Finite element analysis of breakage risk of two kinds of sacroiliac screws in unilateral sacral fractures

Yupeng Ma
Yantaishan Hospital https://orcid.org/0000-0002-1879-6970
Yong Zhao (nihaoedde@126.com)
Dexin Zou
Yantaishan Hospital
Shengjie Dong
Yantaishan Hospital
Xiujiang Sun
Yantaishan Hospital
Gong Cheng
Yantaishan Hospital
Wei Lian
Yantaishan Hospital
Yuchi Zhao
Yantaishan Hospital
Tao Sun
Yantaishan Hospital
Dan Wang
Yantaishan Hospital
Shudong Zhang
Yantaishan Hospital

Research article

Keywords: pelvis, sacral fracture, sacroiliac screw, screw breakage, biomechanics

Posted Date: March 17th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-17552/v1

Abstract

To compare the risk of breakage of lengthened sacroiliac screw and ordinary sacroiliac screw for the treatment of unilateral vertical sacral fractures to provide reference for clinical application. A finite element model of Tile C pelvic ring injury (unilateral type Denis □ fracture of sacrum) was produced. The sacral fractures were fixed with lengthened sacroiliac screw and ordinary sacroiliac screw in 6 types of models respectively. The maximal Von Mises stresses and stress distribution of the two kinds of screws in the case of standing on both feet were measured and compared. The maximal Von Mises stress of lengthened screw is less than that of ordinary screw. Compared with ordinary screw, the stress distribution in lengthened screw is more homogeneous. In conclusion, the breakage risk of screws fixed in double-segment is lower than that of screws fixed in single-segment, and the breakage risk of lengthened screws is lower than that of ordinary screw, and the breakage risk of screws fixed in S2 segment is lower than that of screws fixed in S1 segment.

Introduction

Unilateral sacral fractures caused by high-energy injuries are rare[1], and most of the cases accompanied by posterior ring injuries. Vertical fracture of the sacrum (AO type C1.3) are vertically unstable as a result of complete disruption of the posterior arch [2–4], and accompanied by a high rate of morbidity and mortality[4,5]. Many studies have shown that such fractures cause complications such as malunion, nonunion of bones, neurological dysfunction, low back pain, abnormal gait, and bowel/bladder problems, and surgical treatment can reduce long-term complications [6–9]. Therefore, For the cases with unstable sacral fractures, surgical treatment is necessary at the early stage. The goal of the operation is to reconstruct the stability of the posterior pelvic ring by reduction and fixation of the sacral fracture.

A variety of methods for vertically unstable sacral injuries have been advocated, including transiliac rods [10,] transiliac plates[11], percutaneous iliosacral screws[12,13], and spinopelvic instrumentation [14,15]. In the posterior pelvic ring injuries treatment, sacroiliac screw internal fixation technology is commonly used [16]. Sacroiliac screws have significant biomechanical advantages and minimally invasive percutaneous puncture advantages in the treatment of longitudinal fractures of the sacrum.[17].

For the purpose of maximizing the effect of Sacroiliac screws, We did research[18–20] on the ordinary sacroiliac screw and lengthened sacroiliac screw by radiological anatomical and biomechanical methods. Our previous studies have shown that fixation effect will be increased when used lengthened sacroiliac screw and fixed the S1 and S2 [19,20]. However, there are few studies that have assessed the breakage risk of lengthened sacroiliac screw and factors involved in screw breakage. Nevertheless, Whether an increase in screw breakage risk accompanies the increase in screws' length? In other words, What is the relationship between the length of sacroiliac screws and mechanical safety performance? Solving this problem is of great value in guiding the application of sacroiliac screws in unilateral sacral fractures. However, No related studies have reported.

The purpose of this study is to make a biomechanical comparison of two kinds of sacroiliac screws in various modes for fixing unilateral longitudinal sacral fractures using three-dimensional finite element technique, and assess factors involved in screw breakage and provide a theoretical basis for clinical practice.

Methods

Finite Element Method[20] is adopted in this research which we established in Our earlier studies. (Fig.1) A vertical 600N loaded on the superior surface of the sacrum to simulate the standing human. We compare and measure the stress distribution and von mises stresses of the two kinds of sacroiliac screws in various modes. Material parameters used in the model as shown in table 1 and table 2. [21–23]

Finite element models were constructed from computed tomography (64-slice spiral CT (Philips)) images from a normal female (36 years old, 170 cm, 63 kg). The slices were 1 mm thick. A virtual 3d model of the sacrum and innominatum was created from CT data in DICOM format with image processing software (mimics 10.0). The geometric extents of pelvic cortical and trabecular bones were defined on the basis of The surface mesh. By using four noded linear solid tetrahedral elements with an average edge length of 2 mm, we created an unstructured mesh of bone trabeculae in Abaqus/CAE. The cortical bone surrounding the trabecular bone is represented by a triangular shell element. The thickness of the shell element is 2mm.[21]

We assumed tied condition between the inner surface of cortical bone and the surface of trabecular bone. Young’s modulus and Poisson’s ratio were taken to be 150 N/mm 2 and 0.2 for trabecular bone, and 18,000 N/mm 2 and 0.3 for cortical bone[18]. The sacroiliac cartilage and interpubic disc were represented as continuum structure occupying the interspace and mesh into hexahedron element. Sacroiliac ligament, sacrospinous ligament and attachment regions constructed according to a previous study[20].

We cut the sacrum in half through the right sacral foramens,to construct a unilateral sacral fracture(AO type C1.3,Denis II) model. The final finite element normal pelvis and unilateral sacral fracture were printed in Fig. 1. In the simulation, we used two 7.3mm cannulated screws (lengthened sacroiliac screw and sacroiliac screw) placed in either S1 segment or S2 segment, or both S1 and S2 segment in a unilateral sacral fracture model.

