STRAIN ANALYSIS OF JEFFERSON FRACTURE IN CADAVER MODEL

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ABSTRACT:

An atlas bone of a male cadaver of person who had died of ishemic hearth attack 9 months ago at the age of 39 was extracted to testing the biomechanical data of the model. Strain gauges which are able to measure strain were mounted on internal and external surfaces of anterior arc and on upper and lower surfaces of posterior arc. Consequently, a shortening of between -7.3×10^{-6} and -387×10^{-6} in the exterior surface of anterior arc and lengthening of between 103×10^{-6} and 488×10^{-6} in the interior surface of anterior arc were observed. The value of lengthening was between 124×10^{-6} and 453×10^{-6} in the upper surface of the posterior arc while the value of shortening was between -89×10^{-6} and -303×10^{-6} in the lower surface of posterior arc. These data prove mathematically that atlas fracture caused by axial loading first described by Jefferson, is a burst fracture.

Keywords: Cadavers model, Jefferson fracture, strain analysis

INTRODUCTION

Experimental injuries in the cervical spine have been generated using whole cadaver (15) (Table 1) or the cervical spine specimen (4) (Table 2)

Table 1. Experimental cervical spine trauma in the whole cadaver.

Study	Loading Force (N)	Neck Position	Loading Velocity (m/sc.)	Loading Direction
Yoganandan	3000 - 14700	Neutral	4.2 - 5.4	Axial
Nusholtz	3200 - 10800	Flexion	4 - 5.9	Axial
Alem	3000 - 17000	Neutral	7 - 11	Axial

Table 2. Experimental trauma models in the cervical spine speciemen

Study	Loading Force (N)	Neck Position	Loading Velocity (m/sc.)	Loading Direction
Bauze & Ardran	1420	Flexion	Unknown	Axial
Mc Elhany	960 - 6840	Neutral	0.64	Axial
Maiman	645 - 7440	Neutral/Flexion/Extension	0.025 - 1.52	Axial

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In this type of experimental study, cervical spine deformation (ligamentous or bone injury) might bear a different load response due to various related factors of loading duration and frequency, loading force, application site, loading direction and the position of cervical spine, head and thorax before loading. The most severe displacement of cervical spine was observed during a flexion position of the neck under axial loading pressure.in experimental cadaveric studies in which different positions of head, neck and thorax under axial pressure (loading onto the head or hitting a strong surface with head) were investigated (4,12,16,17).

MATERIAL and METHODS

Cadaver model: Model Formation: An atlas bone of male cadaver of a person who had died of ishemic hearth attack 9 months ago at the age of 39 was extracted to testing the biomechanical data of the model. The bone was isolated from surrounding soft tissue, ligaments and medulla spinalis.

Measurement technique and loading conditions: Strain gauges which are able to measure strain were mounted on internal and external surfaces of anterior arc and on upper and lower surfaces of posterior arc (in x and y plans). Strain gauges used (HBM, Spectris Messetechnick GmbH, Germany) has the property of electrical resistance with gauge resistance of 120 Ω, gauge factor was 2 and gauge length of 4 mm (Figure 1).

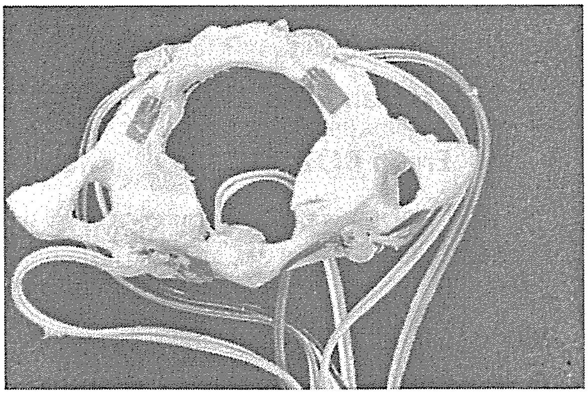


Figure 1. Strain gauges on the anterior and posterior arcs of the atlas.

Mechanical loading on strain gauge caused a change in electrical resistance, of which values were recorded via Wheatstone bridge. Metylmetacrylate models of upper and lower surfaces of the bone were made. The bone was placed between the upper and lower models and axial static forces of 200, 400, 600, 800,1200 Newton were applied upon upper model by an electrohydrolic test machine (Instron Corp, Canton Minnesota).

RESULTS

Values of axial static pressure forces of 200, 400, 600, 800,1000,1200 Newton applied on cadaveric atlas bone and strain gauges mounted on anterior and posterior bone surfaces within plans of ± X and ± Y were recorded (Table 3).

