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ORIGINAL ARTICLE

Modelling Thoracolumbar Fractures in Goat Vertebrae Based on Axial Compression Force

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Abstract

Background/Aim: A profound understanding of the biomechanics underlying thoracolumbar animal models has become important in spine research. Aim of this study was to analyse difference in thoracolumbar fractures based on height loss caused by axial compression force.
Methods: This *in vitro* study used a randomised post-test only control group design. This study used goat vertebrae to make thoracolumbar fracture models based on axial compression force. Samples were divided into three groups on a single vertebral body and three groups on a single functional spinal unit (FSU). Axial compression force was applied to vertebrae and FSU, reducing height by 20 %, 40 % and 60 % in different test groups.
Results: This study showed that the crushing pressure in one vertebra was approximately 4565.76 ± 722.93 Pa and in one FSU, it was approximately 5070.4 ± 703.74 Pa. Different fractures were seen based on height loss. In the 20 % loss group, nine types of wedge fractures were found. In the 40 % loss group, two types of wedge fractures and seven incomplete burst fractures were observed. The 60 % loss group had nine types of complete burst fractures in single corpus testing, two incomplete burst fractures and seven complete burst fractures in single FSU testing.
Conclusion: There were differences in fracture configurations in goat vertebrae based on the height loss due to compression force in the single corpus and FSU.

Key words: Compression fractures; Goats; *In vitro*; Spinal fracture; Medicine.

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Introduction

Almost 90 % of all spinal injuries occur in the thoracolumbar region. Most patients with thoracic and lumbar injuries are young men engaged in high-energy activities. More than 50 % of fractures occur between T11-L1. Approximately 50 % of thoracolumbar fractures are unstable and can lead to significant anatomical injuries, deformities and neurological deficits.[1]

The widely accepted classification system for thoracolumbar spinal injuries still needs to be improved due to the complexity of spinal anatomy, different treatment strategies and the need for a balance between completeness and user-friendliness. Current systems, such as the *Arbeitsgemeinschaft für Osteosynthesefragen* (AO) and Denis classification systems, need to be simplified and more user-friendly. The severity of injuries increases continuously, creating a grey area where treatment modalities such as conservative vs surgical, posterior vs anterior instrumentation and fusion vs non-fusion are still debated.[2]

A profound understanding of the biomechanics underlying thoracolumbar fractures is required for optimal operative management.[3] A modern classification system should incorporate current understanding of biomechanics and modern imaging modalities, achieving a balance between comprehensiveness and simplicity, guiding general treatment guidelines and possessing good intra-observer and inter-observer reliability among physicians of various specialisations and training levels.[4] Unfortunately, there has not been an equal level of attention in studying the biomechanics of thoracolumbar spine injuries.[5]

The human cadaver spine is an ideal model for biomechanical studies and testing of implants, especially in terms of anatomy and size. To simulate clinical situations as closely as possible, spinal implants can be tested *in vitro* on human cadaver segments. However, there are several challenges associated with using human specimens, such as significant variations in geometry, obtaining samples from well-preserved cadavers (healthy population), difficulty in obtaining human samples (especially from younger populations) and the availability of human cadaver spine samples in terms of quantity. Therefore, most *in vitro* experiments have been conducted on animal spines, which are more readily available and have more uniform geometric properties. Animal models have become an important research method in spinal surgery.

Animal models are divided into small animals (mice, rats and guinea pigs), medium-sized animals (rabbits, cats, small pigs and dogs) and large animals (horses, sheep and goats).[6] For spinal biomechanics research, larger animals are more suitable. Goats are an ideal choice due to their ease of availability, affordability and fewer ethical concerns than other large animals. Primate animal models are not considered due to potential ethical issues, given their emotional closeness to humans. Based on the limited research discussing the biomechanics underlying thoracolumbar spinal fractures and the importance of knowledge about the injury mechanism for achieving optimal therapy, the researchers were interested in conducting a study by creating a fracture model on goat spines based on displacement/height loss produced by axial compression force.