Six fixation cases were imitated for finite element analysis: one lengthened sacroiliac screw fixation in S1 segment (L1) one lengthened sacroiliac screw fixation in S2 segment (L2) one lengthened sacroiliac screw fixation in S1 and S2 segments respectively(L12) one sacroiliac screws fixation in S1 segment (S1) one sacroiliac screws fixation in S2 segment (S2) one sacroiliac screws fixation in S1 and S2 segments respectively (S12) (Fig.2-Fig.7)

Assembly is accomplished by placing constraints between interacting surfaces. These interaction surfaces located at the bone-implant interface between the sacrum, the sacroiliac cartilage and the ilium, the pubic rami and interpubic disc, and the bone-implant interfaces in the screw thread. In the screw stem regions Frictionless sliding contact was used between the interaction surfaces of the bone-implant interfaces. We applied a penalty contact with a friction coefficient of 0.3 on the interaction surface of the fracture. The acetabular rotation centre was used as the fixed point to simulate the boundary conditions of the acetabulum.

Results

In either model, the stress concentration area of the screw was found in the corresponding screw area of the sacral fracture area. In the model of using lengthened sacroiliac screws, the maximal Von Mises stress was largest in the L1 model, followed by the L2 model, and least in the L12 model. In the model of using ordinary sacroiliac screws, the maximal Von Mises stress was largest in the S1 model, followed by the S2 model, and least in the S12 model.

When we compared the model of the lengthened sacroiliac screws with that of the ordinary sacroiliac screws, we found the following results. The maximal Von Mises stress in the S1 model was higher than the L1 model, and the maximal Von Mises stress in the S2 model was similar to the L2 model. The maximal Von Mises stress of the S1 segment screw-in model of S12 was higher than that of the S1 segment screw-in the model of L12. Similarly, The maximal Von Mises stress of the S2 segment screw-in the model of S12 was higher than that of the S2 segment screw-in the model of L12. In both S12 model and L12 model, the maximal Von Mises stress of the S1 segment screw was similar to that of the S2 segment screw. (Table 3)

The stress distribution of the lengthened sacroiliac screw was more homogeneous than that of the ordinary sacroiliac screw. In the model of different fixed segments of the same screw, the screw stress distribution of fixed single sacral segment was more concentrated than that of fixed two sacral segments. When both sacral segments were fixed, the distribution of screw stress in the upper segment was more concentrated, and the distribution of screw stress in the next stage was more uniform

Discussion

Unilateral sacral fractures are uncommon in clinical and are often accompanied by instability of the posterior pelvic ring. Sacroiliac screw is well known as a conventional internal fixation technique for posterior pelvic ring injuries[16]. Theoretically, the SI screw fixation can provide stability and a compression effect at the fracture site. However, some clinical studies have raised that conventional sacroiliac screw fixation may not provide sufficient stability universally. Keating et al. [24] applied the sacroiliac screws to achieve an anatomic or near-anatomic reduction in 84% of pelvic fractures, and Ultimately, however, the malunion rate was 44%. Damian et al.[12] showed that sacroiliac screws are clinically unreliable for vertical fractures of the sacrum. More recently, the use of lengthened sacroiliac screw arised[29][30]. This paper described it as “lengthened sacroiliac screw”. The screw is inserted from the external surface of the ilium across the contralateral sacroiliac joint and exit the ilium. Gardner et al[25] described the foundation for the effectiveness of lengthened sacroiliac screw. First, Lengthening sacroiliac screws has the characteristics of better distribution of vertical shear load, reduction of stresses at the screw tip and resistance to displacement. Second, In addition to the absolute length of the screw, lengthened sacroiliac screw screws allow more threads to bind to the bone, which may increase holding power. Third, lengthened sacroiliac screw provides anchorage in the iliac cortical bone, which may increase the screw's role in maintaining reduction. Our sacral fractures based biomechanical investigations[19,20] show that the lengthened sacroiliac screws provide better stability than ordinary screws. However, it was not previously reported before whether the application of lengthened sacroiliac screw is accompanied by an increased risk of breakage.

As one of the essential safety indexes of screws, the maximal Von Mises stress of screws increases While the risk of screw fracture increases. The higher the stress, the greater the likelihood of screw failure. The following results can be summarized from this study. Firstly, Overall, When comparing different fixation modes with the same kind of screws, we found that the maximal Von Mises stress was the largest in the model that only fixed S1 segment, the minor in the model that only fixed S2 segment, and the least in the model that both S1 and S2 were fixed. Secondly, When fixing S1 segment and S2 segment at the same time, the maximal Von Mises stress of the S1 segment screw in the same model is similar to that of the S2 segment screw, regardless of whether it is a lengthened screw model or an ordinary screw model. Thirdly, If considered from fixed segment, the screw fracture risk of double segment fixation is lower than that of single-segment fixation. In double-segment fixation, the fracture risk of the two screws was similar. When different screws were used to compare the same fixed segment, we found that the maximal Von Mises stress of the lengthened screw was lower than that of the ordinary screw, and the lengthened screw had a lower fracture risk than the ordinary screw. In summary, from the perspective of screw safety, it is recommended to use lengthened screws for fixation. The safest fixation method is to use lengthened sacroiliac screws to fix S1 and S2 segments. Even in the absence of lengthened sacroiliac screws, ordinary sacroiliac screws are recommended for fixation of both S1 and S2 segments. If you can only fix it with one screw, regardless of which kind of sacroiliac screw the S2 segment fixation is more recommended than the S1 segment fixation. The results of screw safety analysis are consistent with those of stability analysis.

Through the uniform distribution of stress in internal fixation, the risk of a fatigue fracture in internal fixation can be reduced by avoiding excessive concentration in certain parts. However, in this study, When we compared the stress distribution, we found that the stress distribution of screws was not uniform in any of the models. Compared with different kinds of the screw we used, the stress distribution of the lengthened sacroiliac screw was more uniform. Compared with different fixed segments, the stress distribution of double-segment fixed screws was more uniform. Similarly, these findings are consistent with the results of the stability analysis and the maximum von mises stress analysis.

