The Internet Journal of Spine Surgery
Volume 1 Number 2

Spondylolysis Fracture Angle in Children and Adolescents on CT Indicates the Facture Producing Force Vector: A Biomechanical Rationale

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Citation

K Sairyo, S Katoh, S Komatsubara, T Terai, N Yasui, V Goel, S Vadapalli, A Biyani, N Ebraheim. *Spondylolysis Fracture Angle in Children and Adolescents on CT Indicates the Facture Producing Force Vector: A Biomechanical Rationale*. The Internet Journal of Spine Surgery. 2004 Volume 1 Number 2.

Abstract

The fracture angle of spondylolysis with respect to the frontal plane on CT scan shows variations individually. We hypothesized that the angle may indicate the major force vector responsible for the pars stress-fracture. To prove this hypothesis, the highest stress lines at the pars interarticularis were analyzed using a 3-D finite element model (FEM) of a lumbar motion segment (L3 to S1) during various modes, and compared to the clinical data of fracture angles on CT scan of 32 patients with spondylolysis. The location/direction of high stresses as predicted by the FEM indicated that the extension loading may cause spondylolysis at coronal orientation, and rotation loading, may cause spondylolysis at sagittal orientations. The CT findings revealed that the fracture angle in patients, who were active in sports requiring frequent twisting motion of the trunk, were more sagittal in orientation as compared to sport activities that required less twisting. From the spondylolysis fracture angle on CT, the type of loading (i.e.; extension, rotation) causing stress fracture at pars interarticularis may be determined and the information may be used to prescribe the right type of braces for a particular patient.

INTRODUCTION

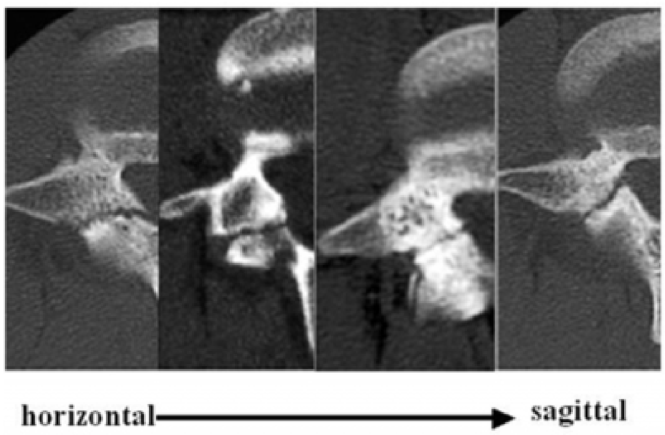
Lumbar spondylolysis is a stress fracture of the pars interarticularis. [1, 2] Increased mechanical stresses at the pars interarticularis during sport activities may increase the incidence of spondylolysis. Since it is a stress fracture, it responds to conservative treatment. [3, 4, 5, 6] However, the success rate for the bony-union using conservative modalities is reported to be from 17 to 47% and therefore not clinically satisfactory. Late diagnosis could be a reason for not obtaining a bony union. [3, 5] Also the low success rate may be due to the unsuitability of the type of brace prescribed for the kind of fracture.

The basic concept for the conservative treatment of any fracture is the rigid immobilization of the fracture site. Effective immobilization of the fracture site might improve the success rate. To determine the effective immobilization device for a particular fracture, we must understand the force vector causing the stress fracture of the pars. Several epidemiological studies have suggested that hyper-extension, rotation, or extension-rotation are the important causative loading modes leading to pars fracture. [7, 8] However, these studies have not been validated with biomechanical studies.

The fracture lines of the spondylolysis can be detected on CT scans. The orientations of these lines vary; i.e., from coronal to sagittal (Figure 1).