Aim of this study was to analyse difference in thoracolumbar fractures based on height loss caused by axial compression force. This study used goat vertebrae to make thoracolumbar fracture models based on axial compression forces.

Methods

This study was an *in vitro* experimental research with a randomised post-test only control group design conducted on goat spines. This design assumes that each unit's population was homogeneous, with similar characteristics for each population.

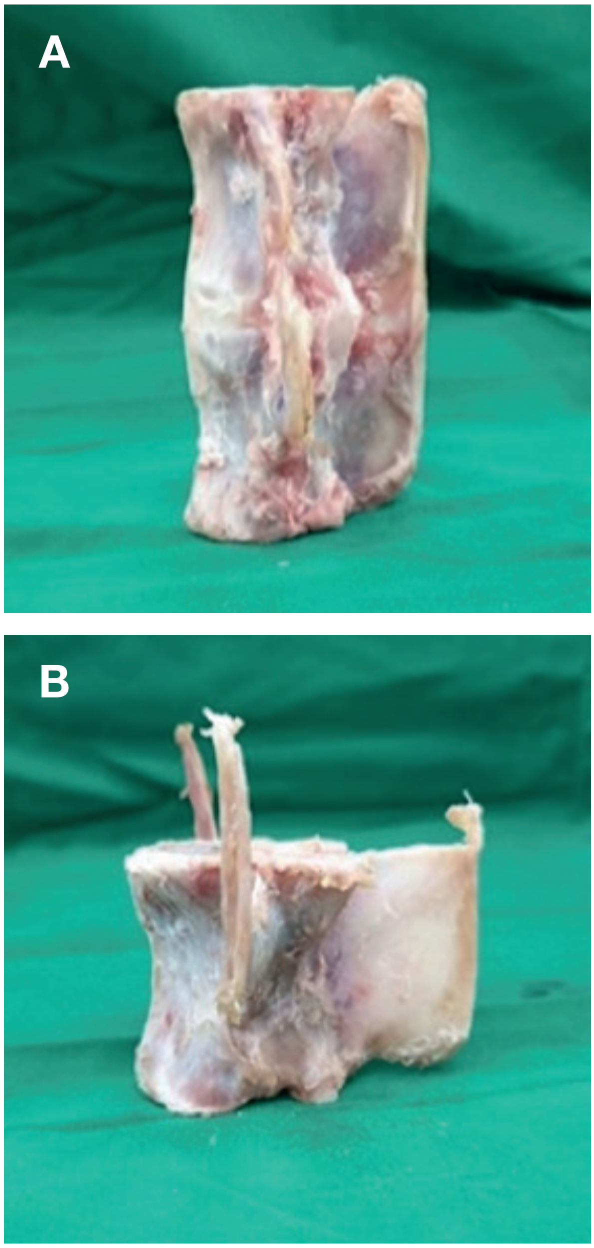

Figure 1: A) Single functional spinal unit (FSU); B) Single corpus;

