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Finite Element Analysis on Iliosacral Screw Fixation for Sacral Stress Fracture: A Comparison between Three Systems

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Abstract

Background: Sacral stress fracture is a rare but severe fracture that can be fixed by screw insertion. However, location and number of screws have been remained controversial. The goal of the present paper is to examine the efficiency of three fixation systems (1S-sup, 1S-inf and 2S) which vary in number and insertion location.

Materials and Methods: A 3D precious model of sacrum based on CT images, fractured from zone 2, was undergone to L_5-S_1 joint forces after the screws inserted in three fixation systems. Finite element method was used for the present research to evaluate stress distribution within the models and find the interfragmentary motion at the sacral fracture line.

Results: Stress is concentrated in vicinity to the fracture gap on the screws. Maximum stress was determined for 1S-inf system, considerably greater than two other systems. Although 1S-sup and 2S systems received similar maximum stress values, the relative displacement between the fragments was more limited in 2S system.

Conclusion: Screw fixation can be an efficient technique to fix the sacral fracture. By considering one screw to be inserted, superior location to the first foramina is more effective. Two-screw fixation system (2S) noticeably reduced the relative displacement between the fragments and prepared proper situation for fracture healing.

Introduction

Stress fracture is the most common type of sacral fractures that requires emergent treatment due to the weight loading of the upper extremities. However, since the symptoms of this rare type of fracture resemble with sciatic pain and also the radiographic findings are normal, the diagnosis of the sacral stress fractures has been generally concealed and the treatment subsequently hindered [1, 2]. Number of incidences of the sacral stress fractures has been increasingly reported within the population, specifically in elders due to their osteoporotic bones [3, 4]. Several sport medicine studies have also reported the sacral stress fractures in athletes [5]. Fracture in the sacrum of two male runners has been reported by Atwell and Jackson [6], and in the sacrum of a female runner who complained low back pain in one-leg stance position by Rodrigues et al. [7]. In another case for a female runner reported by Bottomley, muscular fatigue and bone density have been attributed to the sacral stress fracture [8]. Return to the competition has been reported for runners from 6 weeks [9], to 4 months [10], and even 8 months [11]. Also sacral stress fractures have been observed in army soldiers and military staffs due to repetitive loading on the sacrum [12].

The sacrum bone, in general, underwent to fracture in a superior-inferior direction, specifically in lateral parts. A line passing through the sacrum foramina named in Denis classification system as zone 2 [13], seemingly due to mechanical concept of stress concentration, is a prevalent type of sacral stress fracture [14-16]. It has been stated that the sacrum fracture is commonly occurred in the ala of the sacrum for athletes' population [17, 18]. Furthermore, sacral stress fracture is typically diagnosed in unilateral cases [5].

Treatments for sacral stress fractures generally mostly have been limited to rest, unload the sacrum and avoidance from daily activities and then gradually return to the regular life by continuous following-up the patient [10]. For the harsh cases of fractures in which the sacrum is fragmented into bone parts, however, orthopedic sacroiliac screws have been used to connect the fragments together [19, 20]. By using such a technique which today has been considered as a minimally-invasive fixation method [21], minimization of fragment displacement is expected due to pain relief [22, 23], and also stability provision [24].

Finite element (FE) analysis is an efficient and accurate numerical technique to solve those problems whose geometry or boundary conditions are sophisticated and their analytical solutions are not easily available [25-27]. In these problems, simplifications in geometry of model may lead to deviated answer from the realistic one [28]. By discretizing the geometry of interest into a number of elements, FE method mathematically applies routine governing equations on them and then assembles the effects of every element to find the mechanical characters, e.g. deformation, strain and stress components, at any location of the domain which may be useful from a biomedical point of view [29]. It seems that all the prerequisites to employ FE method have been gathered in orthopedic biomechanics. Human bones with their irregular geometry and boundary conditions which are generally intervened by use of implants and other treatment systems need to be analyzed using FE method [30]. To our knowledge, merely one numerical study has dealt with the role of sacroiliac screws on fixation of the sacral fracture [24]. Jia et al. investigated the effects of fixation systems on stability of the pelvis that underwent a fibular transplantation; however, their main aim was to evaluate the mechanical conditions in regions out of sacrum. Their sacrum model, on the other hand, was considered as an intact bone without fracture [31]. Furthermore, Anderson and Cotton studied the role of cement sacroplasty using FE models that exclude any fracture and concluded that cement injection can locally reduce 40-60% of strain in sacrum [32]. Therefore, the goal of the present study is to investigate the effects of three different types of horizontal sacroiliac screws on fixation of the zone 2 fracture in sacrum using finite element method.