Figure 1

Figure 1: Variation of spondylolysis fracture angle in patients



There have been no prior reports correlating the biomechanical causes with the clinical occurrence of these fracture line orientations. We hypothesized that the angle of the line with respect to the frontal plane may indicate the main load vector responsible for the stress fracture at the pars. Understanding the fracture inducing load from the CT scans may help with the selection of appropriate brace that will lead to effective immobilization of the fracture site; thereby increasing healing rate.

In this study, we analyzed the orientation of the highest stress line at the pars during various lumbar motions using a finite element model of the ligamentous lumbar segment. These results were then compared to the CT findings from the patients.

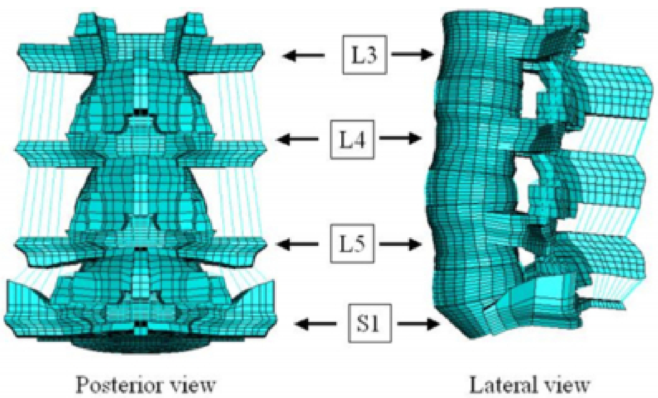
METHODS

FEM STUDY

For the biomechanical study, an experimentally validated 3-dimensional non-linear finite element model (FEM) of the intact ligamentous L3-S1 segment was used, [5, 9, 10] (Figure 2). This model was validated in our earlier study. [5, 9, 10] The Von Mises as well as principal stresses in pars interarticularis at L5, the level where spondylolysis has been most prevalent, were analyzed during each lumbar motion in response to 400 N axial compression and 10.6 Nm moment.

Figure 2

Figure 2: Three dimensional finite element lumbar spine model at L3 to S1 used in this study

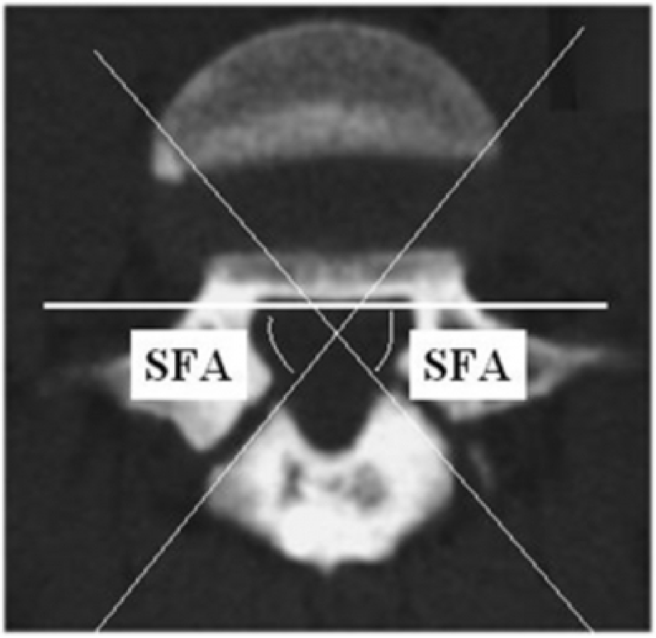


CLINICAL STUDY

Thirty-two patients (27 boys and 5 girls) with bilateral lumbar spondylolysis at L5 were reviewed. Their mean age was 14.6 years old (11 to 18). They were active in the following sports: 10 soccer, 5 base ball, 5 volley ball, 3 soft ball, 3 tennis, 2 basketball, 1 swimming, 1 shot-put, 1 judo and 1 running. For each group, the spondylolysis fracture angle (SFA) with respect to the frontal plane was measured from the CT films (Figure 3). The sport specificity of SFA was investigated.