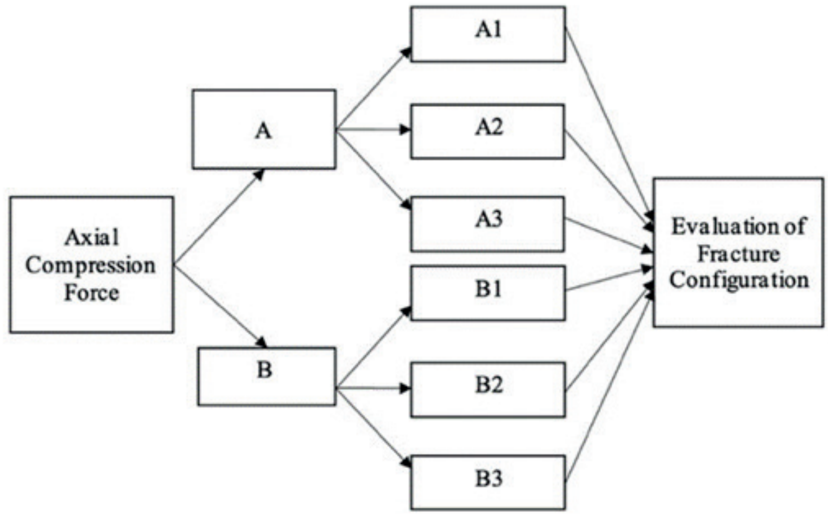

Figure 2: Research flow

The samples were divided into three groups on one vertebral body and three on one functional spinal unit (FSU) (Figure 1). In group test A, vertebrae (L2 vertebrae) were subjected to axial compression force until reduced by 20 % (A1), 40 % (A2) and 60 % (A3) of the vertebral height. Similarly, in group test B of the FSU (T13 – L1 vertebrae), axial compression force was applied until reduced by 20 % (B1), 40 % (B2) and 60 % (B3) of the vertebral height (Figure 2).

Inclusion criteria for the samples in this study were adult goats, not deceased due to illness and not imported goats. The exclusion criteria included young goats, non-local goats and goats with a history of diseases. The sample collection involved thoracolumbar goat vertebrae obtained from a slaughterhouse. The goats selected were approximately 1.5-2 years old males. A total of 27 pieces were collected to meet the required sample quantity in each group. Each thoracolumbar goat vertebrae was cleaned from attached muscles and disarticulated according to the spine segment to be tested.

The vertebral endplates were cleaned from attached discs until completely clear and the facets were cut and aligned with the height of the superior and inferior endplates. The spinal canal was also cleaned from its spinal cord. The bones were grouped, wrapped in gauze soaked in normal saline and placed in plastic bags. The plastic bags containing the vertebrae were stored in a freezer at -20 °C.

The grouped vertebrae were measured and the height of each was recorded (Figure 3A). Then,

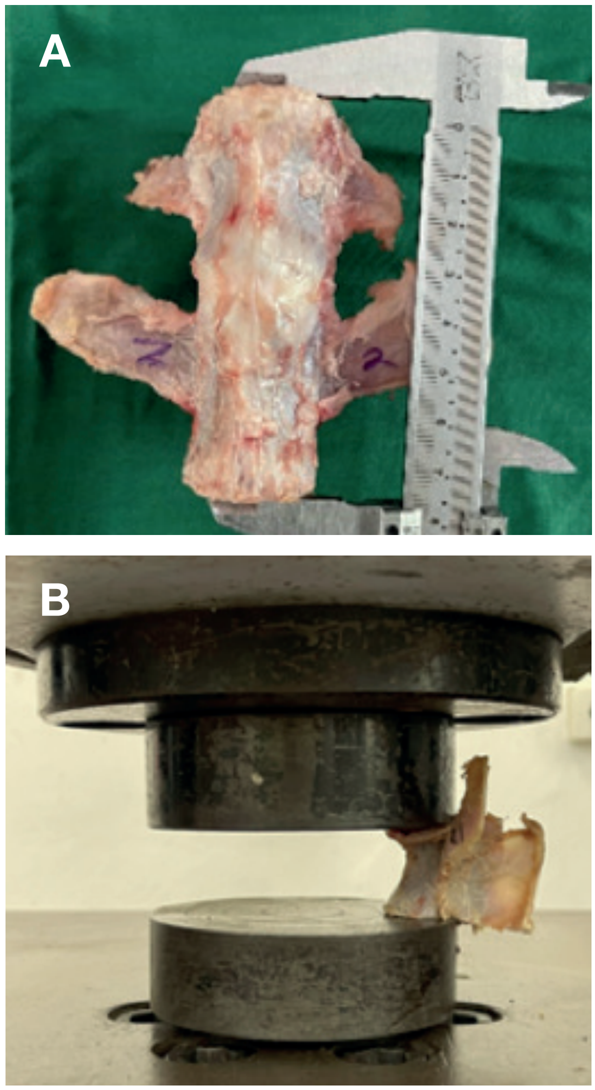

Figure 3: A) Measured height of single function spinal unit (FSU) using Vernier callipers; B) Single corpus after applied compression in hydraulic press

