Biomechanical comparison of four triangular osteosynthesis fixations for unilateral verital sacral fractures

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Research Article

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Abstract

[Objective] To compare the stability and biomechanical characteristics of four commonly used triangular osteosynthesis techniques to treat unilateral vertical sacral fractures and provide a clinical application reference.

[Methods] Finite element models of Tile C type pelvic ring injury (unilateral Denis ▯ sacral fracture) were produced. In four models, sacral fractures were fixed with a combination of unilateral L5, unilateral L4,and L5 iliac lumbar fixation with lengthened sacroiliac screws and normal sacroiliac screws, respectively. The biomechanical properties of the four fixation models were measured and compared under bipedal stance and lumbar rotation.

[Results] The fixation stability of the model with the lengthened sacroiliac screw was excellent, and the fracture end was stable. The stability of fixation using unilateral L4 and L5 segments was close to that of unilateral L5 segment fixation.

[Conclusions] Triangular osteosynthesis transverse stabilization device using lengthened sacroiliac screws can increase the vertical stability of the sacrum after internal fixation and increase the stability of the fracture. When triangular osteosynthesis lumbar fixation segments were selected, simultaneous fixation of L4 and L5 segments versus only L5 segments did not significantly enhance the vertical stability of the sacrum or the stability of the fracture end.

Introduction

Unstable pelvic fractures arising from high-energy trauma are a challenge for clinical treatment, and surgical treatment is mainly used to re-establish the stability of the pelvic ring. Anatomic repositioning and solid internal fixation of the posterior pelvic ring are the main goals of surgical treatment. The sacrum is an essential part of the posterior pelvic ring, and sacral fractures account for about 28%-45% of pelvic fractures, of which unstable fractures account for 17%-30%[1–3]. About 90% of sacral fractures are accompanied by injuries to other parts of the pelvic ring[4]. The primary goals of surgical treatment of posterior pelvic ring injuries are anatomic repositioning and adequate internal fixation, with additional nerve exploration and decompression for patients with associated neurologic impairment.

A variety of methods for vertically unstable sacral injuries have been advocated, including transiliac rods[5], transiliac plates[6], percutaneous Sacroiliac screws[7, 8], and spinopelvic instrumentation[9, 10]. Advocates of these fixation techniques recommend a similar postoperative rehabilitation program with partial weight-bearing or prohibition of weight-bearing for 6–12 weeks postoperatively. Previous posterior ring fixation methods were not strong enough to allow for early weight-bearing functional exercise.

Schildhauer et al.[11] proposed combining a spinal-pelvic fixation system with fixation with sacroiliac screws or sacral plates to treat sacral fractures, called the "triangular osteosynthesis." Studies have shown that triangular osteosynthesis provides more stability, allowing the patient to be fully weight-bearing sooner and return to normal daily activities sooner.

The most used triangular fixation technique for sacral fractures is iliolumbar fixation combined with sacroiliac screws. Excellent postoperative results have been achieved. A literature review shows that there are few biomechanical studies on triangular fixation techniques. In triangular osteosynthesis, What are the biomechanical differences of iliolumbar fixation, which usually fixes the L5 segment or both the L4L5 segment? In triangular osteosynthesis, what are the biomechanical differences between normal sacroiliac screws and lengthened sacroiliac screws? The above questions have not been studied. This study aims to create a model of triangular fixation and investigate its biomechanical properties utilizing a 3D finite element method. This study aims to provide a theoretical basis for the clinical use of this technique.

Methods

1.Finite element modeling

This study was based on CT (64-slice spiral CT (Philips)) scan data of L3-L5 and pelvis of a healthy adult female (165 cm, 35 years, 65 kg). The slices were 1 mm thick. A virtual 3d model of the Lumbar spine and pelvis was created from CT data in DICOM format with image processing software (mimics 17.0). The individual components shown in Fig. 1 below were generated based on the CT gray value segmentation technique. The preliminary model of the pelvic spine obtained from MIMICS cannot be used directly for finite element calculations. The 3D model of the pelvis obtained in MIMICS needs to be further processed in the software 3-Matic to make the model smooth for further processing.

The sacral model was incised along the unilateral sacral foramen to simulate the fracture of the sacrum. The original single sacrum was divided into two parts to make a unilateral vertical sacral fracture model (AO type C3.1, Denis II), as shown in Fig. 2.

The components of the generated model are imported into the 3-Matics Remsh module for meshing. The result of the meshing is a four-node mesh with three degrees of freedom per node. The mesh model of each part was imported back to mimics software to assign material parameters. The material properties of the model are set to non-homogeneous and isotropic material.

The model material is assigned to different skeleton parts using a grayscale-based method. The mimics come with a formula to assign the ashes values into ten levels. The material assignment formula is based on literature studies.[12]

Model the implant using Solidworks software. It was imported into 3-Matics for the pelvic bone model assembly, and meshing was performed. Then it was imported into mimics for assigning material properties, and the implant's material was titanium alloy.

2. Finite element model validation

The finite element model uses spring units to simulate the pelvis and the primary ligament structure around the lumbar spine to ensure the mobility and stress transmission of the sacroiliac joint joints of the lumbar spine joints. From the displacement results of the pelvic model, the maximum mobility of the anterior edge of the sacrum tended to move forward and downward, and the iliac bones on both sides tended to rotate in agreement with the literature[27]. The partial lumbar spine movement results were excellent and consistent with the in vitro experimental results.

3. The establishment of ligament and muscle model and the application of load

The mesh models of bones and screws were imported into the software Abaqus, and then spring damping cells were used to simulate the ligaments and muscles. The generated model is shown in Fig. 3. The model material parameter settings and ligament parameter settings are shown in Table 1 and Table 2[12–17].

Table 1
Parameters of the lumbar spine model and implants

Material	Elastic modulus, MPa	Poisson ratio	Cross-section area, mm2
Disc Annulus	8.4	0.45	
Disc Nucleus	Mooney–Rivlin c1 = 0.12, c2 = 0.03		
Anterior longitudinal ligament	7		63.7
Posterior longitudinal ligament	7		20
Ligamentum flavum	3		40
Intratransverse ligament	7		1.8
Capsular ligament	4		30
Interspinous ligament	6		40
Supraspinous ligament	6.6		30
Implants	11400	0.3	

Table 2
model parameters of pelvic ligaments

Material	K, N/m	Number of springs
Anterior and capsule sacroiliac ligament	700	27
Posterior sacroiliac ligament	1400	15
Interosseous sacroiliac ligament	2800	8
Iliolumbar ligament	2800	30
Sacrospinous ligament	1400	9
Sacrotuberous ligament	1500	15
Superior pubic ligament	500	24
Arcuate pubic ligament	500	24

The sacroiliac joint and pubic symphysis were set as bound constraints. Six degrees of freedom constraint was performed at the bilateral acetabular nodes. A force of 600 N was applied vertically downward to the surface of the upper endplate of L3 to simulate the human body under its gravity when standing upright. 100 N of slave load and 7 Nm of torque were applied to the upper endplate of L3 around the mechanical axis of the spine to simulate the forces acting on the lumbar rotation.

In this study, a normal sacroiliac screw was defined as a sacroiliac screw whose length crossed the fracture line to the midline of the sacrum. Lengthened sacroiliac screws were defined as those whose length crossed the fracture line and penetrated the contralateral iliac bone. Four internal fixation models were established in this study, Fig. 4–7: (1) Unilateral L4 + L5 segment iliolumbar fixation + S1 normal sacroiliac screw (L4L5NS1) (2) Unilateral L4 + L5 segment iliolumbar fixation + S1 lengthened sacroiliac screw (L4L5LS1) (3) Unilateral L5 segment iliolumbar fixation + S1 normal sacroiliac screw (L5NS1) (4) Unilateral L4 + L5 segment iliolumbar fixation + S1 lengthened sacroiliac screw (L5LS1).

The length and diameter of the lumbar pedicle screws and iliac screws were 45 mm, 6.5 mm, and 70 mm, 7.5 mm, respectively. The diameter of the sacroiliac screws was 7.3 mm. the material properties were set to titanium alloy.

Boolean operations were performed for the four internal fixation models. The vertical displacements of the above four internal fixation models were recorded and compared with the normal model. Point a and point b was marked on the vertical fracture line of the sacrum (Fig. 2), and two points a1a2 b1b2were generated when the fracture was separated, and the distance between these two points was recorded, respectively, and the distance was the value of suture separation. The maximum von miles of fixation were recorded, and the cloud of von miles of fixation was analyzed to evaluate the stress distribution of internal fixation.