Materials and Methods

In order to develop a realistic simulation case in the present numerical research, three-dimensional model of sacrum has been obtained based on computed tomography (CT) images (slice thickness = 2.5 mm, voltage = 120 kV) using CATIA software (CATIA, Dassault Systeme, version 5R19). Loading and boundary conditions have been considered to be in appropriate accordance with the reality. The superior area of the sacrum which is in contact with intervertebral disc of L_5-S_1 joint has been undergone to loading from the upper extremities in neutral standing position. Equally-distributed load of 565 N has been applied to the joint area and the sacroiliac joints have been fixed under the assumption of quasi-rigid joint. Three different treatment criteria have been considered to evaluate the effects of number and insertion location of the screws. In the first type, one screw has been inserted into the bone fragments of the sacrum superior to the first foramina (1S-sup).

The second type of the fixation is the same as the first one but the screw has been inserted below the first foramina (1S-inf). Finally for the third system of fixation (2S), two screws have been placed in both locations of the previous systems. Since the screws that were assumed to pass through the pelvis and sacrum fragments, two ends of the screws within the pelvis have been fixed. The interface of the screws and the bone fragments of the sacrum have been assumed perfectly-bounded. The gap between the two fragments has been considered as 0.25 mm. Figure 1 demonstrates three models of simulation.

Linear elastic material properties have been considered for the sacrum fragments and the fixation screws as well. Table 1 presents the mechanical properties for cortical bone and stainless steel for sacrum and screws.

The model has been discretized into 66358, 64158 and 76335 tetrahedral elements for three mentioned models respectively as shown in figure 1. Maximum size of the element has been set to 4 mm. Static solution has been considered in the finite elements analysis in Abaqus software (Abaqus, Dassault Systeme, version 6.10).

Results

Contours of von Mises stress in the models of interest have been demonstrated in figure 2. It is obvious that the stress is concentrated at the fracture gap in vicinity to the region where the screw has been inserted. The maximum stress within the 1S-inf system of fixation is greater than other systems of fixation. The fixation system of 1S-sup received slightly lower maximum amount of von Mises stress in comparison with 2S system.

Relative displacement at the gap between the fragments of sacrum bone can be a measure of efficiency of the sacroiliac screw systems in fixation of the fracture. The final aim of use of the screw fixation system was to minimize displacement of the fragments. However, the screws have been inserted in superior regions of the sacrum due to anatomical limitations, and consequently, it could be predicted that the fracture line receives diverse amounts of displacement. To this end, a path has been defined along the fracture line adjacent sides of the fragments from superior to inferior region. Figure 3 and table 2 show the graph and raw data of displacement difference between the fragments against the normalized distance along the defined path.