Figure 3

Figure 3: Measurement of spondylolysis fracture angle (SFA) on plain CT scan



RESULTS

FEM STUDY

During all lumbar motions, the highest Von Mises stresses were seen at the pars interarticularis. During extension or axial rotation to the contralateral side, the stresses were higher compared to the other motions (Figure 4). Extension and left axial rotation depicts typical example of the stress distribution (Figure 5). High stress area is observed around the right pars interarticularis. Video 1 shows the animation of extension motion of our finite element lumbar spine. With extending the lumbar spine, the changes of Von Mises stresses are shown by the corresponding color. The highest stress is observed at the pars interarticularis.

Figure 4

Figure 4: Von Mises stress results during lumbar motion

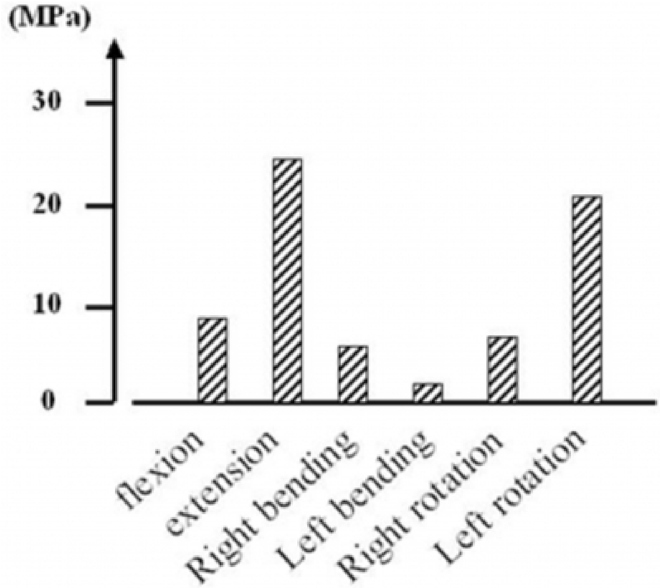
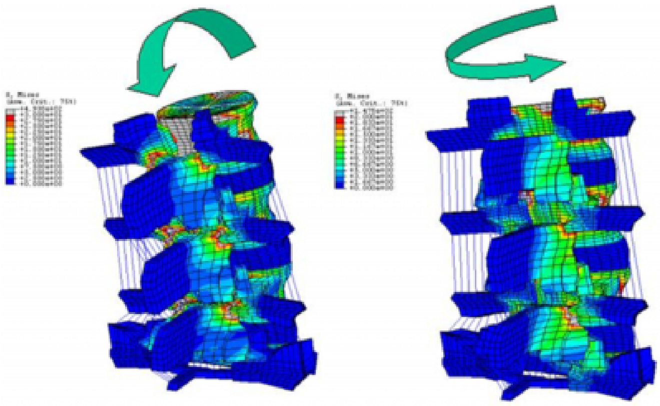


Figure 5

Figure 5: Stress distribution at the posterior structures: Note the high stress around the pars interarticularis during both lumbar motions.



Video 1: Animation of lumbar extension of the lumbar finite element model with showing the change of Von Mises stresses

The direction of these high principal stresses in the pars interarticularis were investigated at the location where the fractures were observed on the CT images (Figure 6). The direction of stress in the pars region was about 45 degrees in all loading modes, except in extension. In extension, the direction was more coronal (Figure 7).

Figure 6

Figure 6: High stress lines analyzed by maximum principal stress during extension and rotation. The line in this figure indicates the slice where the image was obtained.