Results

1. Sacrum vertical displacement distance

Under the action of 600N vertical compression, the sacral upper surface median in the vertical direction displacement was recorded, and the results are shown in Fig. The vertical displacement in the normal pelvic model was 0.157 mm. All four fixation models could not achieve the stability of the sacrum in the normal mode. Comparing the four fixation models, the sacral vertical displacement L4L5LS1 < L5LS1 < L5NS1 < L4L5NS1.The values were 0.1738, 0.1864, 0.2307, 0.241. Whether the L5 segment was fixed or Whether the L4L5 segment was fixed simultaneously, the vertical displacement distance of the sacrum with the application of the lengthened sacroiliac screw was smaller than that with the normal sacroiliac screw. When the normal sacroiliac screw was applied, the vertical displacement distance of the sacrum was less than that of the L4L5 segment when fixing the L5 segment alone. When lengthened sacroiliac screws were applied, the vertical stabilization displacement distance of the fixed L4L5 segment sacrum was smaller than that of the fixed L5 segment only. However, the values of the two results were close. 100 N follower load and 7 N/M torque were not significant for vertical displacement of sacrum, and the results of the four groups of models were close.

2. Fracture separation value

The fracture separation values of the four fixed models were recorded under 600 N vertical pressure, Table 3, Fig. 9. comparing the a1-a2 values, the minimum value of L4L5LS1 was 0.1738 mm. The maximum value of L4L5NS1 was 0.241 mm. comparing the b1-b2 values, the minimum value of L4L5LS1 was 0.074 mm, and the maximum value of L5LS1 was 0.1844 mm. Under 100N under slave load and 7N.m torque, The bone seam separation values were recorded for the four fixation models, Table 3, Fig. 10. Comparing the a1-a2 distance, L5LS1 has a minimum value of 0.017mm, followed by L4L5LS1 with 0.019mm. l4L5NS1 has a maximum value of 0.08mm. comparing the b1-b2 distance, L5LS1 has a minimum value of 0.0168mm, followed by L4L5LS1 with 0.0194mm. l4L5NS1 has a maximum value of 0.0397mm.

Table 3
Experimental results in each simulation state

	600N				100N 7NM		
	Vertical displacement distance(mm)	a1-a2	b1-b2	Maximum von Misses stress(Mpa)	a1-a2	b1-b2	Maximum von Misses stress(Mpa)
NOR	0.159						
L4L5NS1	0.4072	0.241	0.102	131.1	0.0659	0.0397	87.18
L4L5LS1	0.2805	0.1738	0.074	107.9	0.0191	0.0194	42.65
L5NS1	0.3677	0.2307	0.09	111	0.0659	0.0397	44.83
L5LS1	0.2937	0.186	0.184	112.2	0.0171	0.0168	40.8

3. The von Misses stress

The maximum von Misses stress of the implant was recorded, Fig. 11, Table 3. The maximum von Miles stress of L4L5NS1 was the largest at 131 MPa under a vertical force of 600 N. The other three models were close in value. The maximum vonMiles stress of L4L5NS1 was the largest at 87.1 MPa under a slave load of 100 N and a torque of 7 N/m. The other three groups of models were close in value. Analyzing the Von Mises stress distribution of the four groups of internal fixation models, the triangular fixation under a vertical load of 600 N showed that the stresses were concentrated around the fracture ends of the linked pedicle screws and iliac screws, as well as the sacroiliac screws. Analyzing the Von Mises stress distribution of the four groups of internal fixation models, stress concentrations were observed at the pedicle screw and iliac screw attachment bar and around the sacroiliac screw fracture under a vertical load of 600N. Under a 100N slave load + 7Nm torque, stress concentrations were observed at the pedicle screw, the pedicle connecting rod, the iliopsoas screw connecting rod, and the sacroiliac screw fracture.

Discussions

The sacrum is an essential component of the pelvic ring, and unstable sacral fractures severely affect the integrity and stability of the posterior pelvic ring. It leads to traumatic spine-pelvis separation, and poor fracture repositioning can affect body weight-bearing and lower limb function. The treatment of unstable sacral fractures aims to rebuild the stability of the spine and pelvis, restore the biomechanical conduction of the lower extremity-pelvis-spine, and perform nerve decompression simultaneously when combined with nerve injury. The traditional posterior fixation methods commonly used in clinical practice include sacral rod fixation, posterior tension band plate fixation, and sacroiliac screw fixation. Sacroiliac screws and iliolumbar fixation were the most commonly used.

The advantage of iliolumbar fixation lies mainly in reconstructing the spine in the vertical direction. In 1994, Kach and Trentz [18]first reported the successful treatment of longitudinally displaced sacral fractures using pedicle nailing and inter-iliac crest bracing, introducing the concept of the spine-pelvis bracing technique. We achieved the lumbar-pelvic fixation by connecting the L4 and L5 pedicle nails to the iliac crest screws with a nail rod. This technique is effective against vertical pelvic instability because it fixes the lumbar spine and pelvis with an arch nail system and has a bracing and closing effect, which is vertical. When there is concurrent sacral nerve injury and sacral canal occupancy, we can make posterior exploration for decompression and nerve repair simultaneously. This technique applies to all vertically unstable pelvic fractures. However, there are inherent disadvantages of this fixation method: sizeable surgical incision, which may cause complications such as infection and nonunion; slightly less effective fixation for unstable transverse fractures, which may cause fracture line separation; restriction of lower lumbar movement, which may cause scoliosis due to fixation on one side; the need to remove the internal fixation after fracture healing; and the need to bend the connecting rod, which increases the difficulty of fixation. Schildhauer et al. [11]concluded that the iliolumbar fixation method does not maintain the rotational stability of the posterior pelvic ring. Because of its enhanced vertical stability, a 2-point fixation in the vertical direction cannot accomplish rotational stability. This type of fixation does not allow early weight-bearing.

Sacroiliac screw fixation is a significant advance in treating unstable sacral fractures and has become a minimally invasive technique commonly used to treat these fractures. These are the advantages of sacroiliac screws, such as minimal surgical injury, low rate of postoperative infection, and low incidence of heterotopic ossification. Compared with other posterior internal fixation techniques, the incidence of vascular and nerve injury caused by sacroiliac screws is higher, about 2%-15%[19]. Kraemer et al. [20]compared the extraction force of sacral body long screws, sacral body short screws, and sacral wing short screws, and the mean extraction force was 925 N, 327 N, and 71 N in order, and the difference was statistically significant. Sacroiliac screws that have been lengthened are utilized to strengthen the stability of the sacral fracture. Gardner and Routt [21]proposed lengthened sacroiliac screws. The screws penetrate from the sacroiliac joint on one side to the sacroiliac joint on the other, achieving adequate stability.Jazini et al. [22]concluded that vertical shear is the primary stress-causing instability of the posterior pelvic ring and confirmed by biomechanical tests that this stress is distributed over the entire screw. Therefore, one longer screw allows for a more reasonable distribution of stresses[23]. The most extended screw that spans the entire sacroiliac complex is the lengthened sacroiliac screw, which is particularly suitable for bilateral sacral fractures. The number of cortical bones crossed medially and laterally by the lengthened sacroiliac screws is essentially the same at the fracture line, providing a balanced fixation. The lengthened sacroiliac screws used in this study are screws that penetrate the contralateral cortex. Sacroiliac screws have some shortcomings. ating et al. [24]obtained an intraoperative rate of 84% anatomic repositioning or subatomic repositioning using the sacroiliac screw technique. However, the healing rate of the deformity was found to be as high as 44% at follow-up.

Griffin et al. [25]concluded that sacroiliac screw fixation of vertical sacral fractures is more likely to result in internal fixation failure and loss of reduction.

The strength of iliolumbar fixation and sacroiliac screw fixation is not sufficient. Schildhauer et al. [11]proposed Triangular osteosynthesis, a vertically oriented spinal one pelvic fixation combined with a transverse fixation device. The biomechanical study by Schildhauer et al. [26]also showed that triangular fixation was stronger than sacroiliac screw fixation for unstable sacral fractures. There are still many questions about the biomechanical properties of triangular fixation that need to require attention. We, therefore, performed a finite element biomechanical study of Triangular osteosynthesis.

This study modeled a finite element model with a longitudinal cut through the right sacral foramen to create a unilateral vertical sacral fracture model (AO C3.1 DENISS II). Unilateral vertical sacral fractures involving the L5/S1 tuberosity are often exceedingly unstable; however, in this case, the budget was simplified, and the fracture line did not involve the L5/S1 tuberosity. In the fixation model, sacroiliac screws were used for trans-S1 segmental fixation, with normal sacroiliac screws and lengthened sacroiliac screws, respectively. Increasing the length of sacroiliac screws on the biomechanical properties of internal fixation with triangular fixation was evaluated. The design of the iliolumbar fixation model in the fixation model took into account that the fracture model was a unilateral sacral vertical fracture using a unilateral iliolumbar fixation model. This paper used two L4L5 segments or a single L5 segment for lumbar fixation. The evaluation of whether increasing the fixation segment affects the biomechanical properties of internal fixation was compared.