The following points need to be pointed out in this study. Firstly, although an unstable anterior ring is the feature of Tile C pelvic ring injury, Considering that the stability of the posterior pelvic ring may be affected by a variety of fixation modes of the anterior pelvic ring fracture, This study did not imitate the injury and fixation of the anterior pelvic ring, but only maintained the normal state of the anterior pelvic ring. The anterior pelvic ring had a slight effect on the stability of the posterior pelvic ring and did not affect our comparison of several study models. Secondly, to best simulate the pelvic stability, in our research, we reserved multiple important pelvic ligaments. Meanwhile, To eliminate any unpredictable forces that might affect the measurement, we did not imitate the muscles to simulate the additional stability caused by them. Thirdly, it was not feasible to simulate all the features of comminuted sacral fractures accurately, in our study, We used a well-accepted method to imitate a unilateral sacral sagittal fracture through the unilateral sacral foramen, which is considered to be the typical type of simulated sacral fracture (Denis II). Moreover, Our model method had a straight and smooth fracture, which not only facilitated the standardization of the model but also did not affect the accuracy of mesh generation and subsequent calculation. Fourthly, To best mimic the normal state of the pelvis while standing, we position the pelvis so that the top surface of the symphysis pubis aligned with the bottom surface of the sacrum. Fifthly, The finite element model of our study is independent of bone, and our conclusions theoretically applicable to both young and elderly patients.

Conclusion

The breakage risk of screws fixed in double-segment is lower than that of screws fixed in single-segment, and the breakage risk of lengthened screws is lower than that of ordinary screw, and the breakage risk of screws fixed in S2 segment is lower than that of screws fixed in S1 segment.

Declarations

Acknowledgements

Not applicable.

Funding

This research was supported by National Natural Science Foundation of China (No. 81301553 & No. 81641171), Distinguished Middle-Aged and Young Scientist Encourage and Reward Foundation of Shandong Province, China (No. BS2013SF015), Shandong Provincial Key R&D Program of China (No. 2018GSF118064), Project of Medical and Health Technology Development Program of Shandong Province, China (No. 2017WS169), Project of Traditional Chinese Medicine Science & Technology Development Program of Shandong Province, China (No. 2017-391) and Project of Science & Technology Development Program of Yantai City, China (No. 2010149-10, No. 2013WS234, and No.2016WS036).

Availability of data and materials

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

Author information

Affiliations

1.Orthopaedics Department, Yantai Shan Hospital, 91#, Jiefang Road, Yantai, 264008, Shandong Province, People's Republic of China

Yupeng Ma, Yong Zhao, Dexin Zou, Shengjie Dong, Xiujiang Sun, Gong Cheng, Yuchi Zhao,Tao Sun, Dan Wang,Shudong Zhang,

2.CT/MR Department, Yantai Shan Hospital, 91#, Jiefang Road, Yantai, 264008, Shandong Province, People's Republic of China

Wei Lan

Contributions

YPM and YZ designed and participated in the whole process of the study and drafted the manuscript. WL, DXZ, YCZ, XJS, and GC carried out the experimental operating. TS and WL participated in the data collection. DXZ and SJD performed the statistical analysis. DW and SDZ participated in the study coordination. All authors read and approved the final manuscript.

Corresponding author

Correspondence to Yong Zhao

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 Nork, S. E., Jones, C. B., Harding, S. P., Mirza, S. K. & Routt, M. L., Jr. Percutaneous stabilization of U-shaped sacral fractures using iliosacral screws: technique and early results. *Journal of orthopaedic trauma* 15, 238-246 (2001).

2 Marsh, J. L. *et al.* Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. *Journal of orthopaedic trauma* 21, S1-133 (2007).

3 Tile, M. Acute Pelvic Fractures: I. Causation and Classification. *The Journal of the American Academy of Orthopaedic Surgeons* 4, 143-151 (1996).

4 HC, S. *Pelvic ring fractures in Rockwood and Green's fractures in adults.*(ed.*Bucholz RW, CourtBrown CM, Heckman JD, Tornetta PIII)* 7th edn, 1415–1462 (Lippincott Williams and Wilkins, 2009).

5 Egol KE, K. K., Zuckerman JD. *Pelvis fracture in Hand book of fractures*. (ed. *Egol KE, Koval KJ, Zuckerman JD*) 4th edn, 327–343 (Lippincott Williams and Wilkins, 2010).

6 Carlson, D. A., Scheid, D. K., Maar, D. C., Baele, J. R. & Kaehr, D. M. Safe placement of S1 and S2 iliosacral screws: the "vestibule" concept. *Journal of orthopaedic trauma* 14, 264-269 (2000).

7 Cole, J. D., Blum, D. A. & Ansel, L. J. Outcome after fixation of unstable posterior pelvic ring injuries. *Clinical orthopaedics and related research*, 160-179 (1996).

8 Failinger, M. S. & McGanity, P. L. Unstable fractures of the pelvic ring. *The Journal of bone and joint surgery. American volume* 74, 781-791 (1992).

9 Matta, J. M., Dickson, K. F. & Markovich, G. D. Surgical treatment of pelvic nonunions and malunions. *Clinical orthopaedics and related research*, 199-206 (1996).

10 Gorczyca, J. T. *et al.* The strength of iliosacral lag screws and transiliac bars in the fixation of vertically unstable pelvic injuries with sacral fractures. *Injury* 27, 561-564 (1996).

11 Ayoub, M. A. Vertically unstable sacral fractures with neurological insult: outcomes of surgical decompression and reconstruction plate internal fixation. *International orthopaedics* 33, 261-267, doi:10.1007/s00264-007-0468-9 (2009).

12 Griffin, D. R., Starr, A. J., Reinert, C. M., Jones, A. L. & Whitlock, S. Vertically unstable pelvic fractures fixed with percutaneous iliosacral screws: does posterior injury pattern predict fixation failure? *Journal of orthopaedic trauma* 17, 399-405 (2003).

13 Ayoub, M. A. Type C pelvic ring injuries in polytrauma patients: can percutaneous iliosacral screws reduce morbidity and costs? *European Journal of Orthopaedic Surgery and Traumatology* 22, 137-144, doi:10.1007/s00590-011-0811-0 (2012).