Table 3. Observed values of the strain ($\varepsilon \times 10^{-6}$) under different axial forces.

	Force (N)					
	200	**400**	**600**	**800**	**1000**	**1200**
Anterior arc exterior	-73	-123	-184	-250	-320	-387
Anterior arc interior	103	168	242	324	410	488
Posterior arc superior	124	196	264	320	368	453
Posterior arc inferior	-89	-140	-185	-217	-245	-303

Positive values strain on bone surfaces lengthening while the negative value represents bone shortening.

DISCUSSION

The first cervical vertebra (C1), which carry the head is designated as atlas of mythology of Greek origin which was punished by Zeus to carry the world over his shoulders(3). The distinct anatomical fëature of atlas as compared to other parts of the spine is the lack of vertebra corpus. It supports head through condylarthrotic joint formed with occipital condyles to which superior articular facets stacked. Inferior articular facet forming a diarthrotic joint with axis has a smooth surface while the joint surface on the back facet of anterior arc which enables atlas rotate of 30 degrees has a concave shape. Atlas bone has an abundant of cortical structure while the highest amount of bone mass is found in lateral masses. Anterior and posterior arcs connecting lateral masses are very thin bone laminae. Transverse ligament which strengthens the joint between odontoid and anterior arc via attaching to the internal surface of lateral mass is the most prominent ligament of this region. Since the atlas is embedded in neck muscles, it does not directly encounter the injury, it is affected by blow as to the head position during blow and the orientation of the force applied to the head.

Atlas fractures are frequently caused by axial loading. In this type of injury described by Geoffrey Jefferson in 1920, the load is oriented to lateral masses(7). Axial loading causes an exterior deviation of lateral masses via concave structure of superior articular facets, the load is also envied to anterior - posterior arcs, transverse ligament and axis. Since anterior and posterior arcs are thin layers of bone, they are more prone to fracture. Since the bones fractured into 3-4 pieces in the arc are pulled outwards, they do not exert a pressure on spinal cord (5,6,8,9,10,11). As to the clinical importance, cervical spine injuries are generally caused by axial loading (1,2,17). In this type of loading, the pressure is mainly applied on bone and ligament rather than on muscles (12,17). Thus, as the force is increased, a strain emerges on transverse ligament in addition to fractures in anterior and posterior arcs. In cadaver studies, it has been found that when outwards dislocation of lateral masses exceeded 6.3 mm transverse ligament couldn't resist the strain and ruptured (14). Cadaver models are the most frequently used models in spinal biomechanical experiments. Although cadaver models are true-like imprints, they bear a number of drawbacks such as difficulty of obtaining the material, limited usage and non-repeatability of the test on the same specimen.

In experiments of cervical spinal injury static or dynamic forces have been applied to a segment of the neck (functional spinal unit) head or to the head -neck complex. Dynamic load causing bone or ligament injury in bone model in which an axial load was applied was around 500-700 N (4,12,16,17) while those causing cervical spinal injury in head -neck complex models was around 3000-17000 N (4,15) loads were applied in a dynamic manner with defined velocity in a given time. The dynamic load of 3.2-5.7 m/sc. in velocity was generally applied so that the experiments resembled the accident in daily life. In this type of experiment, immediate loads could cause more extensive injury with less force. Dynamic forces could be replaced by static ones if the resistance of material is to be tested. Static loads are applied independent of time and velocity and the force required for the