The sacral vertical displacement distance is an important index to assess the vertical stability of the sacrum. Under a vertical load of 600 N, the vertical displacement distance of the normal sacral model in this study was 0.159 mm. none of the four fixation models could achieve the stability of the sacrum in the normal state under fixation. L5LS1 sacrum had the best vertical stability among the four fixation models, followed by L4L5LS1. We found that the fixation model achieved the best state of sacral stability with lengthened sacroiliac screws. Therefore, increasing the length of sacroiliac screws can increase the vertical stability of the sacrum when applying the triangular fixation technique to treat unilateral vertical sacral fractures. Fixation model with L4L5 segment fixation versus L5 segment fixation only, With normal sacroiliac screws, the vertical displacement distance of the sacrum was increased by increasing the lumbar fixation segment. When lengthened sacroiliac screws were applied, the vertical displacement distance of the fixed L4 and L5 segments was smaller than that of the fixed L5 segment only, but the values were close to each other. This phenomenon may be because increasing the lumbar fixation segments alters the normal force transmission in the lumbar spine. The study that increasing the length of the sacroiliac screw increased the vertical stability of the sacrum is consistent with the findings in the literature[14]. The vertical displacement of the sacrum was not significant at 100N follower load + 7NM torque.

The fracture separation distance represents the degree of stability of the fracture line in the fixed state. Under a vertical load of 600 N, the superior fracture line displacement distance was significantly more significant than the inferior fracture line displacement distance. This phenomenon is consistent with the biomechanical characteristics of the pelvis. The sacrum under vertical force, the force is transmitted along the sacroiliac joint-pelvis-acetabulum, so the closer the fracture line is to the mechanical transmission path, the greater the displacement. Comparing the a1-a2 distance in the four fixation models under 600N vertical load and 100N slave load + 7NM torque, the fracture separation distance with lengthened sacroiliac screws was significantly smaller than that in the model with normal sacroiliac screw fixation. However, in the same sacroiliac screw model, there was no significant difference in the a1-a2 distance between the models with the L4L5 lumbar fixation segment and L5 segment. Increasing the length of the sacroiliac screw when applying the triangular fixation technique to fix unilateral vertical sacral fractures increased the stability of the fracture end, and increasing the lumbar fixation segment had no significant effect on fracture stability.

The implant Von Mises stress represents the implant stress state in the finite element model. This study compared four groups of the implant model's maximum Von Mises stress. The maximum Von Mises stress value of L4L5LS1 is the smallest at 107.9 MPa under 600N vertical load. The maximum Von Mises stress value ofL4L5NS1 is the largest at 131 MPa. Under 100N + 7NM from the load, the maximum Von Mises value of the L5LS1 model is a minimum 40.8MPa. The maximum Von Mises value of L4L5NS1 is maximum 87.18MPa. Therefore, the internal fixation stress of the fixed L4L5 plus S1 lengthened sacroiliac screws combination is minor regardless of the standing condition or the lumbar rotation condition. The maximum Von Mises values of the four fixation models in this study did not differ significantly regardless of the motion except L4L5NS1. This result may alter the normal mechanical conduction of the lumbar spine after fixation of the L4L5 segment. Analyzing the Von Mises stress distribution of the four groups of internal fixation models, the triangular fixation under a vertical load of 600 N showed that the stresses were concentrated around the fracture ends of the linked pedicle screws and iliac screws, as well as the sacroiliac screws. Analyzing the Von Mises stress distribution of the four groups of internal fixation models, stress concentrations were observed at the pedicle screw and iliac screw attachment bar and around the sacroiliac screw fracture under a vertical load of 600N. Under a 100N slave load + 7Nm torque, stress concentrations were observed at the pedicle screw, the pedicle connecting rod, the iliopsoas screw connecting rod, and the sacroiliac screw fracture. This result is also consistent with clinical practice.

It is essential to point out that this study has some limitations. This study used a unilateral vertical sacral fracture (AO C3.1 Denis II) type, and the sacrum was cut longitudinally to create a vertical sacral fracture model. However, because of the variety of anterior pelvic ring injuries, their treatment methods are equally diverse, and the different treatment methods will undoubtedly impact the results of this study. The increase of influencing factors will inevitably increase the difficulty of data analysis in this study. Therefore, this study was not designed for anterior ring injuries, preserving the integrity of the anterior ring. This study is a finite element study based on pelvic CT data. Although finite element studies have made significant progress in recent years, there may be some differences between this study and human studies.

Using iliolumbar fixation combined with sacroiliac screws for unilateral vertical sacral fractures (AO C3.1 DENISII), the application of lengthened sacroiliac screws increased the vertical stability of the sacrum after internal fixation. It increased fracture stability when the sacroiliac screws were placed on the S1 segment. The use of triangular fixation with simultaneous fixation of L4 and L5 segments was not significantly effective in positively correlating the vertical stability of the sacrum with the stability of the fracture end. We should try to use the L5 segment for lumbar fixation.

Declarations

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Contributions

YPM and YZ designed and participated in the whole process of the study and drafted the manuscript.YL，TH and HYH carried out the experimental operation and participated in the data collection. All authors read and approved the final manuscript.

Corresponding author

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Ethics declarations

Ethics approval and consent to participate

The ethics committee of Yantai Shan Hospital approved the study. Informed consents were obtained from individual participant included in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Mehta S, Auerbach JD, Born CT, Chin KR. Sacral fractures. J Am Acad Orthop Surg. 2006; 14(12):656–665.
2. Taguchi T, Kawai S, Kaneko K, Yugue D. Operative management of displaced fractures of the sacrum. J Orthop Sci. 1999; 4(5):347–352.
3. Denis F, Davis S, Comfort T. Sacral fractures: an important problem. Retrospective analysis of 236 cases. Clin Orthop Relat Res. 1988; 227:67–81.
4. Gibbons KJ, Soloniuk DS, Razack N. Neurological injury and patterns of sacral fractures. J Neurosurg. 1990; 72(6):889–893.
5. Gorczyca JT, Varga E, Woodside T, Hearn T, Powell J, Tile M. The strength of iliosacral lag screws and transiliac bars in the fixation of vertically unstable pelvic injuries with sacral fractures. Injury. 1996; 27(8):561–564.
6. Ayoub MA. Vertically unstable sacral fractures with neurological insult: outcomes of surgical decompression and reconstruction plate internal fixation. Int Orthop. 2009; 33(1):261–267.
7. Ayoub MA. Type C pelvic ring injuries in polytrauma patients: can percutaneous iliosacral screws reduce morbidity and costs? European Journal of Orthopaedic Surgery & Traumatology. 2012; 22(2):137–144.
8. Griffin DR, Starr AJ, Reinert CM, Jones AL, Whitlock S. Vertically unstable pelvic fractures fixed with percutaneous iliosacral screws: does posterior injury pattern predict fixation failure? J Orthop Trauma. 2003; 17(6):399–405.
9. Jones CB, Sietsema DL, Hoffmann MF. Can lumbopelvic fixation salvage unstable complex sacral fractures? Clin Orthop Relat Res. 2012; 470(8):2132–2141.
10. Ayoub MA. Displaced spinopelvic dissociation with sacral cauda equina syndrome: outcome of surgical decompression with a preliminary management algorithm. Eur Spine J. 2012; 21(9):1815–1825.