14 Jones, C. B., Sietsema, D. L. & Hoffmann, M. F. Can lumbopelvic fixation salvage unstable complex sacral fractures? *Clinical orthopaedics and related research* 470, 2132-2141, doi:10.1007/s11999-012-2273-z (2012).

15 Ayoub, M. A. Displaced spinopelvic dissociation with sacral cauda equina syndrome: outcome of surgical decompression with a preliminary management algorithm. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society* 21, 1815-1825, doi:10.1007/s00586-012-2406-9 (2012).

16 Osterhoff, G., Ossendorf, C., Wanner, G. A., Simmen, H. P. & Werner, C. M. Percutaneous iliosacral screw fixation in S1 and S2 for posterior pelvic ring injuries: technique and perioperative complications. *Archives of orthopaedic and trauma surgery* 131, 809-813, doi:10.1007/s00402-010-1230-0 (2011).

17 Zhang, L. *et al.* An Effective and Feasible Method, "Hammering Technique," for Percutaneous Fixation of Anterior Column Acetabular Fracture. *BioMed research international* 2016, 7151950, doi:10.1155/2016/7151950 (2016).

18 Zhao, Y., Li, J., Wang, D. & Lian, W. Parameters of lengthened sacroiliac screw fixation: a radiological anatomy study. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society* 21, 1807-1814, doi:10.1007/s00586-012-2367-z (2012).

19 Zhao, Y. *et al.* Comparison of stability of two kinds of sacro-iliac screws in the fixation of bilateral sacral fractures in a finite element model. *Injury* 43, 490-494, doi:10.1016/j.injury.2011.12.023 (2012).

20 Zhao, Y. *et al.* Mechanical comparison between lengthened and short sacroiliac screws in sacral fracture fixation: a finite element analysis. *Orthopaedics & traumatology, surgery & research : OTSR* 99, 601-606, doi:10.1016/j.otsr.2013.03.023 (2013).

21 Phillips, A. T., Pankaj, P., Howie, C. R., Usmani, A. S. & Simpson, A. H. Finite element modelling of the pelvis: inclusion of muscular and ligamentous boundary conditions. *Medical engineering & physics* 29, 739-748, doi:10.1016/j.medengphy.2006.08.010 (2007).

22 Dakin, G. J. *et al.* Elastic and viscoelastic properties of the human pubic symphysis joint: effects of lateral impact joint loading. *Journal of biomechanical engineering* 123, 218-226 (2001).

23 Garcia, J. M. *et al.* Three-dimensional finite element analysis of several internal and external pelvis fixations. *Journal of biomechanical engineering* 122, 516-522 (2000).

24 Keating, J. F. *et al.* Early fixation of the vertically unstable pelvis: the role of iliosacral screw fixation of the posterior lesion. *Journal of orthopaedic trauma* 13, 107-113 (1999).

25 Gardner, M. J. & Routt, M. L., Jr. Transiliac-transsacral screws for posterior pelvic stabilization. *Journal of orthopaedic trauma* 25, 378-384, doi:10.1097/BOT.0b013e3181e47fad (2011).

Tables

Table.1 model parameters of pelvic ligaments

Ligament	K(N/m)	Number of springs
anterior and capsule	700	27
posterior (inner layer)	1400	15
intro-osseus	2800	8
sacrospinous	1400	9
sacrotuberous	1500	15
superior pubic	500	24
arcuate pubic	500	24

Table.2 model parameters of various kinds of material

	Young's modulus(MPa)	Poisson's ratio	Element Type
cortical bone	18000	0.3	shell element
trabecular bone	150	0.2	tetrahedral element
sacroiliac cartilage	1000	0.3	hexahedral element
interpubic disc	5	0.45	hexahedral element
screw	114000	0.3	hexahedral element

Table 3. the maximal Von Mises stress of screws (MPa)

	S1 segment	S2 segment
L1	55.61	
L2		49.61
L12	36.98	38.85
	S1 segment	S2 segment
S1	70.49	
S2		50.77
S12	46.49	44.14

Figures

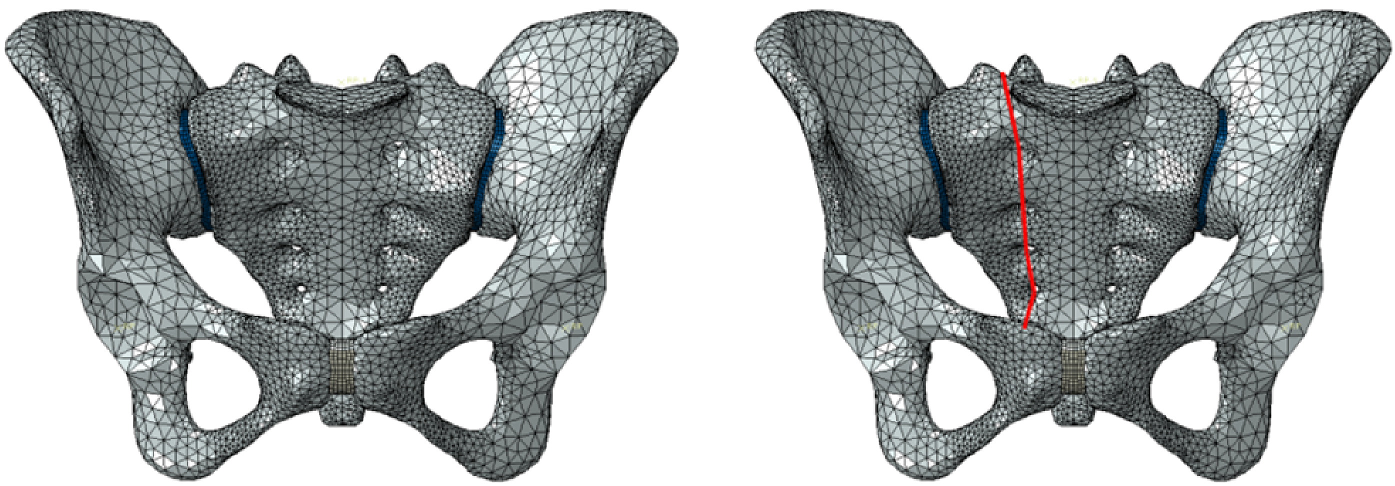

Figure 1

Pelvic three dimension finite element model (The left is normal pelvic and the right is unilateral sacral fracture.)

