Parameters of lengthened sacroiliac screw fixation: a radiological anatomy study

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Abstract

Objective To provide the anatomical basis for the feasibility and clinical practice of lengthened sacroiliac screw fixation, by measuring various related indicators of the safe insertion regions of S1 and S2 lengthened sacroiliac screws.

Methods A total of 66 healthy pelvises of adults were scanned by 64-slice spiral CT and the length, width and height of the safe insertion regions for S1 and S2 lengthened sacroiliac screw were measured. The safe screw entrance point locations were described with a quantitative method. The indicators were recorded by descriptive statistics and the statistics of left and right sides, segments of S1 and S2, and different layers (including top, middle and bottom parts) of S1 and S2 were compared.

Results The lengths of ilium within the safe insertion regions for lengthened screws are more than 16 mm. The width and height of the safe insertion region of S1 and S2 are almost all more than 7.3 mm. Generally, the width and height of S1 are larger than those of S2. The reference ranges of the best/safest entrance point locations of lengthened sacroiliac screws are as follows—S1: 42.21–63.69 mm in front of posterior superior iliac spine,

32.77–53.75 mm above the highest point of the greater sciatic notch; S2: 22.68–54.28 mm in front of posterior superior iliac spine, 14.06–33.70 mm above the highest point of the greater sciatic notch.

Conclusion (1) There is anatomical feasibility for the placements of S1 and S2 lengthened sacroiliac screws. (2) $\varnothing$ 7.3-mm partial thread cannulated screw (thread length 16 mm) and $\varnothing$ 6.5-mm partial thread cancellous screw (thread length 16 mm) can be used as lengthened sacroiliac lag screw. (3) The safe insertion space of S1 is larger than that of S2. (4) There is safe space for placement of at least one piece of lengthened sacroiliac screw in both S1 and S2. (5) The best/safest entrance points of S1 and S2 can be approximately located with anatomical landmarks.

Keywords Sacroiliac screw · Pelvis · Anatomy · CT

Introduction

Sacroiliac screw has become a common technology in fixing pelvic posterior ring injuries, and it is also used in sacroiliac joint tumors, sacral insufficient fractures, etc. The lengthened sacroiliac screw, in theory, introduced new minimally invasive treatment options for bilateral sacroiliac joint injury, bilateral sacral fractures and those combining osteoporosis, etc., but related reports have been rarely seen and are limited to small sample size of clinical application research [1]. So far, there is no related basic research on the lengthened sacroiliac screw technology. We used a CT scan imaging technology on normal pelvises to provide anatomical basis for the feasibility of using S1 and S2 lengthened sacroiliac screws and to provide related parameters for the operation to implant the screws successfully.

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Methods

Materials

The study cohort comprised healthy pelvic CT data of 66 adult patients (33 male and 33 female) whose age varied from 21 to 82 years (average 44.5 years old); the CT data were all from the database of our hospital. In the data selection process, all pelvises found with tumor, fracture or variation were excluded from the research.

Equipment and scan mode

A 64-slice CT of Philips was used to scan the inspected patient lying supinely from head to foot. The scanning range was set from the superior margin of L3 to 5 cm below the symphysis pubis. The mAs auto-adjust technology was used to obtain the scan parameters: tube voltage 120 kV, thickness 1 mm, interval -1.5 mm, pitch 1.172, rotation time 0.75 s, matrix 512×512 , Fov 350 mm. The raw data obtained were reconstructed to 1 mm thickness, 50 % interval and 300 HU threshold; MPR and VR were performed with workstation for post-processing the data. The imaging was set to bilateral symmetry and the scan direction was unified to parallel the superior margin of S1 to take the data measurements (Fig. 1).

Methods of measurement

At first, the horizontal scanned images of S1 and S2 segments were observed and measured. A line was drawn

Fig. 1 A set of CT scan directions

across the transbilateral sacroiliac joints from right to left, and it was limited to the bone substance and could not break both the front and back margins of the sacrum, canalis sacralis and sacral foramen. This line was defined as passing through the anterior–posterior middle of the bone substance of the pelvic posterior ring. The intersection points of this line and the margins of ilium and sacrum were dextrosinistrally named as A, B, E, F, C and D, and the length between the anterior–posterior sacral margins (the width of the safe insertion region) was named as S. At three levels—the first appearance of this line (top), the longest length of S (middle) and the disappearance of the line (bottom)—the lengths of AB, AD and S (Figs. 2, 3) were measured.