11. Schildhauer TA, Josten C, Muhr G. Triangular osteosynthesis of vertically unstable sacrum fractures: a new concept allowing early weight-bearing. J Orthop Trauma. 2006; 20(1 Suppl):S44-S51.
12. Zhang L, Peng Y, Du C, Tang P. Biomechanical study of four kinds of percutaneous screw fixation in two types of unilateral sacroiliac joint dislocation: a finite element analysis. Injury. 2014; 45(12):2055–2059.
13. Song W, Zhou D, He Y. The biomechanical advantages of bilateral lumbo-iliac fixation in unilateral comminuted sacral fractures without sacroiliac screw safe channel: A finite element analysis. Medicine (Baltimore). 2016; 95(40):e5026.
14. Zhao Y, Zhang S, Sun T, Wang D, Lian W, Tan J, Zou D, Zhao Y. Mechanical comparison between lengthened and short sacroiliac screws in sacral fracture fixation: a finite element analysis. Orthop Traumatol Surg Res. 2013; 99(5):601–606.
15. Zhao Y, Li J, Wang D, Liu Y, Tan J, Zhang S. Comparison of stability of two kinds of sacro-iliac screws in the fixation of bilateral sacral fractures in a finite element model. Injury. 2012; 43(4):490–494.
16. Faizan A, Sairyo K, Goel VK, Biyani A, Ebraheim N. Biomechanical rationale of ossification of the secondary ossification center on apophyseal bony ring fracture: a biomechanical study. Clin Biomech (Bristol, Avon). 2007; 22(10):1063–1067.
17. Lu YM, Hutton WC, Gharpuray VM. The effect of fluid loss on the viscoelastic behavior of the lumbar intervertebral disc in compression. J Biomech Eng. 1998; 120(1):48–54.
18. Käch K, Trentz O. [Distraction spondylodesis of the sacrum in "vertical shear lesions" of the pelvis]. Unfallchirurg. 1994; 97(1):28–38.
19. Hoernschemeyer DG, Pashuck TD, Pfeiffer FM. Analysis of the s2 alar-iliac screw as compared with the traditional iliac screw: does it increase stability with sacroiliac fixation of the spine? Spine J. 2017; 17(6):875–879.
20. Kraemer W, Hearn T, Tile M, Powell J. The effect of thread length and location on extraction strengths of iliosacral lag screws. Injury. 1994; 25(1):5–9.
21. Gardner MJ, Routt MJ. Transiliac-transsacral screws for posterior pelvic stabilization. J Orthop Trauma. 2011; 25(6):378–384.
22. Jazini E, Klocke N, Tannous O, Johal HS, Hao J, Salloum K, Gelb DE, Nascone JW, Belin E, Hoshino CM, et al. Does Lumbopelvic Fixation Add Stability? A Cadaveric Biomechanical Analysis of an Unstable Pelvic Fracture Model. J Orthop Trauma. 2017; 31(1):37–46.
23. Lucas JF, Routt MJ, Eastman JG. A Useful Preoperative Planning Technique for Transiliac-Transsacral Screws. J Orthop Trauma. 2017; 31(1):e25-e31.
24. Keating JF, Werier J, Blachut P, Broekhuyse H, Meek RN, O'Brien PJ. Early fixation of the vertically unstable pelvis: the role of iliosacral screw fixation of the posterior lesion. J Orthop Trauma. 1999; 13(2):107–113.
25. Griffin DR, Starr AJ, Reinert CM, Jones AL, Whitlock S. Vertically unstable pelvic fractures fixed with percutaneous iliosacral screws: does posterior injury pattern predict fixation failure? J Orthop

Trauma. 2006; 20(1 Suppl):S30-S36, S36.

26. Schildhauer TA, Ledoux WR, Chapman JR, Henley MB, Tencer AF, Routt MJ. Triangular osteosynthesis and iliosacral screw fixation for unstable sacral fractures: a cadaveric and biomechanical evaluation under cyclic loads. J Orthop Trauma. 2003; 17(1):22–31.
27. Sturesson B, Selvik G, Udén A. Movements of the sacroiliac joints. A roentgen stereophotogrammetric analysis. Spine (Phila Pa 1976). 1989 Feb;14(2):162–5.

Figures

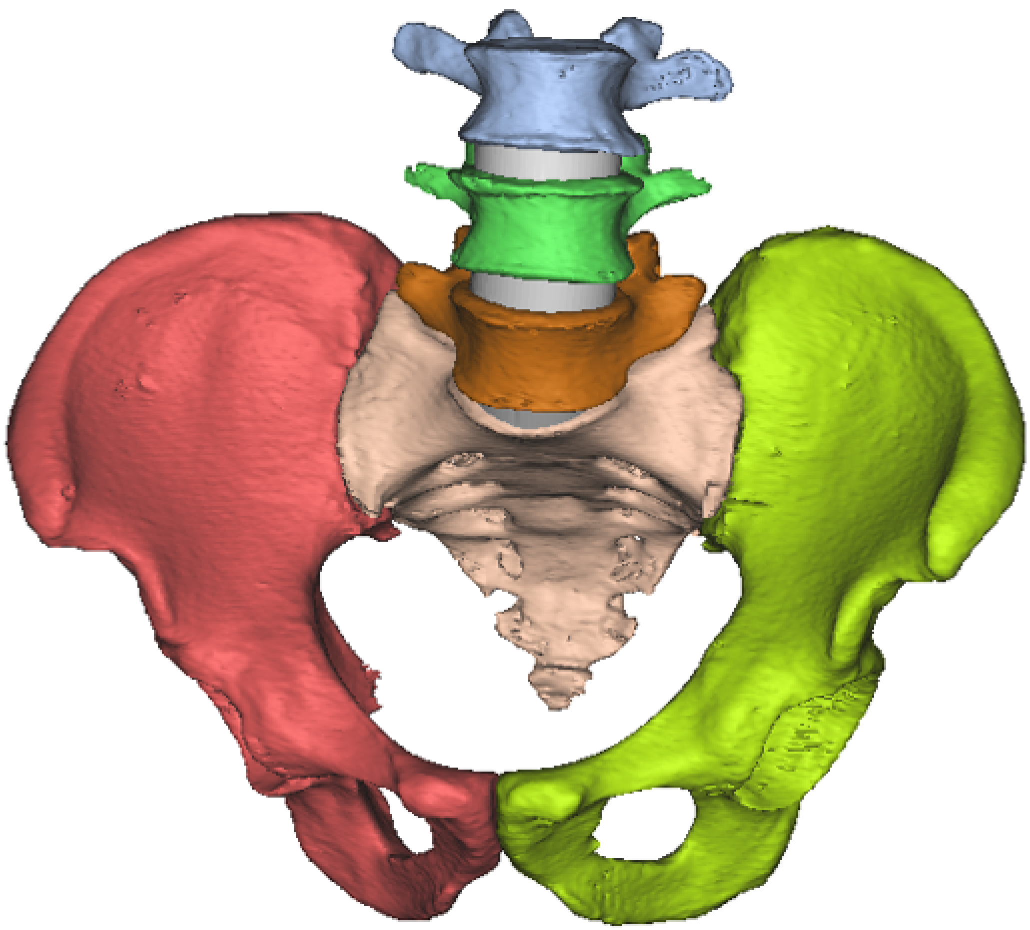

Figure 1

Finite element model generation based on CT data

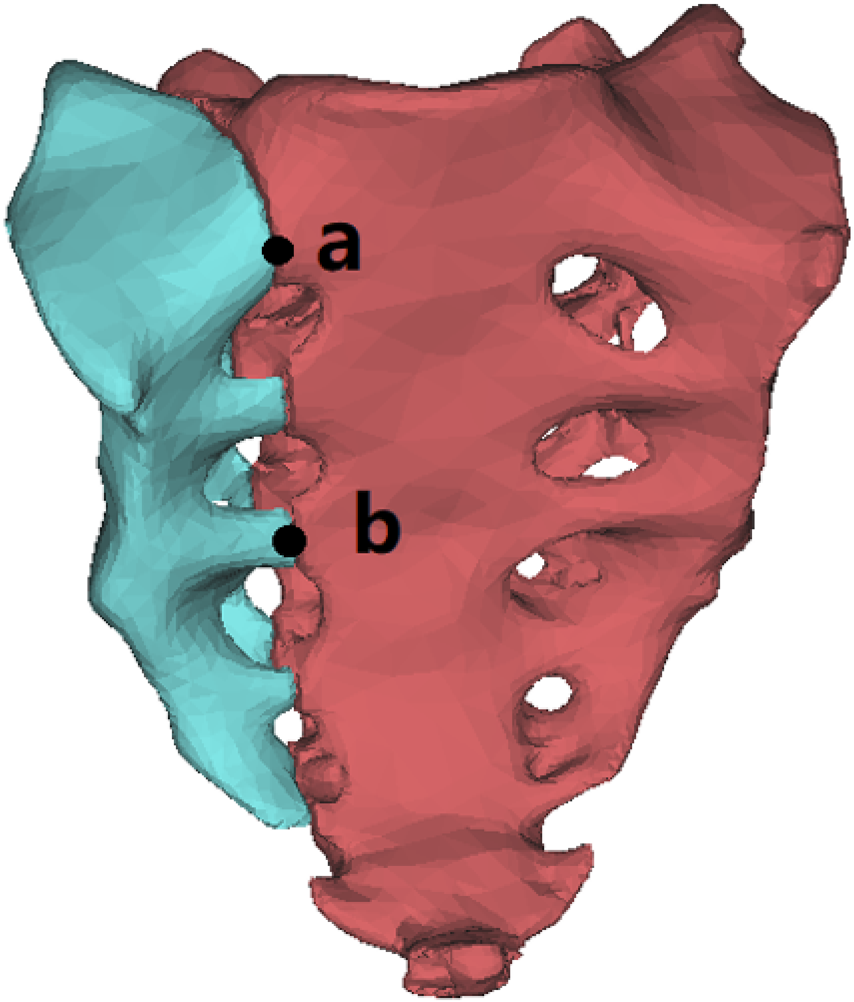

Figure 2

A vertical fracture line was made through the right sacral foramen and points a and b were marked on the fracture line