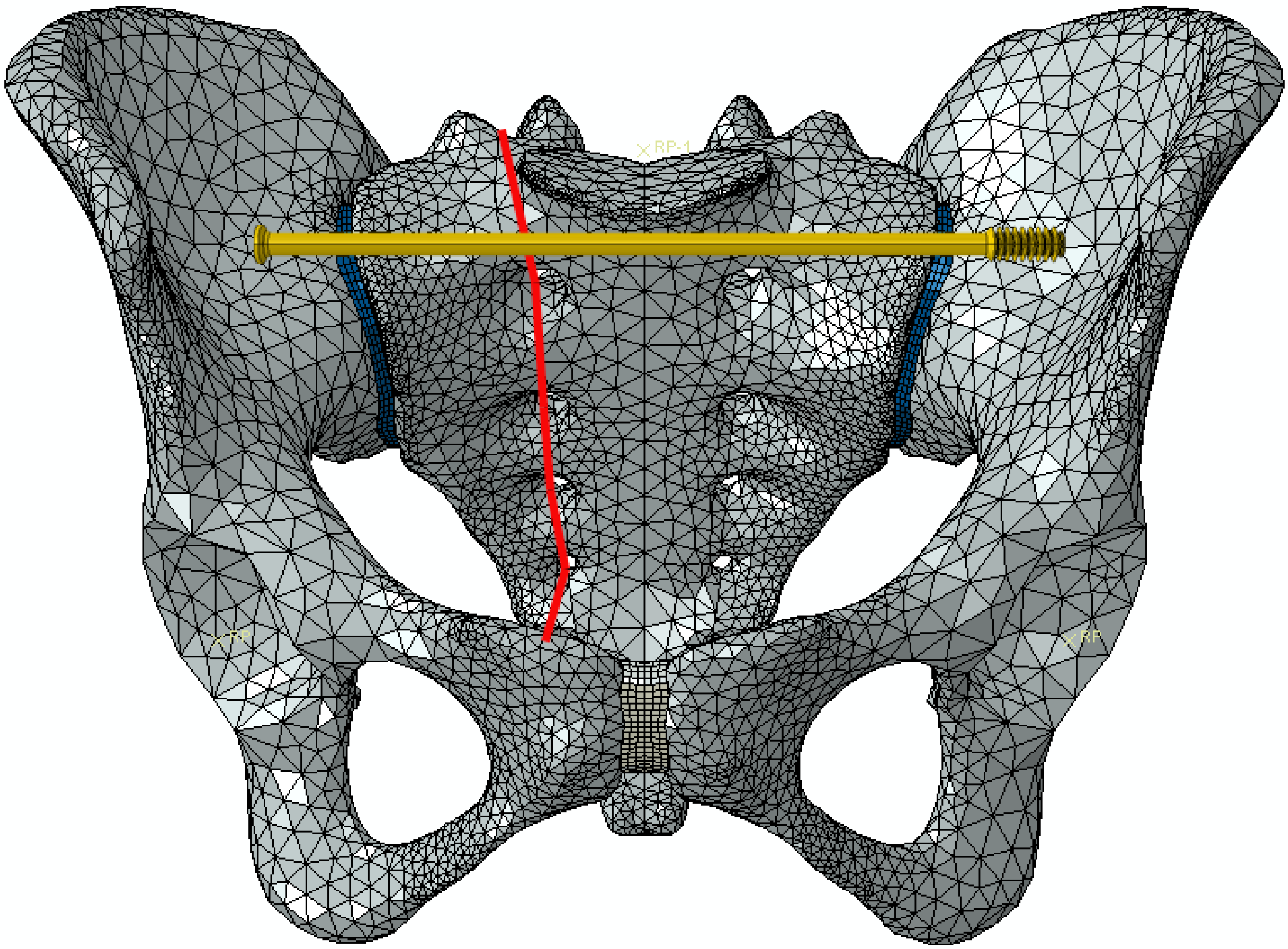

Figure 2

sketch map of L1

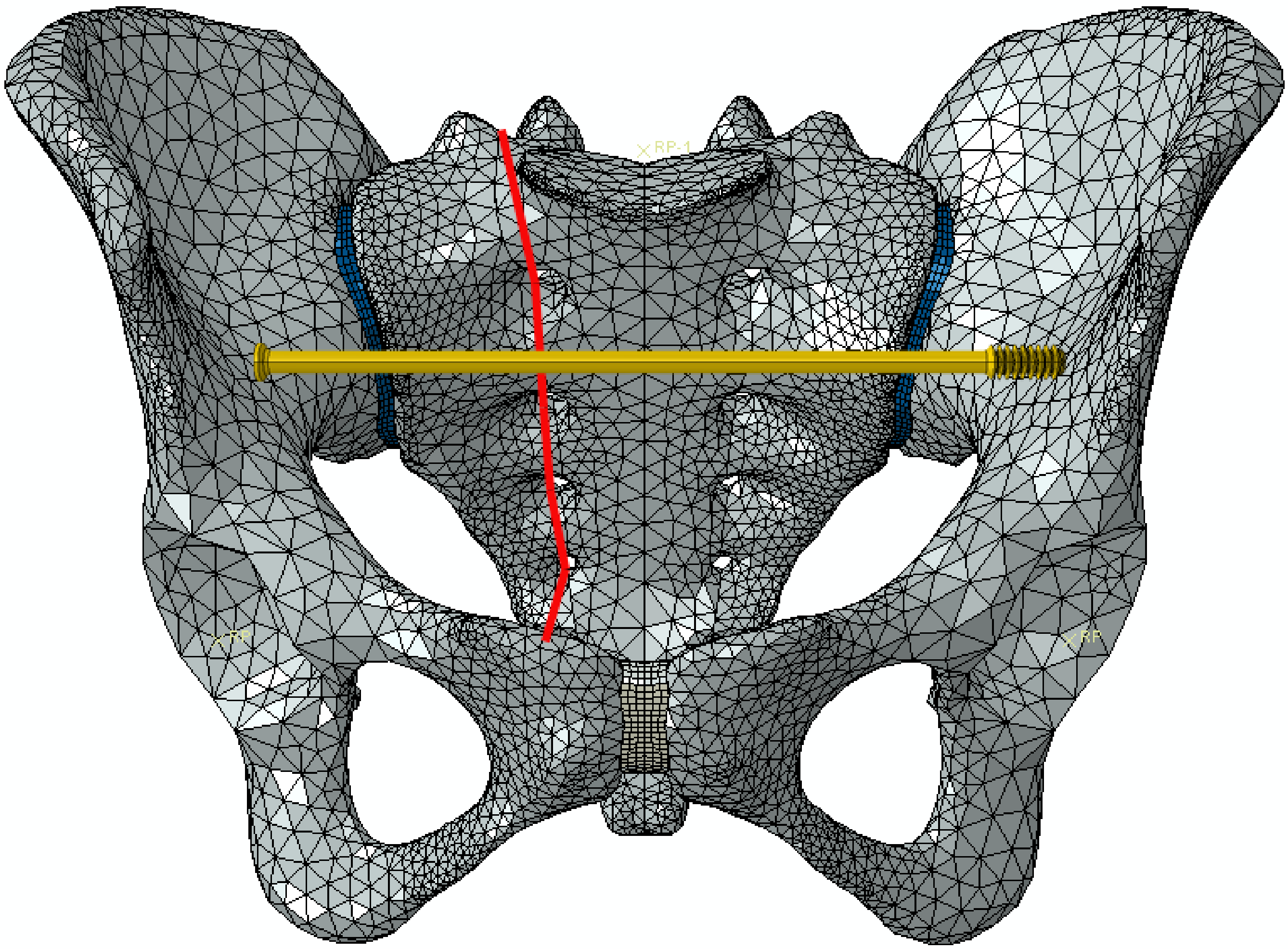