Secondly, the entrance points of the safest placement were measured on the CT reconstruction images. The positions of pelvises were adjusted to the same horizontal level as the top surface of the pubic symphysis and the bottom surface of the sacrum, and the pelvic CT reconstruction images were adjusted to the standard lateral positions. MN, the length of the surface projection of the ligature between the anterior superior iliac spine and the posterior superior iliac spine, was measured. The horizontal line through the highest point of the greater sciatic notch was drawn, and the perpendicular line to that horizontal one was drawn through the safest entrance point A, and the intersection point was named as P. The vertical curve was drawn through the posterior superior iliac spine and the perpendicular line to the vertical curve was drawn through A, and the intersection point was named as Q. The lengths of AP and AQ were measured. The vertical curve perpendicular to MN was drawn through A, and the intersection point was named as O. The lengths of AO, OM and ON were measured (Figs. 4, 5).

The entrance points of S1 and S2 on the top, middle and bottom levels (various As) were placed in the same image and the horizontal length W and the vertical length H between boundary As, the length Y of sacral laterigrade direction and the length X of sacral longitudinal direction were measured (Figs. 6, 7, 8, 9).

A horizontal line was drawn in the pelvic posterior ring from left to right in terms of the above requirement, and the intersection points of the sacrum and the ilium were named as A, B, E, F, C, and D in order. Survey was made according to the same method as above.

Statistics

Statistical description and statistical analysis were done with SPSS 13.0. The distribution characteristics of the data of each group were described, and the concentrating and dispersing trends of the data were analyzed. The testing results of left and right sides, of the same kind of S1 and S2

Fig. 2 Definitions of A, B, E, F, C and D and related measurements (the *upper row* is S1 and the *lower row* is S2)

Fig. 3 Definitions of S and related measurements (the *upper row* is S1 and the *lower row* is S2)

and of different layers (parts) of S1 and S2, were compared with matched *t* testing method. The correlations between the screw placement entrance, the length of the screw and the anatomical index were analyzed with correlation analysis. The screw lengths and the locations of the screw entrance points were figured out by means of statistical reference range calculations.

Results

All the data were in line with normal distribution; there was no difference in the various kinds of indices of lengthened sacroiliac screw implanting region between the bilateral sides of S1 and S2. ($P > 0.05$). AB lengths of the top, middle and bottom parts of S1 and S2 were all larger than

16 mm. The reference length range of lengthened sacroiliac screw for the safest placement region is: S1 136.90–174.34 mm, S2 120.50–149.90 mm. The width and height of the safe placement region of S1 and S2 are almost all more than 7.3 mm, and the width and height of S1 are larger than those of S2 as a whole. The reference range for the best entrance of lengthened sacroiliac screw is figured out by the

measurement of AP and AQ: S1 42.21–63.69 mm in front of the posterior superior iliac spine, 32.77–53.75 mm above the highest point of the greater sciatic notch; S2 22.68–54.28 mm in front of the posterior superior iliac spine, 14.06–33.70 mm above the highest point of the greater sciatic notch. The correlation between the lengths of indexes of the best entrance point and those of the lateral

Fig. 4 Definitions of AP and AQ and related measurements (the *left* is S1 and the *right* is S2)

Fig. 5 Definitions of MN, AO, OM and ON and related measurements (the *left* is S1 and the *right* is S2)

Fig. 6 Definitions of W and related measurements (the *left* is S1 and the *right* is S2)

Fig. 7 Definitions of H and related measurements (the *left* is S1 and the *right* is S2)

Fig. 8 Definitions of Y and related measurements (the *left* is S1 and the *right* is S2.)

Fig. 9 Definitions of X and related measurements (the *left* is S1 and the *right* is S2)

surface projection of ligature of the anterior superior iliac spine and posterior superior iliac spine (AP/AQ/AO/MO/NO and MN) is less tight. Statistical descriptions of various kinds of values obtained by measurements of pelvic posterior ring, through which the lengthened screw is implanted from right to left are given below (Tables 1, 2, 3, 4). The results of the comparisons between groups are showed in “Discussion”.