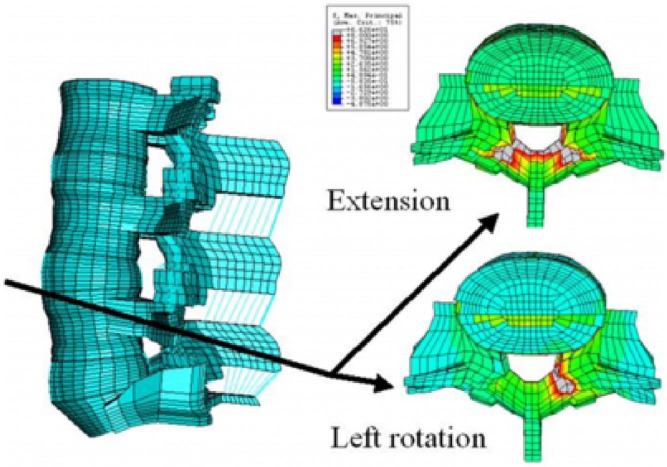
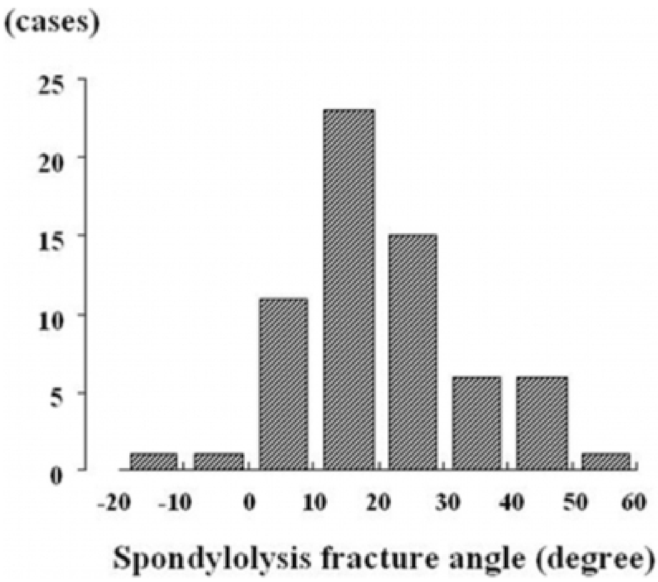


Figure 7

Figure 7: Distribution of the spondylolysis fracture angle in patients



CLINICAL STUDY

The SFA varied individually and ranged from -13 to 53 degrees (Figure 7). SFA varied as a function of the sport played (Figure 8). In this study, the sports were assigned to three groups based on the involvement of the typical trunk motion: trunk twist, non-twist, and undetermined. In the trunk twist group, the players frequently use upper extremities and twist the trunk, i.e. softball, tennis, volleyball, baseball, judo and shot-put. Non-twist sport group included soccer and running, which do not often involve upper extremities. Swimming and basketball were difficult to asses with reference to the twisting of the trunk, and thus were assigned to the undetermined group. Table 1 lists the SFA of these groups. In 60.9% of the trunk twist group SFA was more than 20 degrees, while in non-twist group, the corresponding number was 22.7%. The differences was significant (p<0.05, chi-square).

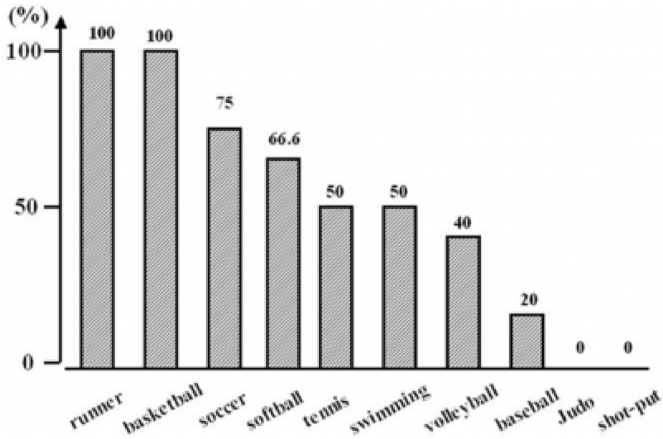
Figure 8

Table 1: Sports specificity of the spondylolysis fracture angle

	Spondylolysis fracture angle	
Group	≧ 20°	< 20°
Trunk twist	28	18
Non-twist	5	17
Undetermind	1	5

Figure 9

Figure 8: Percentage of patients with low number of the spondylolysis fracture angle less than 20 degrees in each sport.