the height loss/displacement to be tested was calculated, which was 20 %, 40 % or 60 % of the vertebral height. The vertebrae and FSU were subjected to compression testing using a hydraulic compression machine at a speed of 0.25 mm/s (Figure 3B). The vertebral body was placed at the edge of the compression testing apparatus to apply compression force and displacement specifically to the vertebral body. Once the displacement reached the target, the machine was stopped and replaced with the next sample. The results of each group (one vertebra and one FSU) subjected to compression testing with 20 %, 40 % and 60 % displacement were evaluated for the type of fracture that occurred and recorded.

The variables in this study were the displacement and fracture configuration that occur in the spine. Displacement is the distance of the force acting parallel to the axis of the body, measured on a nominal scale. The fracture configuration was the type of fracture experienced by one vertebral bone, measured on a categorical scale based on AO scale.

The collected data was statistically analysed using SPSS software version 26.0. The significance level (α) was set at 0.05 and results were considered significant if p-value < α (0.05). Since this study involved quantitative data, the Chi-square test was employed and if not met, the Kolmogorov-Smirnov test was used for data processing.

Results

The crushing pressure of each vertebra sample was recorded. It was found that in a sample of one vertebra, the crushing pressure was 4565.76 ± 722.93 Pa (Figure 4), while in 1 FSU, the crushing pressure was found to be 5070.4 ± 703.74 Pa (Figure 5).

Compression was performed until a height loss of 20 %, 40 % or 60 %. The testing groups were divided based on whether the testing was conducted on single vertebra or FSU. In the single vertebra testing, nine types of wedge fractures were found in the 20 % height loss group, two types of wedge fractures and seven types of incomplete burst fractures in the 40 % height loss group and nine types of complete burst fractures in the 60 % height loss group. No other fracture types were observed in the 20 % and 60 % height loss groups and no complete burst fractures were found in the 40 % height loss group.

In the FSU unit testing, nine types of wedge fractures were found in the 20 % height loss group, two types of wedge fractures and seven types of incomplete burst fractures in the 40 % height loss group and two types of incomplete burst fractures and seven types of complete burst fractures in the 60 % height loss group. No other fracture types were observed in the 20 % height loss group, no complete burst fractures were found in the 40 % height loss group and no wedge fractures were found in the 60 % height loss group.