Discussion

The so-called “lengthened sacroiliac screw” is a single screw inserted through bilateral sacroiliac joints and the sacral body. So far, there has been no unified appellation for this kind of screw. Some reports called it “transsacral fixation” [1] and others called it “significantly longer screw”, “specific longer screw” [2] or “transiliac–transsacral screw” [3].

Table 1 Statistical descriptions of MN, OM, ON, AO, AP and AQ of S1 and S2

	S1 ($\bar{X} \pm S$) (mm)	S2 ($\bar{X} \pm S$) (mm)
MN	140.53 $\pm$ 8.18	140.53 $\pm$ 8.18
OM	87.16 $\pm$ 7.09	99.82 $\pm$ 11.50
ON	54.74 $\pm$ 12.69	42.22 $\pm$ 16.81
AO	8.29 $\pm$ 6.20	-11.67 $\pm$ 8.04
AP	43.26 $\pm$ 5.35	23.88 $\pm$ 5.01
AQ	52.95 $\pm$ 5.48	38.48 $\pm$ 8.06

Table 2 Statistical descriptions of AB, AD and S of the three levels of S1

S1 ($\bar{X} \pm S$)	Top (mm)	Middle (mm)	Bottom (mm)
AB	17.12 $\pm$ 3.58	18.02 $\pm$ 3.66	18.53 $\pm$ 3.30
AD	157.00 $\pm$ 9.54	155.62 $\pm$ 9.55	152.94 $\pm$ 10.09
S	7.94 $\pm$ 1.82	14.11 $\pm$ 3.13	8.00 $\pm$ 1.79

Table 3 Statistical descriptions of AB, AD and S of the three levels of S2

S2 ($\bar{X} \pm S$)	Top (mm)	Middle (mm)	Bottom (mm)
AB	16.95 $\pm$ 3.36	17.17 $\pm$ 3.14	16.26 $\pm$ 3.30
AD	136.35 $\pm$ 7.57	135.20 $\pm$ 7.50	130.39 $\pm$ 7.28
S	7.30 $\pm$ 2.80	10.80 $\pm$ 3.25	7.00 $\pm$ 1.61

Table 4 Statistical descriptions of H, W, X and Y of S1 and S2

	S1 ($\bar{X} \pm S$) (mm)	S2 ($\bar{X} \pm S$) (mm)
H	13.61 $\pm$ 4.20	9.17 $\pm$ 3.62
W	4.58 $\pm$ 2.66	5.15 $\pm$ 1.60
X	11.50 $\pm$ 4.46	9.79 $\pm$ 2.80
Y	7.22 $\pm$ 2.68	3.32 $\pm$ 1.84

This paper used the term “lengthened sacroiliac screw” to describe it. Because the lengthened sacroiliac screw obtains fixation by traversing bilateral sacroiliac joints and sacral body, this technology can solve the problem of bilateral sacroiliac joint fractures/dislocations [3]. In addition, because the screw is significantly longer than ordinary sacroiliac screw, even if it is used for unilateral sacroiliac joint injury or sacral fracture, it can also in theory increase firmly the degree of fixation. So, the lengthened sacroiliac screw is more applicable to repair surgery after the first failure of sacroiliac screw fixation [1] and pelvic posterior ring injury combined with osteoporosis. Therefore, the

lengthened sacroiliac screw is an improvement over sacroiliac screw, and is also a special kind of sacroiliac screw.

At present, indications for lengthened sacroiliac screw fixation include bilateral sacroiliac joint fractures and dislocations, markedly comminuted and displaced posterior pelvic injuries, sacral insufficiency fractures, revision or nonunion procedures and patients with osteoporosis, obesity, severe craniocerebral trauma, anticipated noncompliance, etc. In addition, our biomechanical research on unilateral and bilateral sacral fractures of Tile C pelvic ring injury showed that compared to conventional sacroiliac screws, lengthened sacroiliac screws should be used for the fixation in sacral fractures as far as possible because of their excellent fixing effects; the most stable fixation was obtained by the combination of the lengthened sacroiliac screws of S1 and S2 segments. Therefore, the need for increasing stability effect of fixation is the indication for two screws fixation (one lengthened sacroiliac screw fixation in S1 and S2, respectively). This is the immediate reason for studying the parameters of lengthened sacroiliac screw fixation in the S1 and S2 segments.