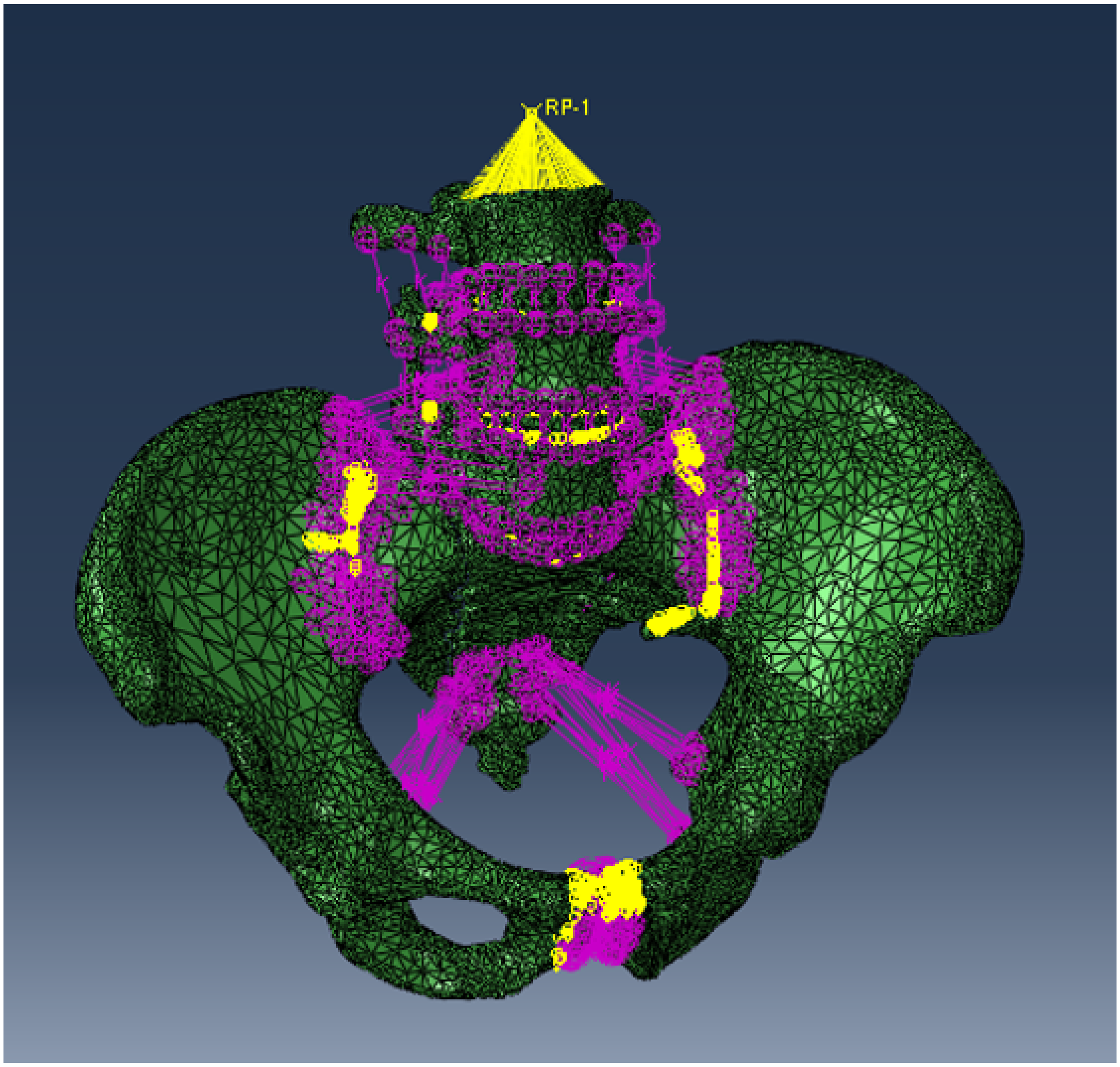

Figure 3

Finite element model after material assignment and ligament linkage

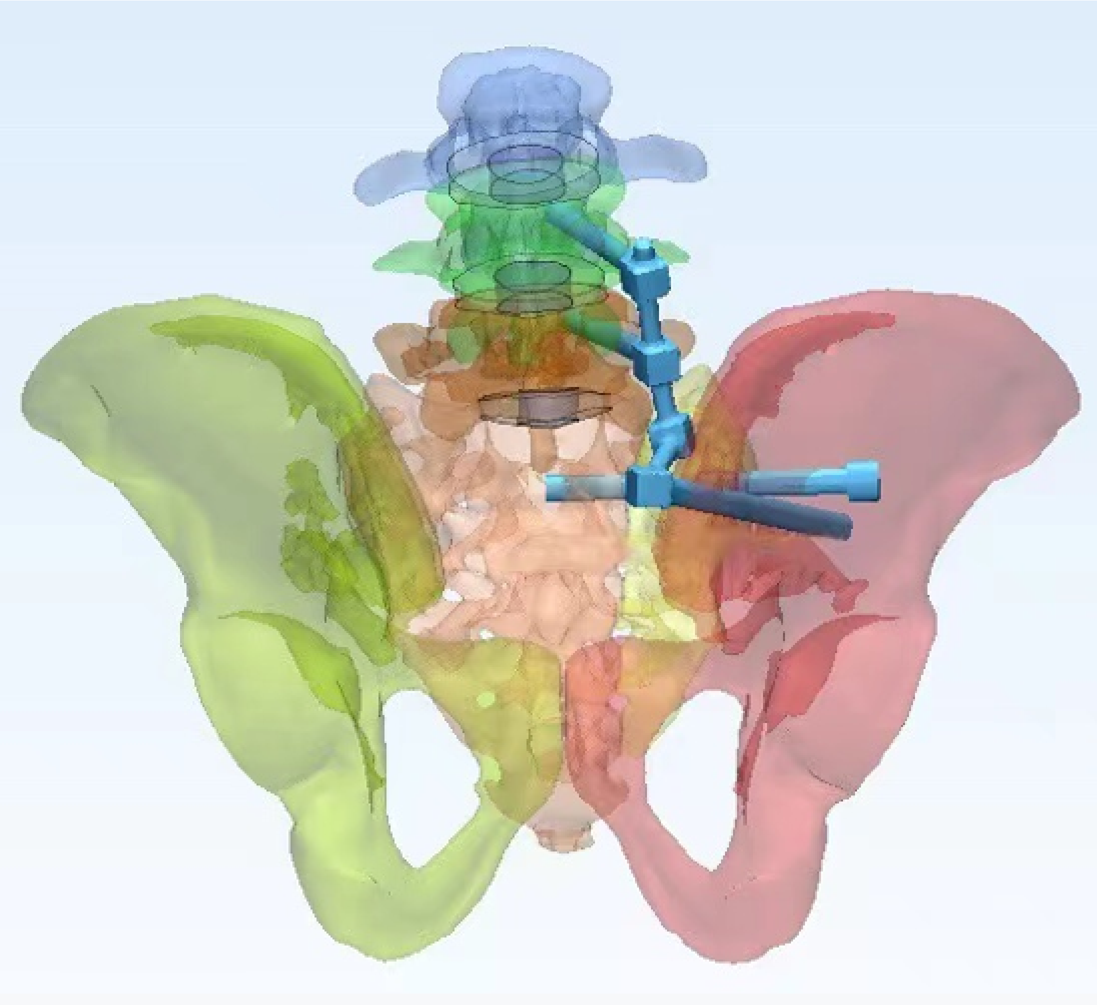

Figure 4

sketch map of L4L5NS1