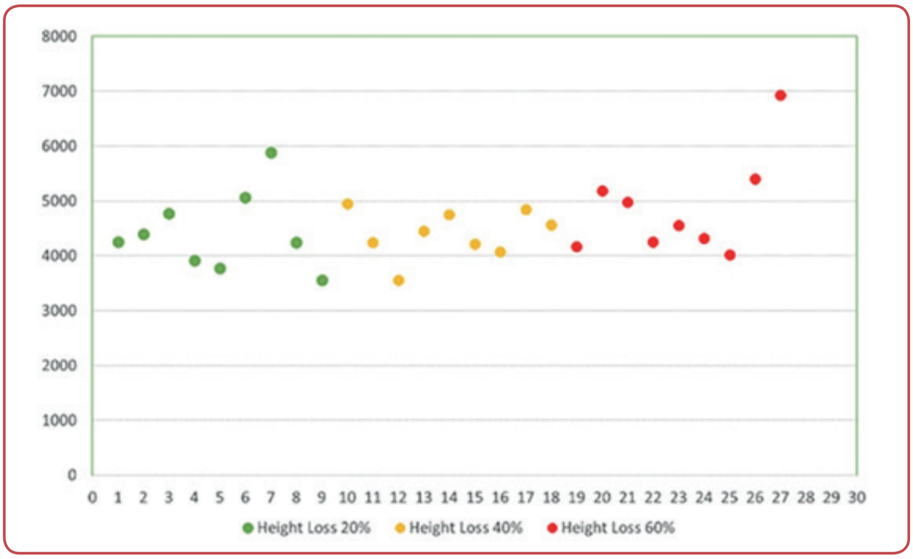

Figure 4: Distribution of axial compression in single corpus

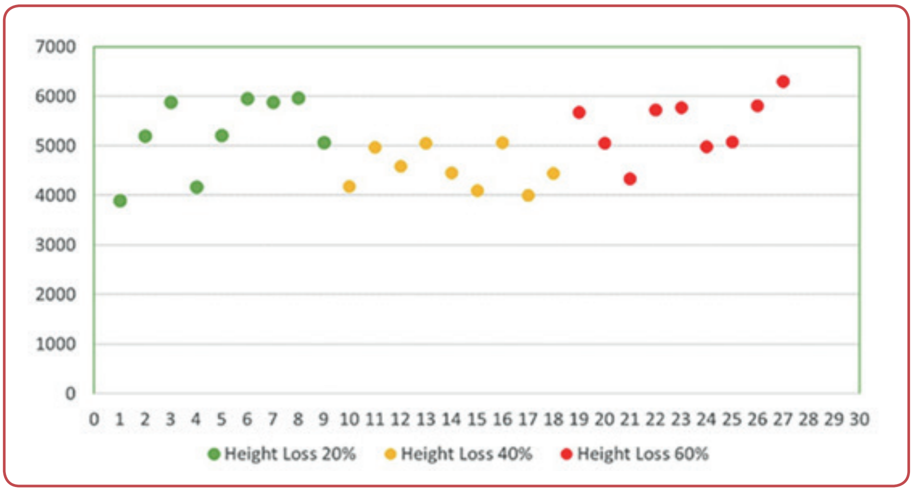

Figure 5: Distribution of axial compression in double corpus or single function spinal unit (FSU)

Table 1: Kolmogorov-Smirnov test at single vertebra

Height loss	Fracture type			p-value
	Wedge	Incomplete burst	Complete burst	
20 %	9	0	0	0.009
40 %	2	7	0	
60 %	0	0	9	

Table 2: Kolmogorov-Smirnov test at single functional spinal unit (FSU)

Height loss	Fracture type			p-value
	Wedge	Incomplete burst	Complete burst	
20 %	9	0	0	0.009
40 %	2	7	0	
60 %	0	2	7	

From the Kolmogorov-Smirnov test results in the single vertebra testing group, a p = 0.009 was obtained, indicating a significant difference in the types of fractures occurring in the groups with 20 %, 40 % and 60 % height loss (Table 1). Similarly, in the single FSU testing group, the Kolmogorov-Smirnov test resulted in a p = 0.009, signifying a significant difference in the types of fractures occurring in the groups with 20 %, 40 % and 60 % height loss (Table 2).

Discussion

The thoracolumbar vertebrae in goats have anatomical and biomechanical characteristics similar to those of humans.[7] Many previous studies have used goat bones as experimental subjects, including the development of vertebral bone defects, experiment model from vertebroplasty experiment, or semen augmentation for spinal mechanical stability.[8] Due to these similarities, goats were used as samples in this study.

In this study, research was conducted on a single functional unit and also directly on the vertebral bones. Direct studies on vertebral bones were conducted to assess the worst-case scenario of a spinal bone condition where the vertebral disc is already stiff and completely non-functional. As a result, the entire load is directly borne by the vertebra, as seen in patients with degenerative disorders of their vertebral discs.