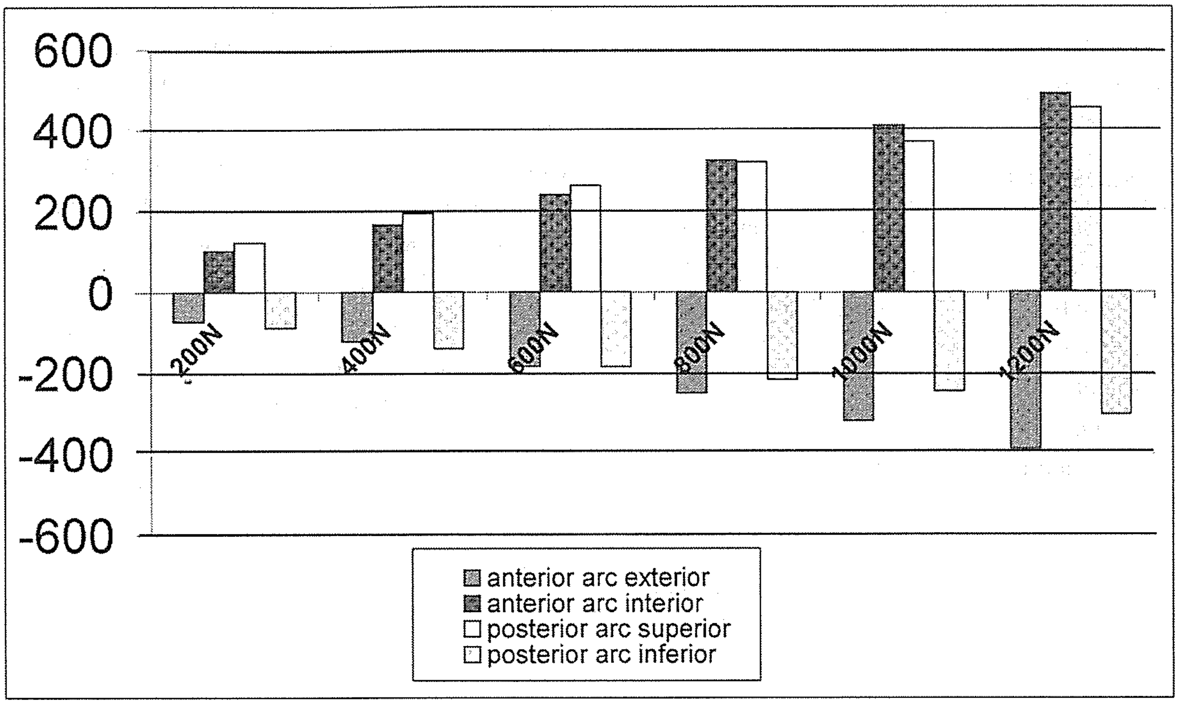
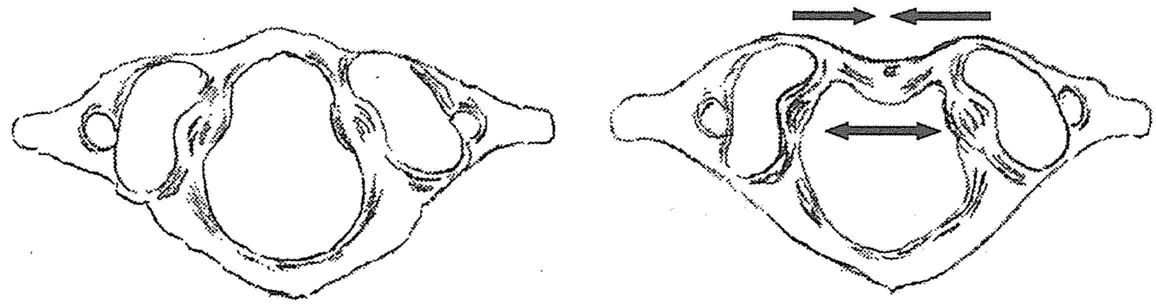


Figure 2. Measured values of strain on the anterior and posterior arcs of atlas under different axial loadings.

transformation of elasticity to the plasticity is generally bigger than the one applied in dynamic loading.

Dynamic loading has no implication when the resistance of a single material of a functional unit such as atlas is to be recorded due to the fact that the aim is to reveal the mechanic response of vertebra to axial force vectors instead of generating spinal injury. Selection of the force to be applied was realised taking into consideration of force values calculated for transverse ligament injury. The axial load required for transverse ligament rupture was found to be 340-1040 N (14). Atlas fractures are considered as instable in the case of transverse ligament rupture (13,14). In this study, strain analysis on atlas fractures of both stable and instable nature in term of the clinical entity was realised via loads of 200-1200 N.

No data yet existed on biomechanical investigation of atlas bone under static load. Strain gauges were mounted on internal and external surfaces of anterior arc and upper and lower surfaces of posterior arc which are potential locations prone to fracture. Since strain gauges were mounted horizontally to fracture lines, changes of form occurred in these sites of bone during axial loading were measured in single dimension (± X or ±Y). Consequently, a shortening of between -7.3×10^{-6} and -387×10^{-6} in the exterior surface of anterior arc and lengthening of between 103×10^{-6} and 488×10^{-6} in the interior surface of anterior arc were observed. The value of lengthening was between 124×10^{-6} and 453×10^{-6} in the upper surface of the posterior arc while the value of shortening was between -89×10^{-6} and -303×10^{-6} in the lower surface of posterior arc (Figure 2-3-4).



A B

Figure 3. Exterior surface shortens while interior surface lengthens.

A: Pretrauma

B: Under axial loading

A B

Figure 4. Upper surface of the posterior arc lengthens while lower surface shortens.

A: Pretrauma

B: Under axial loading

These data prove mathematically that atlas fracture caused by axial loading first described by Jefferson, is a burst fracture.

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