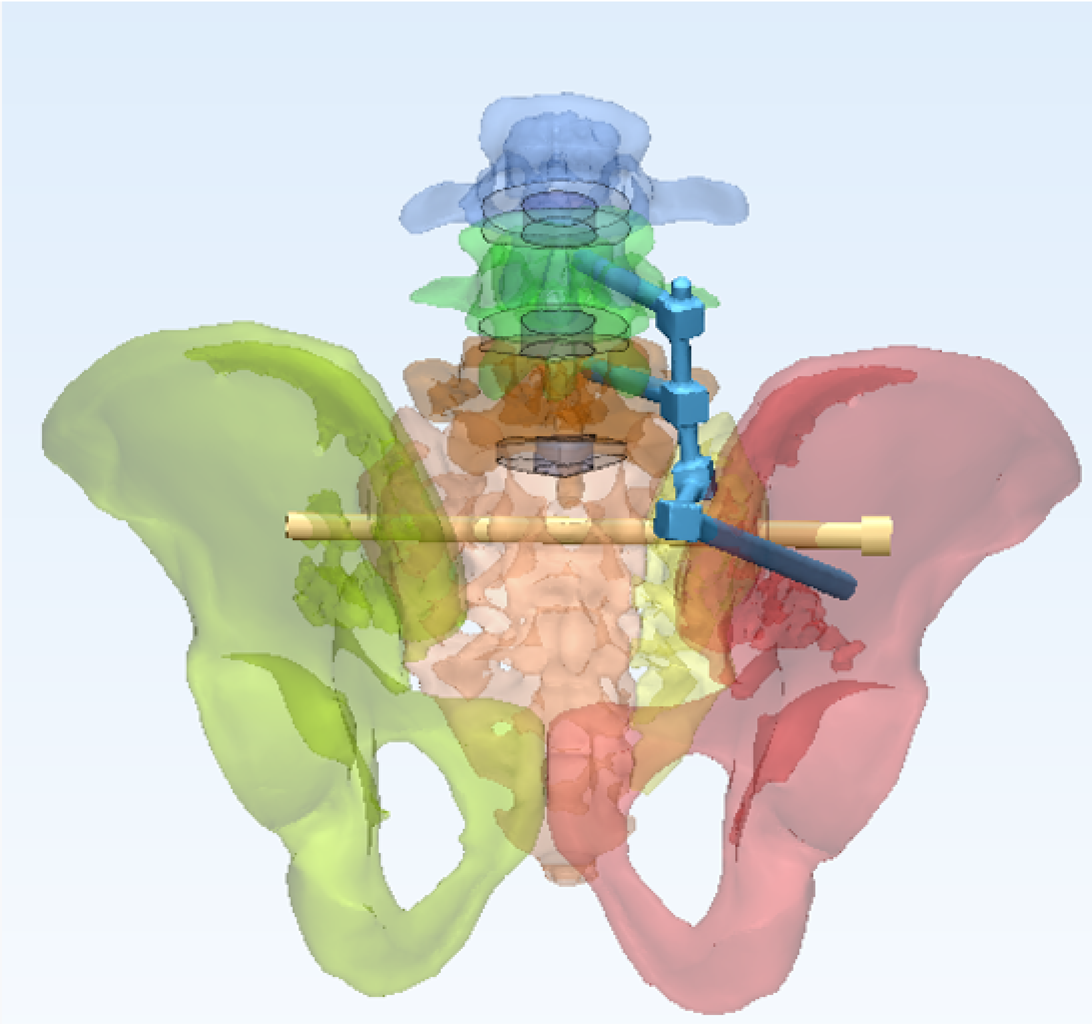

Figure 5

sketch map of L4L5LS1

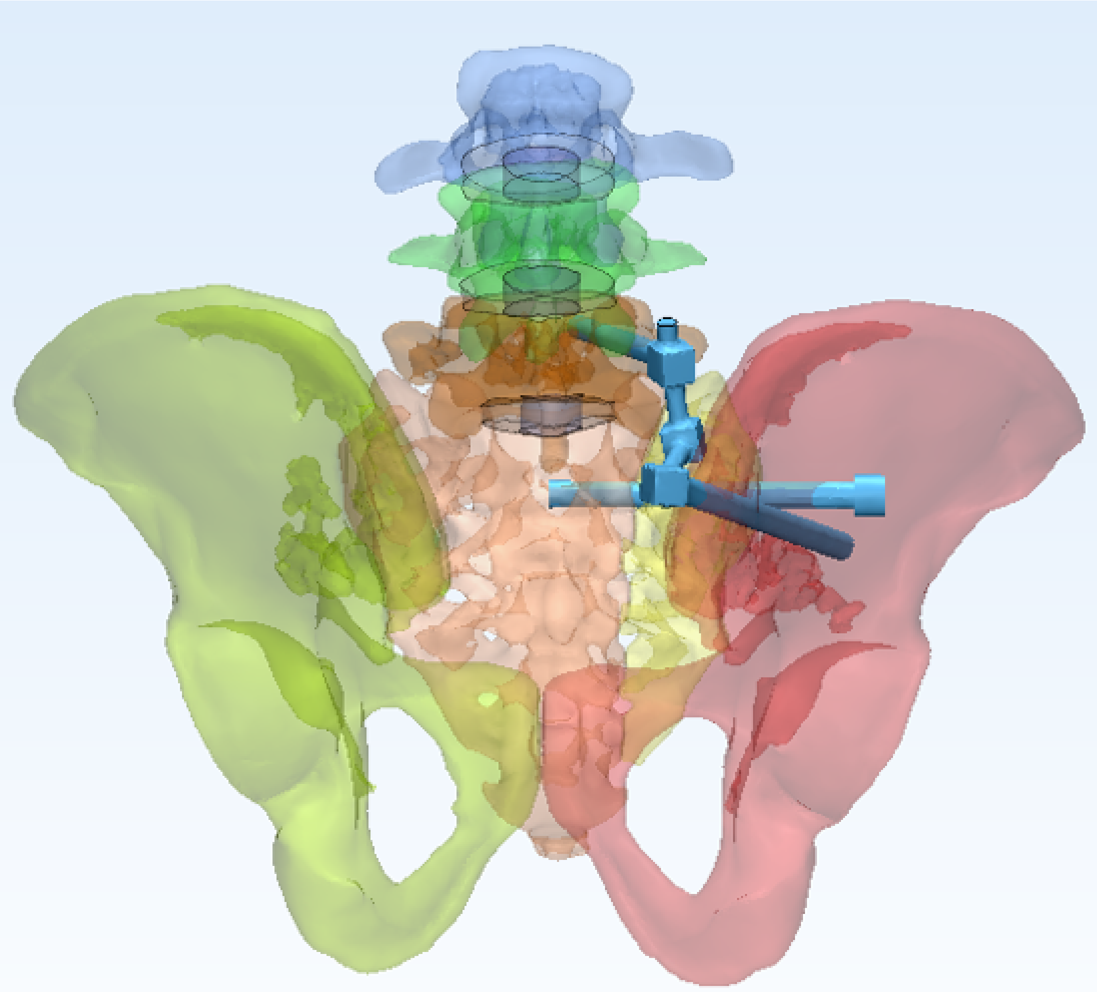

Figure 6

sketch map of L5NS1

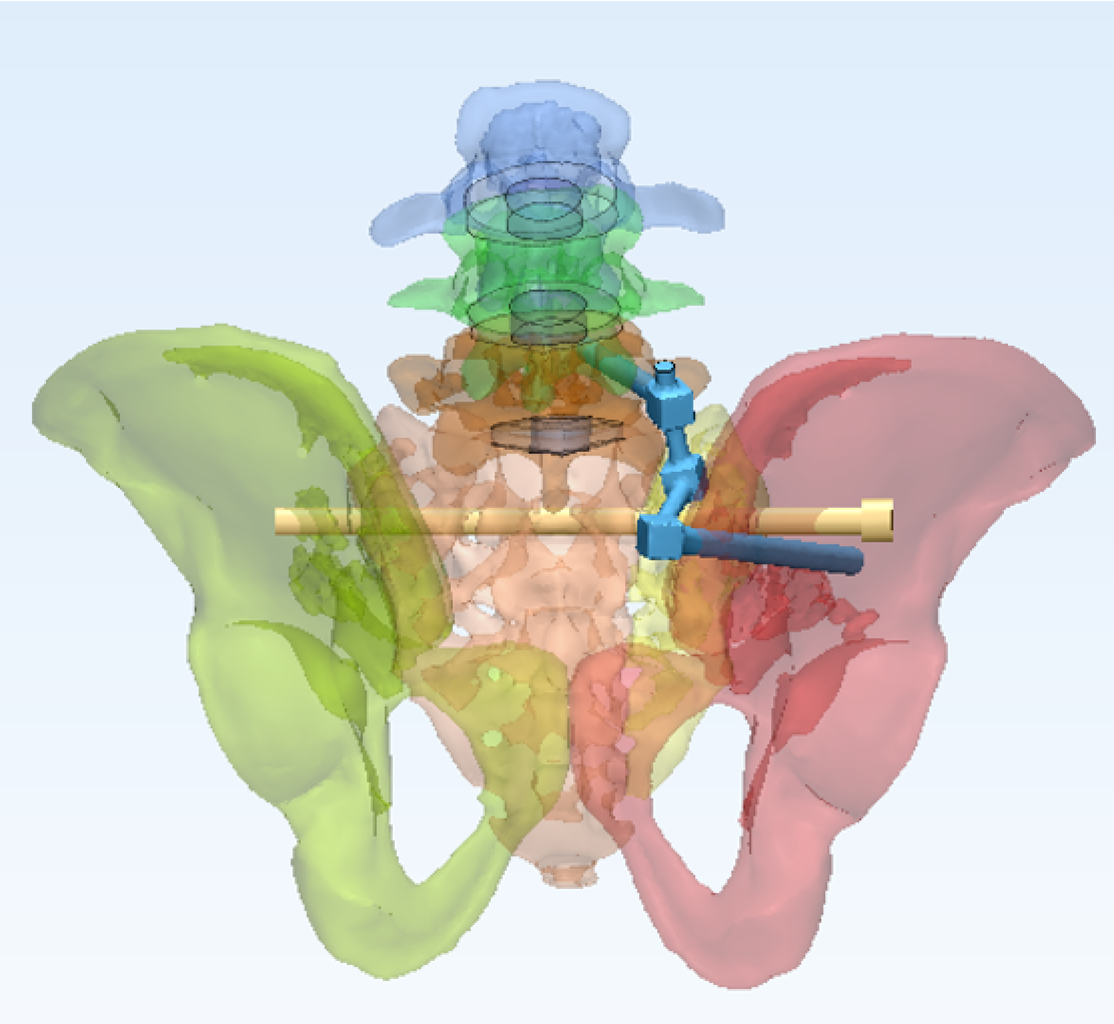

Figure 7

sketch map of L5LS1

