MECHANICAL RESPONSES IN TRAUMATIC CERVICAL SPINE INJURIES BY HIGH-SPEED IMPACT

G. L. Chang, K. H. Tsai, *R. M. Lin

Institute of Biomedical Engineering, Department of Orthopedics, Medical Center*, National Cheng Kung University, Tainan, Taiwan

INTRODUCTION

Cervical spine fractures are among the most serious orthopedic injuries and often have devastating effects on the individual's quality of life. In particular, burst fractures are associated with a high risk of quadriparesis. Axial loading has long been considered to be the mechanism of burst fractures, the bony pattern of vertebral injury has been well described, and is often associated with bone fragments in the canal and varying degrees of neurologic deficit.(1,2,3,4)

In the engineering literature, the majority of impact research was motivated by the automotive industry and involved studying the response of human simulators. Willen (1) conducted biomechanical studies of the thoracolumbar cruch fracture using a drop-weight technique on fresh cadaveric three-vertebrae segments. But crush fractures were rarely found in clinical conditions. Southern and Panjabi (2) used serial impacts of increasing weights on the same specimen to produce different kind of fracture models including extension-compression, flexion-compression and pure compression trauma. However, multiple impacts make the results away from the fact. From the above reports, it is difficult for us to select the accurate mass for high speed impact. And during the testing, it is also difficult for us to judge the fractures if they occurred.

In this study we attempted to produce clinically relevant fractures in the porcine cervical spine under high speed trauma and put the emphasis on the difference of disc deformation between fractured and non-fractured specimens. The loading-time curve and BMD(bone mineral density) of fractured and non-fractured specimens during trauma were also documented.

MATERIALS AND METHODS

A total of ten fresh, frozen lower cervical porcine spines (Landrace in species) with average age of two and half years old were obtained from local abattoir. The specimens (C3-C5) were dissected of all soft tissue, leaving the ligaments and intervertebral discs intact. In order to obtain a stable fixation, the vertebrae C3 and C5 were embedded in a two-component polyester based resin in a circular plastic mould. To measure specimen deformation of vertebral body and disc, during trauma, several steel balls (1/16" diameter) were glued, using cynoacrylate, onto the cleaned surface at the anterior and posterior halves of each superior and inferior end-plate.

After specimen preparation, CT and radiography were emploied to determine the QCT values of the middle vertebrae (C4) and check the conditions of the specimen whether intact or not before impact. Then all specimens were subjected to high-speed impact trauma and followed by CT and radiography again to detect the fracture pattern. Finally, the time-force and time-deformation curves of

fractured and non-fractured groups were caculated by sequential data and high speed film digitization, and comparison of BMD and above curves between fractured and non-fractured groups were made.
To produce and record the high-speed spinal trauma, the specimen was mounted on a platform eccentrically below a guided drop mass. The 10 kg mass used in this study was raised to a hight of 1.75 m above the specimen. This height corresponds to an impact velocity of 5.86 m/sec under frictionless conditions. To simulate the flexion-compression trauma, eccentric impact was designed by shifting the cylinder 2 cm anteriorly from the geometric center position. On the platform below the specimen was placed a 3 component load cell to measure the external force. A high-speed camera was placed to the side of the specimen and filmed the sagittal plane motion during trauma at 2,500 frames/sec.

RESULTS

The mean values of the mechanical responses and CT evaluation of cervical spine in high-speed impact trauma were summarized in Table 1. The mean values of BMD and maxmal force of the fractured group were 331.3 g/cc and 10844 nt, respectively, however in non-fracture group were 408.0 g/cc and 14311 nt. There were six specimens fractured in total ten cervical spine. They usually happened on the lower vertebrae, that is, C4 or C5.
The typical force-time of fractured and non-fractured groups of cervical spine during high-speed impact were illustrated in figure 1. In force-time curves of fractured group, there was a steep downward decline in the midway, therefore there were two peaks in the curves. The time of sequence of fracture took about 21.5 ms which was much longer than that of non-fractured one which was 17.2 ms.
From the digitized high-speed move film, the steel balls were digitized for the changes of disc height during high-speed impact. In fractured group of anterior disc, the upper disc (C3-C4) deformed a little and regained the height later while the lower disc (C4-C5) deformed large permanently (figure 2). In non-fracture group, however, the height of upper and lower discs were deformed only slightly during high-speed impact.