As we all know, the values measured with a 64-slice CT scan can objectively reflect the actual anatomy parameters of osseous structure. In addition, because that measurements were obtained with the assistance of the CT workstation computer accessory software, the measurement error must be smaller than that of ordinary gross anatomy, which facilitates carrying out radiological anatomy studies of large sample size. It should be pointed out that pelvises are scanned in prostration state of volunteers and, because of the diversity of lumbosacral angle measurements from this kind of scan, such as the length, width and height of sacral ala, sacral body and ilium, etc., the measurements are not equal to those of actual anatomy, which would lead to serious error. In view of this, we set the CT scanning direction utilizing the isotropic 64-slice CT. We set all the sample scanning directions as parallel to the superior border of S1 vertebral body, thus effectively avoiding error from the position and lumbosacral angle of individual differences. This is the issue that some pelvic related morphology research did not notice or mention.

As in the ordinary sacroiliac screw, the lengthened sacroiliac screw must get out of the way of the sacral canal, sacral foramen and L5 nerve root located in the front of and above the sacral ala [4], and must not perforate any border of the sacral segment, ensuring location in the sacroiliac joint and the sacral bony structure all the way. Because the above anatomical requirements for the lengthened sacroiliac screw are bilateral, for the symmetric pelvic structure, the best implanting direction of the lengthened sacroiliac screw is perpendicular to the sacral vertical axis, which is different from the conventional sacroiliac screw that is located from post-outside to anteroinside [5]. In this study,

there is no difference in the indexes of safe screw implanting region between bilateral sides of the S1 and S2. Therefore, the pelvis is symmetric, excluding fracture, variation and bone diseases. Accordingly, we conclude that there is no difference in the anatomical requirements of implanting lengthened sacroiliac screw between pelvic bilateral sides.

There are two kinds of lengthened sacroiliac screws: one is the lag screw and the other is the position screw. Because the position screw thread is across both sites of the sacral fractures or sacroiliac joints, it has no specific requirement with regard to the length of the sacroiliac joint. However, the thread of the lengthened sacroiliac lag screw must locate on one site of the fracture or sacroiliac joint, so the morphological characteristics of the region of the lengthened sacroiliac screw thread located in it is particularly important. Our research found that the vertical axis of the screw is not perpendicular to the iliac bone plate, because that the lengthened sacroiliac screw is implanted horizontally, which makes the medullary canal have a larger host space to accommodate the lengthened screw, and makes it possible for the screw thread to embed within the iliac bone double cortex more tightly. The anatomical characteristic offers potential for implanting the lengthened lag cancellous screw with partial thread. We measured the iliac length AB to provide the related anatomical parameters for the lengthened sacroiliac lag screw used for bilateral sacroiliac joint fractures/dislocations and for unilateral (the lateral implanting point of the lengthened sacroiliac screw) sacroiliac joint fracture/dislocation (Fig. 10). This study found that the length AB of the top, middle and bottom parts of S1 and S2 were all larger than 16 mm. With the screw thread length (16 and 32 mm) of AO ϕ 7.3 mm part thread cannulated screw and ϕ 6.5 mm part thread cancellous screw as reference, we think that the two screws, both with screw thread length of 16 mm, can be used as lengthened sacroiliac lag screws in S1 and S2. Then, our measurement statistics of S1 shows: compared with groups pairwise, the lengths of the iliac plates of the top part, the

widest part (middle part) and the bottom part are all significantly different, and the length of the three parts increases from top to bottom. There is no significant difference between the lengths of the top and the middle iliac plates of S2, which are both larger than the length of the bottom part of the iliac plate. So, we infer that with the lengthened sacroiliac screw implanted at different levels of height of S1, the screw thread capacity of the iliac bone increases from above to below gradually. When the lengthened sacroiliac screw is implanted in the top part and middle part of S2, there is no difference in screw thread capacity of the iliac bone between the two levels. But compared with the top and middle parts, the screw thread capacity of the iliac bone decreases significantly when the screw is implanted in the bottom part. In addition, we found that the length of the iliac plates in the widest screw implanting part (middle part) of S1 was larger than that of S2. So, we conclude that the screw thread capacity of the iliac bone in the widest screw implanting regions of S1 is superior to that of S2.