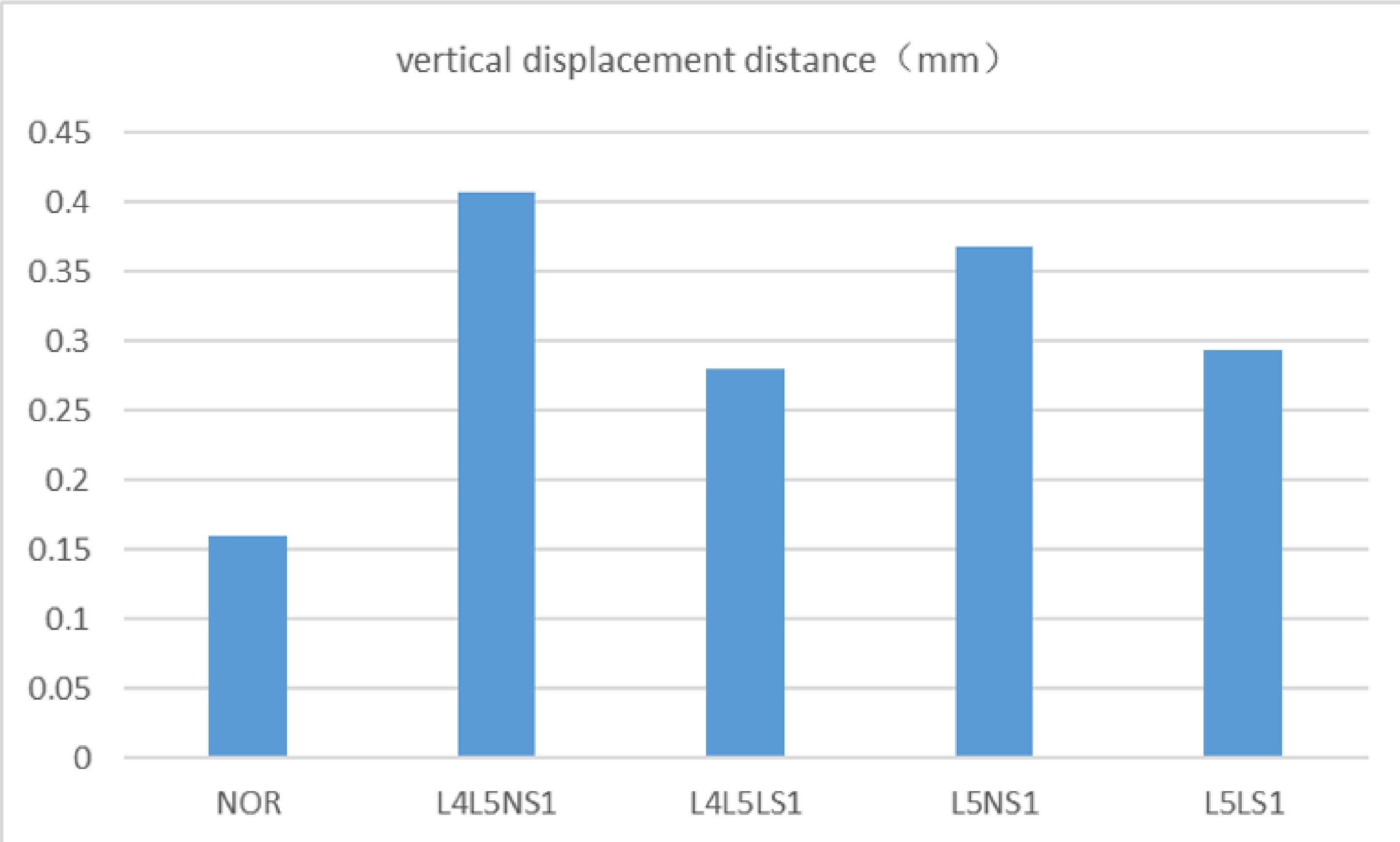

Figure 8

vertical displacement distance Under 600N vertical load

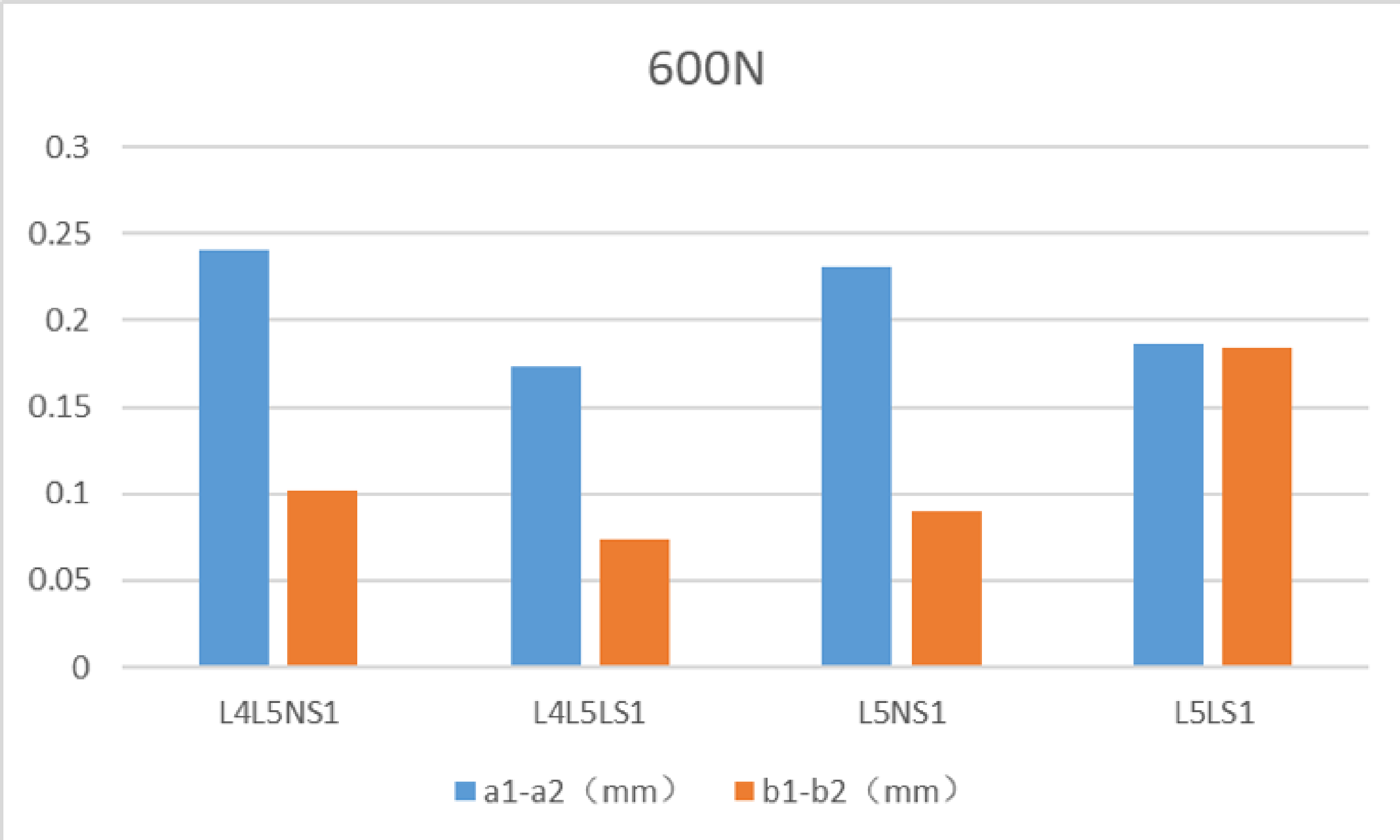

Figure 9

Fracture separation value under 600N vertical load