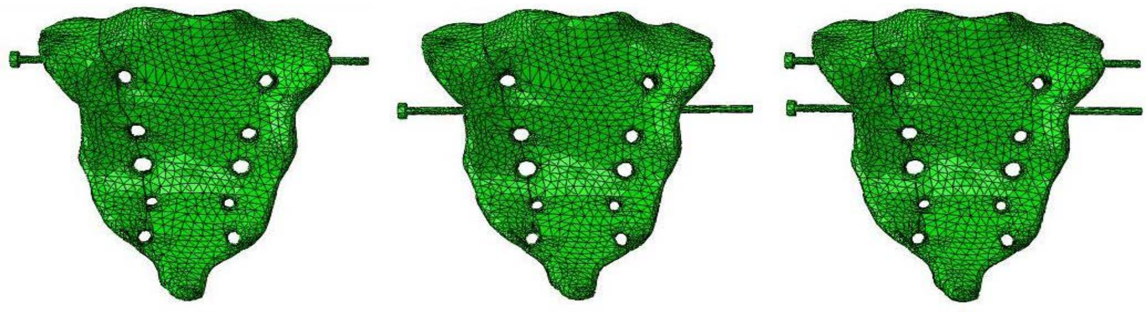

Figure 1. Three systems of fixation used for sacroiliac insertion of screws

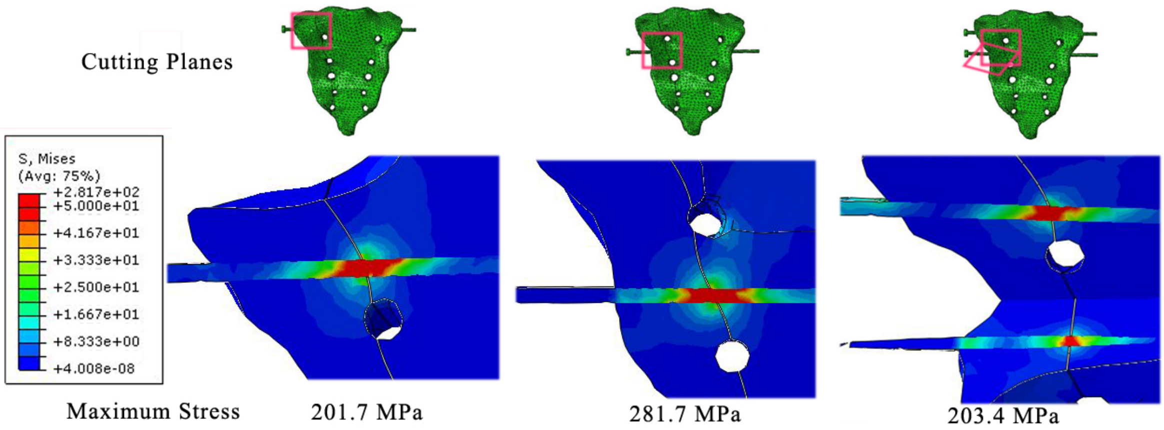

Figure 2. Contours of von Mises stress in cut views through the models with their maximum amounts

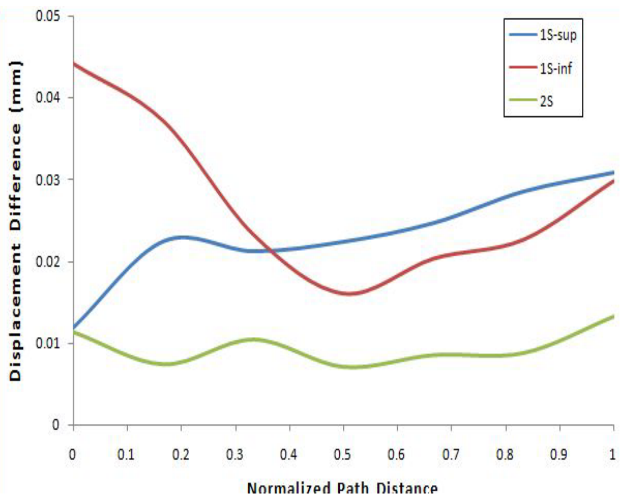

Figure 3. Variations of displacement difference against normalized distance along the defined path for three systems of fixation

Table 1. Material properties for the sacrum and fixation screws

Material	Young's Modulus (GPa)	Poisson's ratio
Sacrum	12	0.25
Screw	200	0.30

Table 2. Displacement difference between the fragments in three screw fixation systems along the defined path

Normalized path length (~ %)	Displacement difference (mm)		
	1S-inf	1S-sup	2S
0	0.011832	0.044056	0.011269
16	0.022404	0.037052	0.007353
33	0.021162	0.023188	0.01038
50	2.23E-02	0.016018	0.007032
66	0.024641	0.020298	0.008483
83	0.028513	0.02262	0.008743
100	0.030815	0.029782	0.013184

Table 3. Maximum ISFs for three fixation systems

System of Fixation	1S-inf	1S-sup	2S
Maximum IFS	0.12	0.17	0.05

In the second system of fixation, i.e. 1S-inf, displacement difference between the fragments varies irregularly along the path rather than two other systems. The variation in the third system (2S) is considerably lower than other systems and remains at a constant level of displacement difference. Maximum interfragmentary strains (IFSs) based on the theory of Perren and Cordey [33], have been developed in table 3 for three systems of fixation.