The vertebral bodies are not morphologically homogeneous. Homogeneity in the anterior trabecular region can be observed, but there is significant inhomogeneity in the posterior vertical and transverse. There were a difference of 25 % and 20 % in bone volume between the superior and inferior posterior areas of the thoracolumbar and lumbar vertebrae.[9] Other studies have also found the same, where there was a higher density on the posterior side by 1.28 times compared to the anterior side.[10] This underlies compression fractures occurring more on the anterior than on the posterior side. In addition to its weaker strength, the inferior posterior side of the vertebra does not have a cortical shell, so this bone segment must be able to withstand its load from the strength of its trabeculae, in contrast to the other side, which is reinforced by posterior elements, so its strength does not depend entirely on bone trabeculae and is less dense. In this study, the theory that there are more compression fractures on the anterior side than on the posterior side of the vertebrae was confirmed.[10, 11]

This study found that at a height loss of 20 %, most of the fractures that occurred were compression fractures. Meanwhile, complete burst fractures were predominantly observed at a height loss of 60 %. A strong correlation was also found between height loss and fracture type. This data can serve as a basis for predicting structural damage from the degree of corpus destruction/height loss and emphasises the importance of height loss evaluation. Changes in the Cobb angle indicate instability in the damaged spinal segment and predict the progression of occurring deformities. Increased height loss can also be a predictive value for other spinal damages and will undoubtedly affect the therapy. Previous studies have found that in the thoracolumbar vertebrae, a kyphotic angle of 15–30 degrees or vertebral body height loss (VBHL) of more than 50 % strongly correlates with instability.[12]

In its correlation with the level of canal encroachment, previous studies have found a strong association between vertebral height loss and canal encroachment based on MRI. In the study by Seo et al, it was found that canal encroachment is strongly related to both posterior and anterior height loss but not strongly associated with age, T-score, gender and kyphotic angle. Additionally, significant height loss from the beginning is associated with the progressiveness of canal encroachment. Patients with initially large height loss were found to experience worsening canal encroachment up to > 20 %. This study also found that the progression of height loss will be faster in complete burst fractures than in compression fractures, meaning that, if related to this study, a height loss of 60 % has the fastest progression and should be closely monitored and considered for surgery sooner than if it's less than 60 %.[13]

Another study by Yuksel et al also found a strong relationship between height loss and various parameters of other vertebrae. Larger height loss was associated with a higher level of neurological impairment based on ASIA compared to lower height loss. From their analysis, it was found that height loss had a sensitivity, specificity, positive predictive value and negative predictive value of 100 % in predicting the severity of neurological impairment based on ASIA. This association was stronger than the sagittal index and canal compromise parameters.[14]

Regarding damage to the poster ligamentous complex (PLC), a study by Radcliff et al linked PLC damage to height loss, kyphosis, translation and canal encroachment. Their research found that height loss was not associated with PLC damage and only translation exceeding 3.5 mm was related to PLC.[12, 15]

This study has limitations, including non-uniform time between specimen preparation and experiment execution. Due to the limited availability of goat specimens as samples, only two vertebral samples could be obtained per day, resulting in the collection of 54 samples over three weeks. This may introduce variability in vertebral strength due to degradation that may have occurred. Due to limitations in research equipment, the compression test was conducted using a machine that gradually compressed the bone, whereas it would have been better to perform sudden compression. Sudden compression force would more accurately represent real-world conditions.

Conclusion

There were differences in the fracture configuration that occurs in goat vertebrae based on the magnitude of the applied force or height loss in the testing with one corpus and/or one FSU. This research is expected to serve as a foundation for future studies on the biomechanics and pathology of spinal fractures. Additionally, it is anticipated to provide a basis for research involving implant testing on the spinal column.

Ethics

This study was conducted at the Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. Ethical Clearance was granted by the Animal Care and Use Committee (ACUC), Universitas Airlangga. The Ethical Clearance No 2.KEH.170.11.2023, dated 22 November 2023.

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None.

Conflicts of interest

The authors declare that there is no conflict of interest.

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Data access

The data that support the findings of this study are available from the corresponding author upon reasonable individual request.

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Resources: FF, PAA, KDH
Data curation: FF
Writing - original draft: FF, KDH
Writing - review and editing: PAA, KDH
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