Figure 3

sketch map of L2

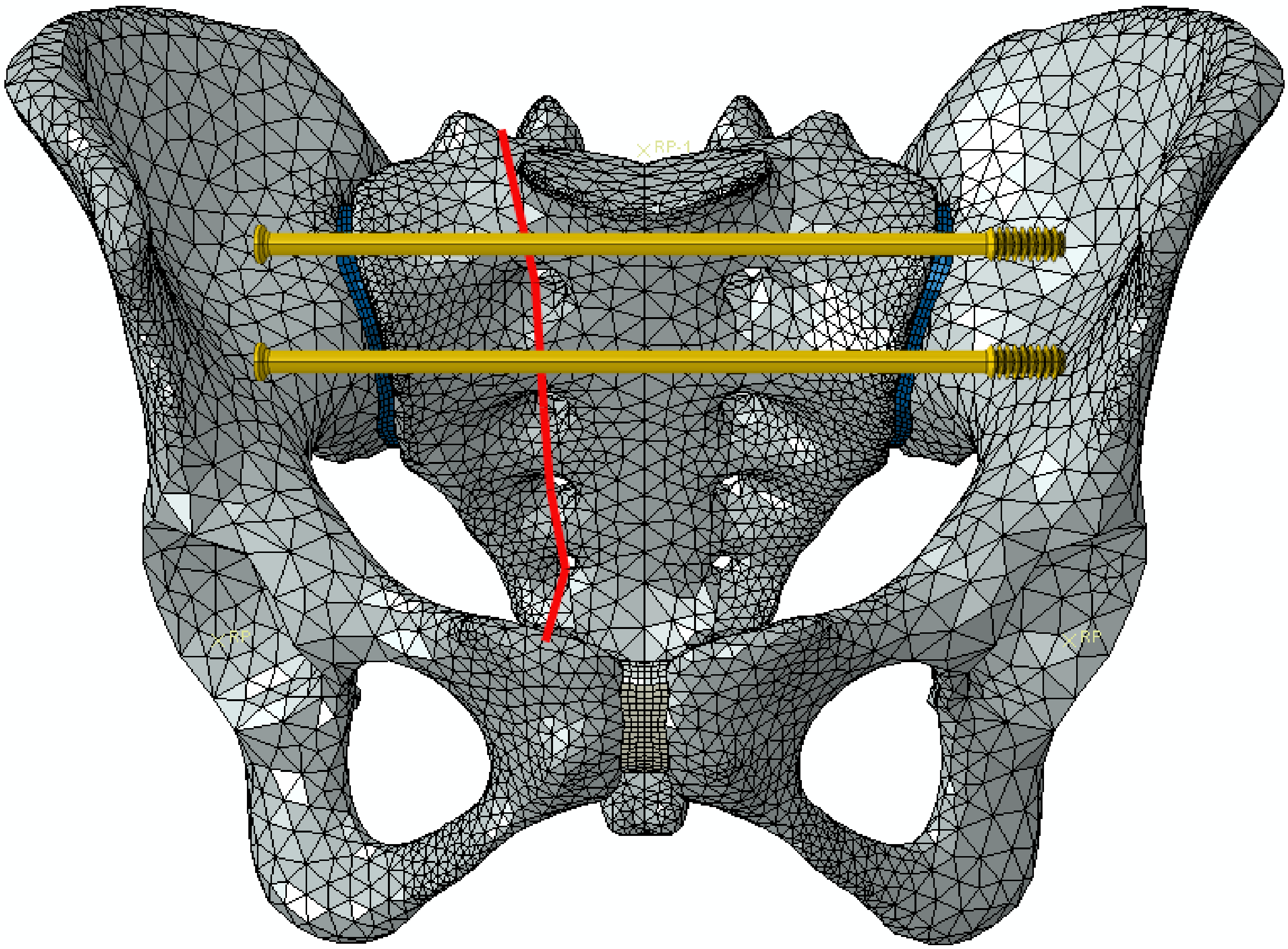

Figure 4

sketch map of L12

