, zygoma suture, with combinations of these creating comminuted, tripod fractures of the zygoma. Tests with a softer baseball did result in injury but these had fewer resulting zygoma bone fragments and occurred at velocities 50% higher than the major league ball.

Keywords: zygoma, orbit, baseball

INTRODUCTION

Little league baseball is the most popular sport among youth athletics, as approximately 16 million children participate in some form of organized baseball in the United States.[1] The average annual injury rate between 1994 and 1998 among children 5 to 14 years of age was 103,731 per year.[1] Facial fractures resulting from baseball impact can have detrimental effects on the skeletal structure of the face. In particular, a zygoma fracture can present injury to the facial structure as well as the orbit.[2-5] Preventing these injuries in organized sports like baseball is accomplished through protective equipment and the use of balls with a lower stiffness. The benefit of these devices can be improved if the forces necessary to cause injury are known as a function of ball characteristics.

The zygoma has been the focus of previous research due to the prevalence of facial injuries in sporting and automotive events.[6-13] Previous experimental work has been performed on cadavers using rigid impactors in order to determine fracture tolerances.[9,10,12] The purpose of this study was to develop risk functions to predict the probability of zygoma fracture from impact with a baseball.

METHODS

The methods are divided into two parts. The objective of part one was to develop risk functions for zygoma fracture from baseball impact. The objective of part two was to evaluate the validity of the risk functions by performing experimental tests on human cadavers.

Presented at Rocky Mountain Bioengineering Symposium &
International ISA Biomedical Sciences Instrumentation Symposium
7-9 April 2006, Terre Haute, Indiana, www.isa.org

Part 1: Zygoma Fracture Risk Functions

In order to develop functions for predicting the risk of zygoma fracture, published research on the breaking strength of the zygoma was utilized. Three studies that performed impact tests to the zygoma were selected. Hodgson, Nahum *et al.*, and Schneider and Nahum used rigid impactors to determine the breaking strength of the zygoma to dynamic impacts (Table 1).[9,10,12]

Table 1: Peak Forces (in Newtons) Resulting in Zygoma Fracture

Nahum (1968)			Schneider (1972)	Hodgson (1967)
1828	1971	1397	1580	1762
1477	1628	1068	1140	2882
2740	3470	943	970	1735
2816	2304	1548	2850	1601
1406	1014	1699	1910	
1891	912	1859	1630	

A cylindrical rod with an area of 1 in^2 was used in the three tests to impact the zygoma of the cadaver subjects. The force during impact was recorded using load cells attached to the cylindrical impactors. This compilation yields a sample size of 28 data points to use for the development of the zygoma fracture risk functions.

It was assumed that the distribution of zygoma strength for the human population has a normal distribution. Therefore, the sample of strength data (x) was assumed to have a normal distribution of mean (μ) and standard deviation (σ) described by the normal distribution function (Equation 1). The data was also assumed to be non-censored values of the force resulting in zygoma fracture. The cumulative distribution function represents the probability that a given value of force will cause a zygoma fracture. This relationship was obtained by integrating the normal distribution function, using the error function (erf) for each value of applied force (Equation 2). This has no closed form solution, however, the risk of fracture can be determined for any value of impact force by integrating the density function at the desired force. This process resulted in a relationship for risk of zygoma fracture based on the exerted force alone.

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)} \qquad \text{Equation (1)}$$

$$D(x) = \frac{1}{2}\left[1 + erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right] \qquad \text{Equation (2)}$$

A more useful relationship was obtained by mapping the force exerted by the baseball at a range of speeds to the strength data. Therefore, the force exerted by the baseball when striking an object was necessary to develop the risk functions. Experiments by Vinger *et. al.* (1999) determined the force exerted onto an orbit from baseball impact.[13] Load cells in an artificial orbit measured the force during baseball impacts at a range of impact velocities. The artificial orbit was mounted on a sliding table to allow reward motion following impact. Vinger *et. al.* (1999) used a variety of balls having Compression Displacement (CD) ratings of 25 to 291. The CD rating for a baseball is determined by compressing the ball 6.35 mm (0.25 in) between two flat plates. The displacement must be obtained within 12 to 15