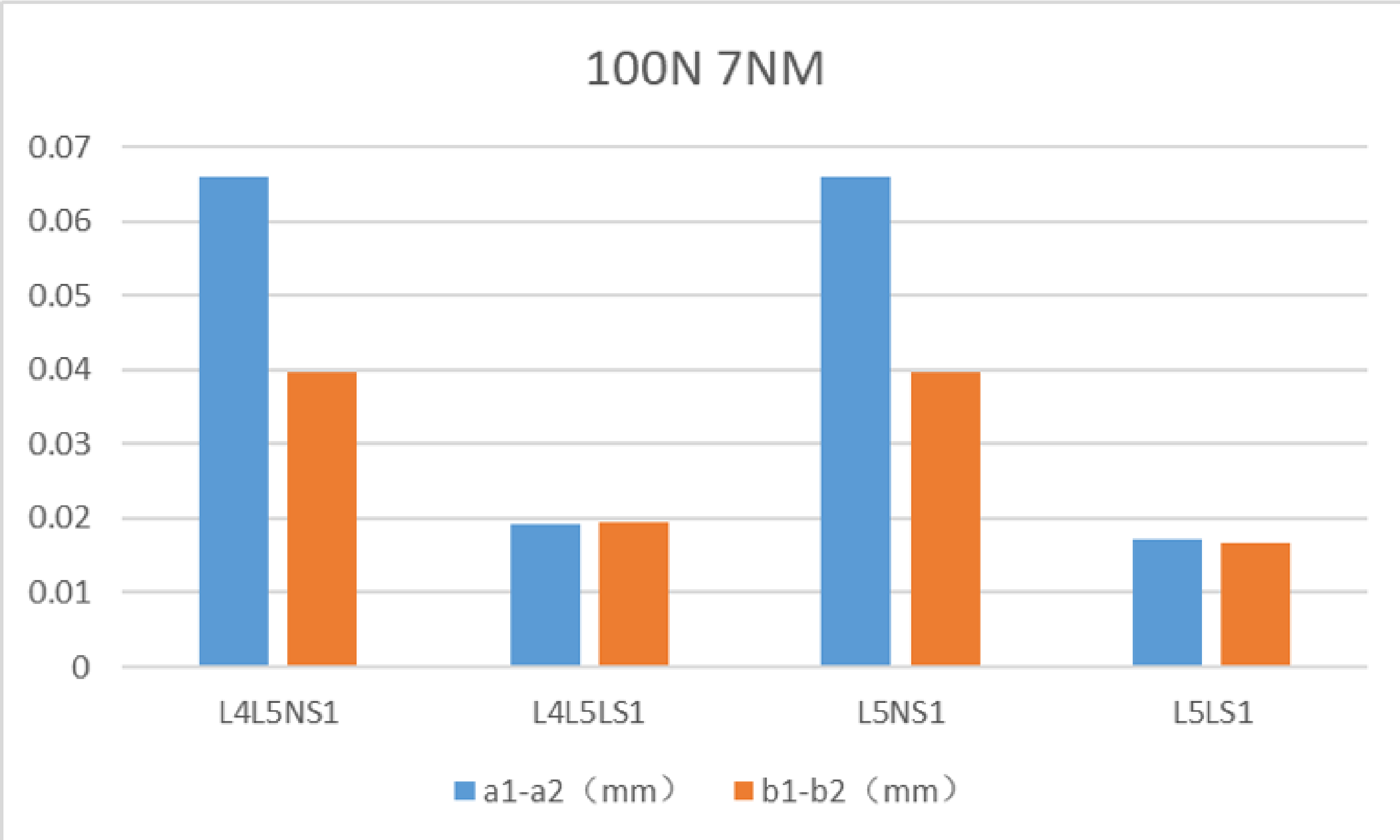

Figure 10

Fracture separation value under 100N slave load and 7Nm torque

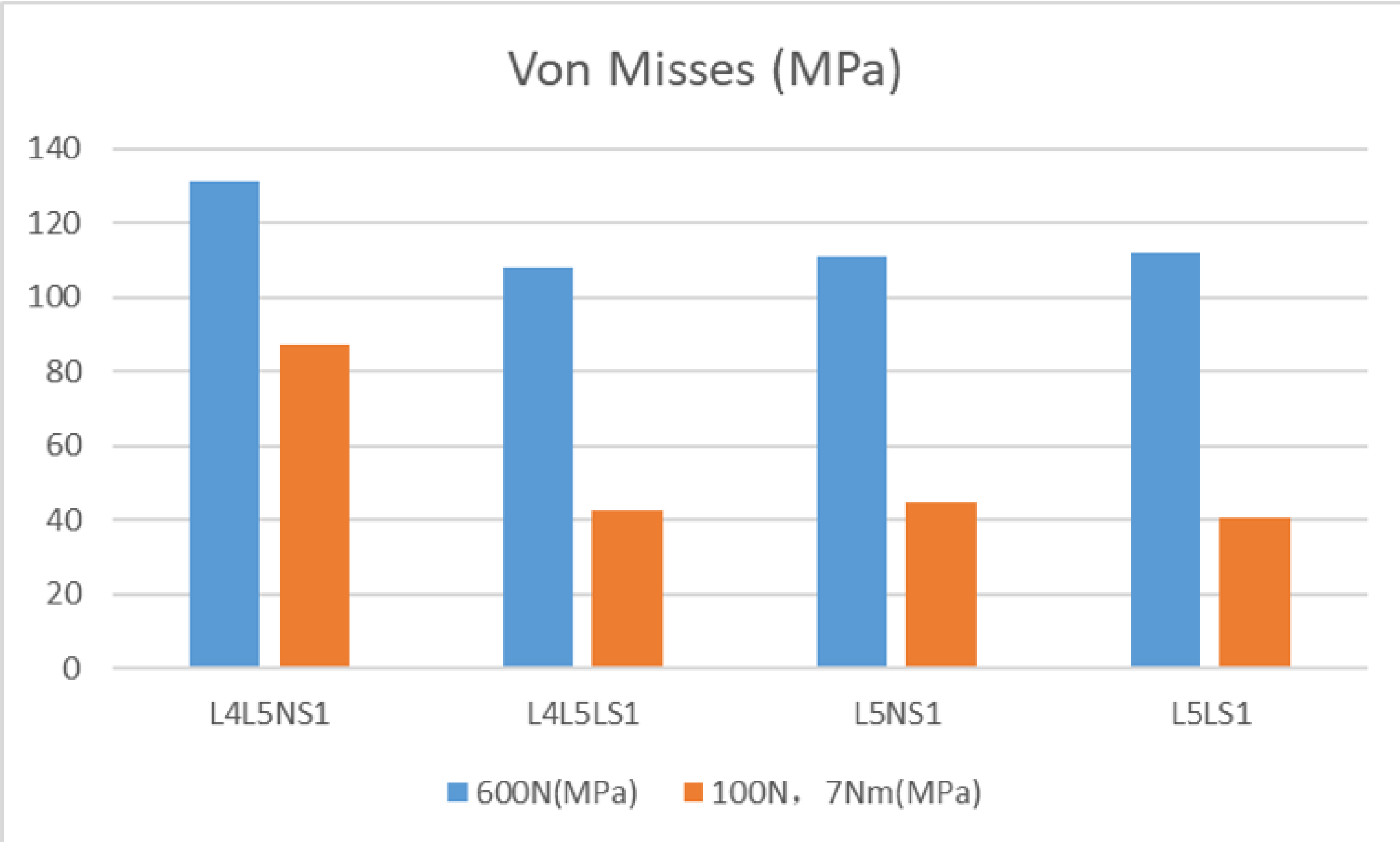

Figure 11

The Maximum von miles stress