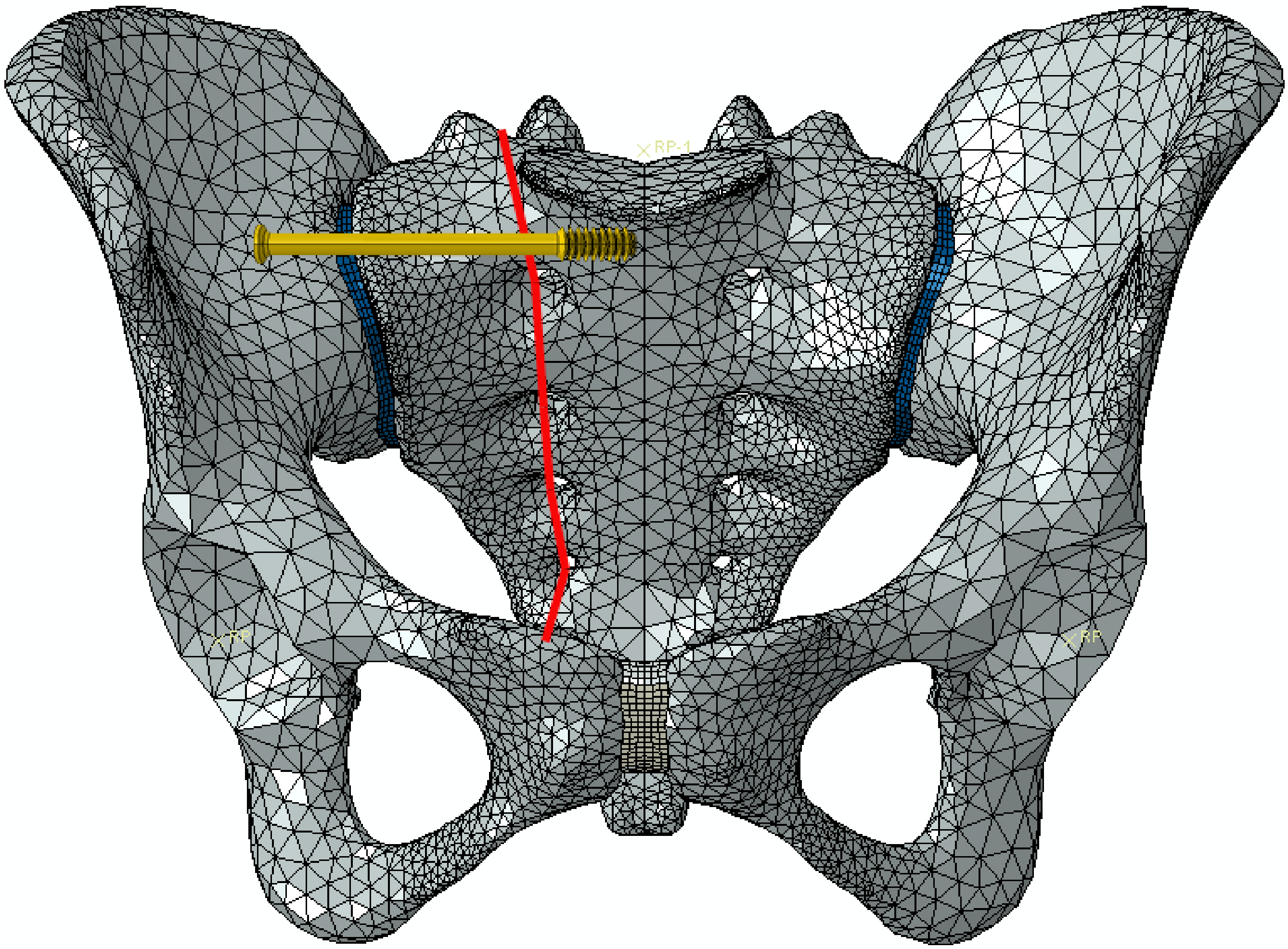

Figure 5

sketch map of S1

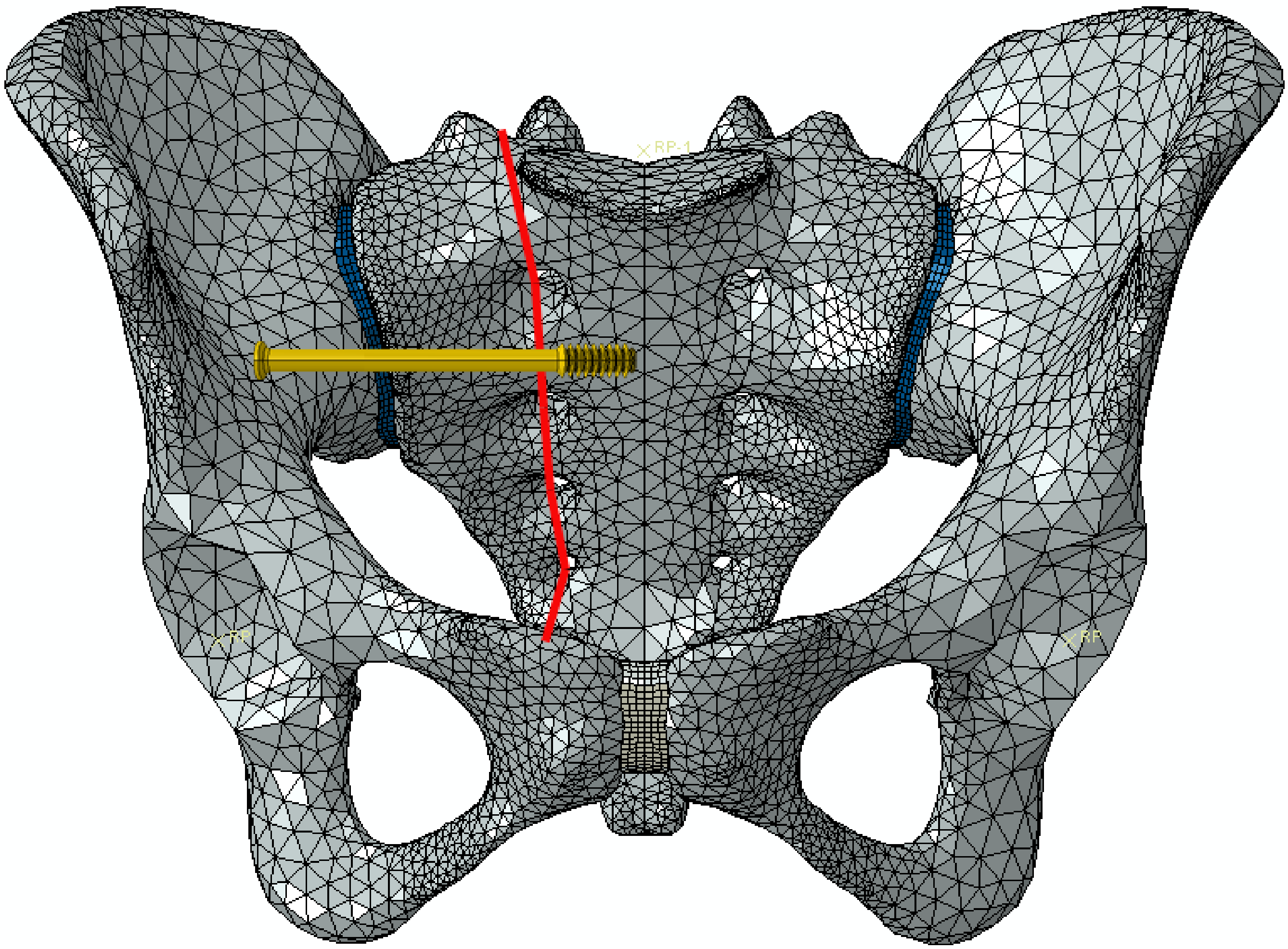