DISCUSSION

The spondylolysis in children and adolescents frequently occurs along with forward slippage. [11]The disorder in the aged patients sometimes causes radiculopathy requiring surgical intervention. [1] The bony healing of the fracture in the spondylolysis should be the main goal to avoid further complications described above. The bony healing can be achieved with an appropriate non-operative/conservative treatment. Earlier studies [3, 4, 5, 6] reported that a complete stop of sport activities along with trunk immobilization using a brace was effective for fracture healing. However, the success rate reported has not been favorable, being between 17 to 47%.

In order to immobilize the fractured pars using a brace, first we should understand the external force causing the stress fracture of the pars. If we do not understand the force, we can not immobilize the spine effectively. We hypothesized that the spondylolysis fracture angle (SFA) on CT may indicate the main lumbar motion that resulted in the stress fracture at the pars interarticularis.

From the biomechanical study, we confirmed that the pars interarticularis was the area of maximal stress in any type of lumbar motion. However, the stress was very high during extension and rotation. The stress pattern changed with the load type/motion. The results indicate that extension loading may cause a more coronally oriented spondylolysis, and rotational loading causes a more sagittally oriented fracture line. The clinical study using CT revealed that the SFA in patients with trunk twist group showed more sagittal orientation, compared to the non-twist group. Thus, the clinical findings are in good agreement with the results of biomechanical study using the finite element model.

Based on these biomechanical and clinical studies, we may divide the patients in two categories, extension induced or rotation induced spondylolysis. When the fracture indicates a sagittal orientation, we need the brace which will specifically immobilize the rotation motion. On the other hand, for the patients with the fracture angle more coronally oriented, we need a brace which will effectively immobilize the extension lumbar motion. To further prove this hypothesis prospective randomized clinical trials, using a specific brace according to the CT-based fracture angle, may show to be helpful.

Another strategy to improve the success rate of the conservative treatment is to establish the reliable diagnostic method at the early stage of the lumbar spondylolysis. Although spondylolysis at the terminal (pseudoarthrosis) stage can not be healed without surgery, early staged spondylolysis has high potential to heal osseously with conservative treatment. [6]Recently, we have been proposing that the signal changes of pedicle on MRI indicate the early stage of spondylolysis. [12]Gold standard for the diagnosis of this disorder is Scottish Terrier Collar sign on oblique view of plain radiographs. This study showed the fracture angle varied individually (range -13 to 53 degrees), and there were some spondylolysis showing the fracture angle being more coronally oriented. For such spondylolysis, the lateral view of the plain radiograph is more suitable rather than oblique view to diagnose the stress fracture at pars interarticularis.

Surgeons should aware this variations of the fracture angle in the lumbar spondylolysis, and observe carefully lateral view of plain radiographs as well as oblique view for diagnosing spondylolysis.

The limitation of the clinical study is the classification of the sports. In this study, the sports were assigned to three groups based on the involvement of the typical trunk motion: trunk twist, non-twist, and undetermined. In this study, we classified the soccer in the non-twist group, because soccer does not use upper arm frequently (even though the player twists their trunk during soccer). Thus, to solve this limitation, we should analyze more number of patients, which is very specific for the grouping. The considerable sport for trunk twist group is hockey, since the players seem not to extend the trunk much. On the other hand, for the non-twist group, classic ballet dancer is considered. For the future study solving the limitation, patients who are very active on these kinds of sports should be included.

ACKNOWLEDGEMENT

Work supported in part by a fellowship grant from DePuy Spine, Inc, Raynham, MA. The authors wish to thank SriLaksmi Vishnubhotla, BEng., for her help during editing process.

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