DISCUSSIONS AND CONCLUSIONS

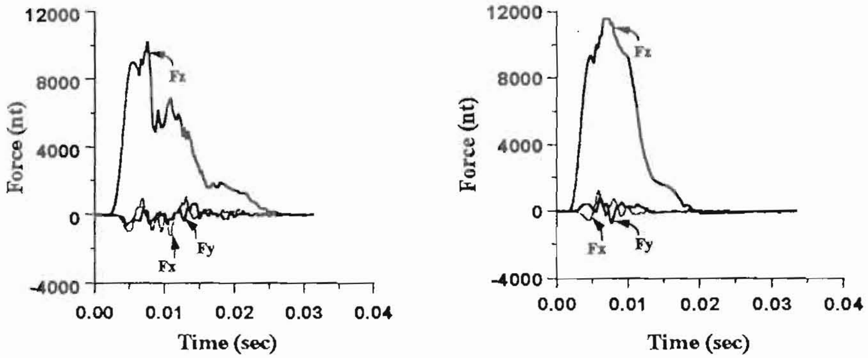
The mean value of BMD of fractured group was 331.3 g/cc, that of unfractured group was 408.0 g/cc. The larger value of BMD, the higher strength of bone. Even in high speed-impact model of cervical spine, fracture were also easy to occur in the specimen of lower BMD. In the force-time diagram of fractured group, there were two peaks in the curve obviously. In this study, a high-speed impact to cervical spine may result in fractures of end-plate, body or pedicle and/or facet joint subluxation. We can't sure the serial order of fracture events at first and second peak in the curve of fractured group, but there was a great difference with non-fractured group that just had one peak in the maximal force-time curve (Fz).
In the deformation-time curve, the disc in C4-C5 of fractured group were always larger deformity than that of non-fractured group. This also was a great difference between fractured and non-fractured groups and could be a good guide as well as force-time curve to judge whether the specimen was fracture before the detection

of CT and X-ray. The discs of non-fractured group and C3-C4 of fractured group were deformed slightly and recovered later during high-speed impact. Maybe the incompressible nature of disc was present even in high speed impact.

In the past reports, some studies demonstrated that the selection of suitable specimens is the first important step for reproducibly simulating vertebral burst fractures *in vitro*. They claimed that burst fractures were consistently created in specimens from individuals of less than 40 years of age, and in good physical condition. In this study, although we used porcine cervical spine with two and half years old to subject high-speed impact trauma, the force motived relevant fracture patterns were identically with human beings. From the above results, porcine spine should be not less suitability than human beings in biomechanical testing (static or high-speed impact testing), if the species and age were selected.

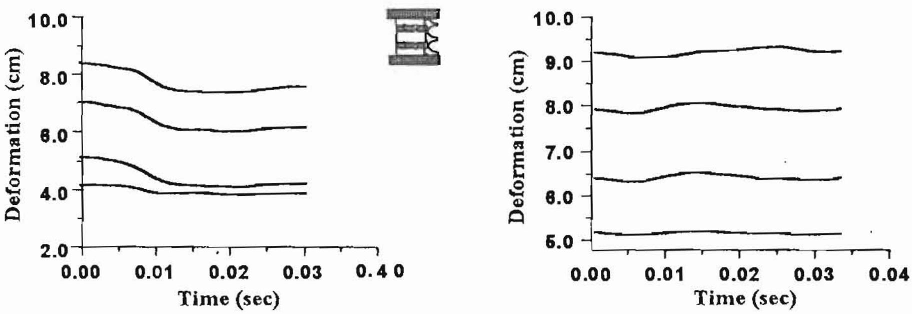
Table 1. The comparison of the mechanical responses and CT evaluation between fractured and non-fractured groups by high-speed impact trauma.

Preparation no.	BMD (g/cc)	Max. force (nt)	Impact time (ms)	Fracture pattern	
Fracture					
#2	306.8	11625	21	C3	bursting
#3	329.6	11304	24	C5, superior	endplate + pedicle
#5	388.4	10654	19	C4, inferior	bursting,
#7	311.7	9907	24	C4	facet joint + pedicle
#8	326.9	11385	20	C4, inferior	bursting + pedicle
#10	324.2	10194	21	C4, inferior C5, superior	pedicle fracture + dislocation
Mean (SD)	331.3 (29.4)	10844 (700)	21.5		
Non-fracture					
#1	441.9	17011	18	no fracture	
#4	383.7	11620	18	no fracture	
#6	372.6	13427	17	no fracture	
#9	433.9	15187	16	no fracture	
Mean (SD)	408.0 (34.9)	14311 (2315)	17.2		



a. fracture b. non-fracture

Figure 1. Typical force-time curves of servical spine during high-speed impact trauma. There are apparent differences between a. fractured and b. non-fractured groups.



a. fracture b. non-fracture

Figure 2. The deformation-time curves of anterior discs of servical spine during high-speed impact trauma. a. fractured and b. non-fractured groups.

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