Figure 6

sketch map of S2

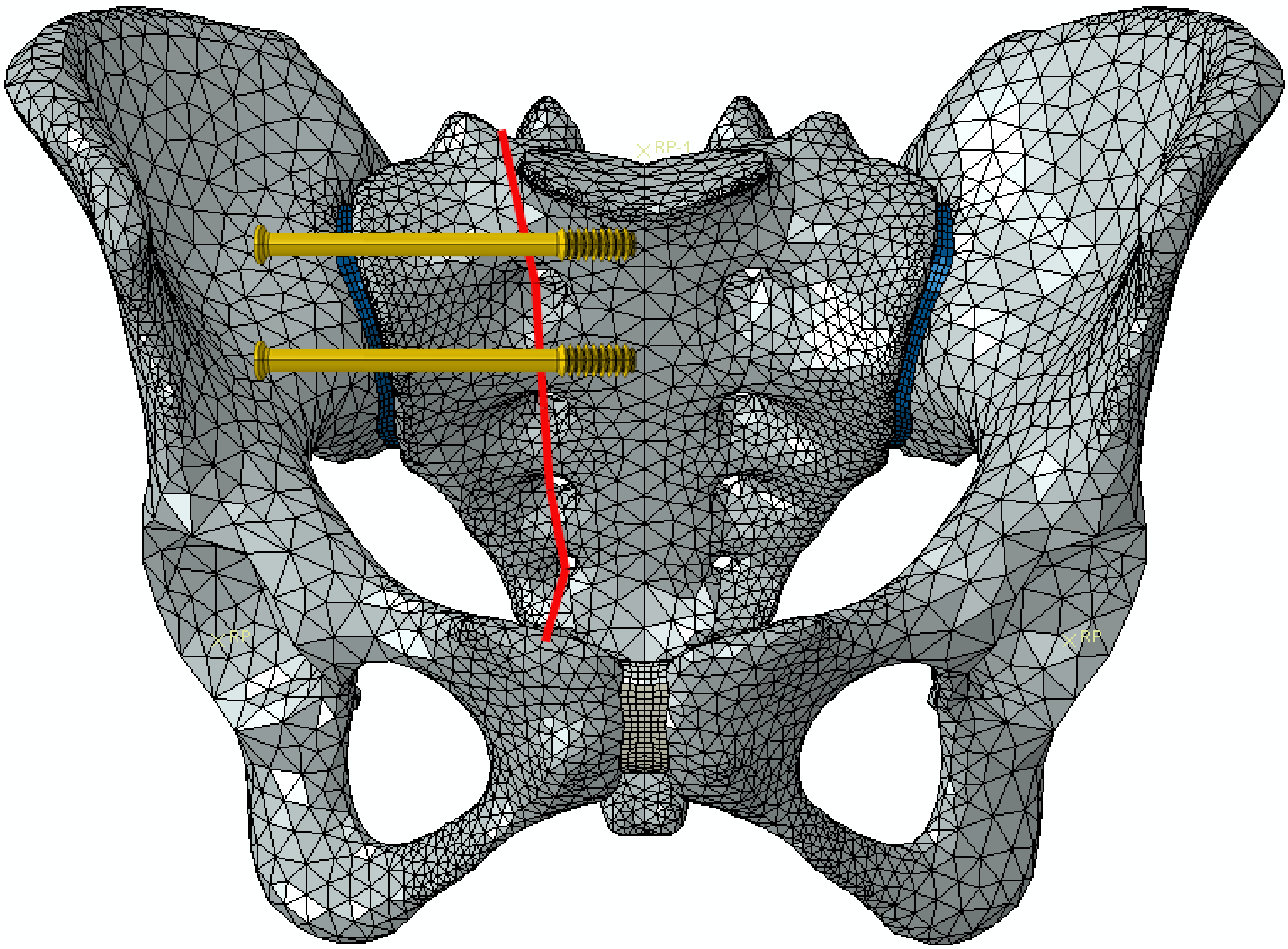

Figure 7

sketch map of S12