Discussion

A precious model of sacrum based on CT data was employed. Efficiency of three fixation systems based on the insertion of sacroiliac screws on zone 2 sacral fracture was examined using finite element analysis. Maximum stress was determined for 1S-inf and concentration of stress was observed in vicinity to the screws.

Contours of von Mises stress in the cut planes though the models indicate that the most critical region in fixation systems is in vicinity to the screws. In three models of interest maximum amount of stress is observed on the orthopedic screws in the gap between the fragments of sacrum bone. The principal reason for this outcome is the concentration of stress at that region where the medium and material discontinuities occur simultaneously. Noticeable difference in Young's modulus between bone and stainless screw (12 GPa in comparison with 200 GPa) causes the screw to bear higher share of the exerted load.

The second model (1S-inf) receives higher amount of von Mises stress which is considerably greater than two other systems of fixations. Since the loading on the L_5S_1 joint on top of the sacrum is out-of-plane, lowering the insertion location of the screw increases the moment arm due to loading and consequently imposes higher stress on the second system of fixation. The first model and the third one experience similar maximum von Mises stress which implies that when the screw has been inserted superior enough, maximum stress value is effectively limited disregarding to insertion of another screw below the first one.

Differences in the displacement of adjacent points linked together by the defined path (Fig. 3) shows that the second fixation system (1S-inf) is of higher relative displacement between two sides of the fracture. This implies that most deteriorated system for fracture healing may occur in 1S-inf system. Superior regions in 1S-inf case receive larger relative displacements due to its remarkable exposure to the loading prior to the load being transferred to the screw. By approaching to the location of the screw, relative displacements in all systems of fixation become minimum in 1S-inf and 2S or plateau in 1S-sup system. In 2S system of fixation which incorporates two sequential screws, two minimums is observable – one spatially coincided with plateau in 1S-sup, and, another with minimum in 1S-inf. Thus, it can be deduced that minimizing the relative displacement as a prerequisite for healing the fracture of sacrum can be achieved by screw fixation systems. Comparison between the systems of fixation stated that 2S system reveals lower relative displacement. This finding is in accordance with results of the FE study of Jia et al. Although they simulated the reconstruction of pelvis by replacement of fibular graft, the screw insertion into the sacrum roughly resembles with the present case. They finally reported that use two screws can more minimize the displacements between the bony parts [31]. Also, the difference in fragments' motion is roughly restrained along the defined path.

According to the interfragmentary strain theory [33], the third system of fixation prepares more appropriate condition to heal the fracture along the fracture line. In conclusion, sacroiliac screw insertion can be considered as an effective minimally-invasive fixation technique to minimize the displacement between fragments of the sacrum. Although the maximum stress values in two systems of 1S-sup and 2S are similar, displacement difference between the fragments is more minimized in 2S system.

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Authors' Contributions

All authors had equal role in design, work, statistical analysis and manuscript writing.

Conflict of Interest

The authors declare no conflict of interest.

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References

1. Major NM, Helms CA. Sacral stress fractures in long-distance runners. Am J Roentgenol 2000; 174(3): 727-9.
2. McFarland EG, Giangarra C. Sacral stress fractures in athletes. Clin Orthop Relat Res 1996; (329): 240-3.
3. Frey ME, Katsuri G, Adler RA, et al. Management of Sacral insufficiency fractures. Spine Line 2008; 2: 10-6.
4. Schindler OS, Watura R, Cobby M. Sacral insufficiency fractures. J Orthop Surg 2007; 15(3): 339-46.
5. Fredericson M, Salamancha L, Beaulieu C. Sacral stress fractures. Physician Sports Med 2003; 31(2): 31-42.
6. Atwell EA, Jackson DW. Stress fractures of the sacrum in runners: Two case reports. Am J Sports Med 1991; 19(5): 531-3.
7. Rodrigues LMR, Ueno FH, Filho ESV, et al. sacral stress fracture in a runner: A case report. Clinics 2009; 64(11): 1127-9.
8. Bottomley MB. Sacral stress fracture in a runner. Br J Sports Med 1990; 24(4): 243-4.
9. Eller DJ, Katz DS, Bergman AG, et al. Sacral stress fractures in long-distance runners. Clin J Sport Med 1997; 7(3): 222-5.
10. Kahanov L, Eberman L, Alvey T, et al. Sacral stress fracture in a distance runner. J Am Osteopath Assoc 2011; 111(10): 585-91.
11. Johnson AW, Weiss CB Jr, Stento K and Wheeler DL. Stress fractures of the sacrum: An atypical cause of low back pain in the female athlete. Am J Sports Med 2001; 29(4): 498-508.
12. Volpin G, Milgrom C, Goldsher D and Stein H. Stress fractures of the sacrum following strenuous activity. Clin Orthop Relat Res 1989; (243): 184-8.
13. Denis F, Davis S, Comfort T. Sacral fractures: an important problem. Retrospective analysis of 236 cases. Clin Orthop Relat Res 1988; 227: 67-81.
14. Bonnin JG. Sacral fractures and injuries to the cauda equina. J Bone Joint Surg Am 1945; 27(1): 113-27.
15. Byrnes DP, Russo GL, Ducker TB and Cowley RA. Sacrum fractures and neurological damage. Report of two cases. J Neurosurg 1977; 47(3): 459-62.
16. Worsdorfer O, Magerl F. [Sacral fractures] German [Abstract]. Hefte Unfallheilkd 1980; (149): 203-14.
17. Haasbeek JF, Green NE. Adolescent stress fractures of the sacrum: Two case reports. J Pediatr Orthop 1994; 14(3): 336-8.
18. Miller C, Major N, Toth A. Pelvic stress injuries in the athlete: Management and prevention. Sports Med 2003; 33(13): 1003-12.
19. Routt ML Jr, Simonian PT, Mills WJ. Iliosacral screw fixation: Early complications of the percutaneous technique. J Orthop Trauma 1997; 11(8): 584-9.
20. Hak DJ, Baran S, Stahel P. Sacral fractures: Current strategies in diagnosis and management. Orthopedics 2009; 32(10): 20-25.
21. Mendel T, Radetzki F, Wohlrab D, et al. CT-based 3-D visualisation of secure bone corridors and optimal trajectories for sacroiliac screws. Injury 2012 http://www.ncbi.nlm.nih.gov/pubmed/23246561.
22. Mathis JM, Barr JD, Belkoff SM, et al. Percutaneous vertebroplasty: A developing standard of care for vertebral compression fractures. Am J Neuroradiol 2001; 22: 373-381.
23. Belkoff SM, Mathis JM, Jasper LE and Deramond H. The biomechanics of vertebroplasty: The effect of cement volume on mechanical behavior. Spine 2001; 26(14): 1537-41.
24. Zhao Y, Li J, Wang D, 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 2012; 43(4): 490-494.
25. Garcia JM, Doblare M, Seral B, et al. Three-dimensional finite element analysis of several internal and external pelvis fixations. J Biomech Eng 2000; 122(5): 516-522.

26. Anderson AE, Peters CL, Tuttle BD and Weiss JA. Subject-specific finite element model of the pelvis: Development, validation and sensitivity studies. J Biomech Eng 2005; 127(3): 364-73.
27. Bachtar F, Chen X, Hisada T. Finite element contact analysis of the hip joint. Med Biol Eng Comput 2006; 44(8): 643-51.
28. Dalstra M, Huiskes R, van Erning L. Development and validation of a three-dimensional finite element model of the pelvic bone. J Biomech Eng 1995; 117(3): 272-8.
29. Dawson JM, Khmelniker BV, McAndrew MP. Analysis of the structural behavior of the pelvis during lateral impact using the finite element method. Accid Anal Prev 1999; 31(1-2): 109-119.
30. Kluess D, Souffrant R, Mittelmeier W, et al. A convenient approach for finite-element-analyses of orthopaedic implants in bone contact: Modeling and experimental validation. Comput Methods Programs Biomed 2009; 95(1): 23-30.
31. Jia YW, Cheng LM, Yu GR, et al. A finite element analysis of the pelvic reconstruction using fibular transplantation fixed with four different rod-screw systems after type I resection. Chin Med J (Engl) 2008; 121(4): 321-6.
32. Anderson DE, Cotton JR. Mechanical analysis of percutaneous sacroplasty using CT image based finite element models. Med Eng Phys 2007; 29(3): 316-325.
33. Perren SM, Cordey J. The concept of interfragmentary strain. In: Uhthoff HK. Current concepts of internal fixation of fractures. Berlin: Springer-Verlag GmbH; 1980: 63-77.

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