From the statistics, it is observed that the lengths of AD of S1 and S2 are reduced from up to bottom, i.e., with the descending of the screw entrance, the length of the screw is increasingly smaller. At present, the length of the longest AO ϕ 7.3 mm cannulated screw is 150 mm; according to the measurement results, it can be used as lengthened sacroiliac screw in S2, while longer screws are suggested in S1 for patients with different pelvises. In addition, from our correlational study, it is found that AD and MN of S1 and S2 are not correlated, i.e., the length of the lengthened sacroiliac screw cannot be estimated through the measurement of MN, which is easily obtained and measured in the lateral view of X-ray plain film or C-arm fluoroscopy. Therefore, the length of the screw should be estimated by CT before operation; however, it is difficult for patients whose sacroiliac joints of both sides are injured.

A biomechanics study by Van Zwienen showed that significant differences were found in the load to failure and rotation stiffness between the techniques with two screws

Fig. 10 Drawings of lengthened sacroiliac lag screws (the *left* is unilateral fixation and the *right* is bilateral fixation.)

and a single screw in S1 [6]. Similarly, it is estimated that there is great possibility that the biomechanical performance of two or more lengthened screws is better than that of only one screw. Therefore, the measurement results of the safe width for the lengthened screw implantation in S1 and S2 show that the middle parts of S1 and S2 are the widest, while the top and bottom parts show no difference. After comparing this with ϕ 7.3 mm cannulated screw, it is found that theoretically there is space for one lengthened sacroiliac screw placed in the horizontal direction in the widest part of S1 and S2; it was same with the top parts of S1 and S2 and the bottom part of S1. After the pairwise comparisons of top, middle and bottom levels of S1 and S2, it is found that there is no significant difference between the width of the top parts of S1 and S2, while for the middle and bottom part S1 is significantly wider than S2. Therefore, the width advantage of S1 makes it safer to place the lengthened sacroiliac screw in S1 than S2 theoretically. The statistics of this study show that with the ϕ 7.3 mm cannulated screw as standard, there is sacral longitudinal space for one screw placed in the laterigrade direction of S1 and S2, but there is more longitudinal space in S1 than in S2. It is noteworthy that our research conclusion is based on the measurement and calculation of the laterigrade direction and longitudinal direction of the sacrum. It is completely possible that two lengthened sacroiliac screws are placed in S1 in an oblique manner at the same time, which can be more easily realized with ϕ 6.5 mm cancellous screw.

The statistical comparison study shows that no matter in S1 or S2, H is significantly different from W and X is significantly different from Y . The latter are both larger than the former. Therefore, it is estimated that the up and down regions of screw placement are larger than the back and forth regions, and implanting the lengthened sacroiliac screw in the longitudinal direction of the sacrum is safer than in the laterigrade direction.

From our clinical work, it is found that the posterior gluteal line is not clear in plain film, C-arm fluoroscopy and CT; therefore, in our research, we used three obvious bony landmarks—anterior superior iliac spine, posterior superior iliac spine and the highest point of the greater sciatic notch—for the entrance of lengthened sacroiliac screw and ascertained the reference range. Since the placement direction of ordinary sacroiliac screw is not

constant, with greater space and more direction to choose, the report of its entrance points are not the same. However, the direction of placement of lengthened sacroiliac screw is horizontal, vertical to the sacral sagittal plane, so its entrance point is more stable. Based on this, we tried to find the relation between the best entrance points and the lateral surface projection of ligature of the anterior superior iliac spine and posterior superior iliac spine (AP/AQ/AO/MO/NO and MN), but failed. Hence, there is no clear correlation between the best entrance points of S1 and S2 and the length of the lateral view of the ilium. This shows that in practice, it is necessary to locate the entrance point in terms of image in a personalized way.

In conclusion, the data obtained from this research gives anatomical support to the lengthened sacroiliac screw placement guided by C-arm, CT and even computer navigation, which is of guidance to prospective research and clinical practice. The hypothesis we put forward, apart from anatomy, for example, biomechanics, is related to morphology and radiological anatomy. It is only by combining the observation and measurement of radiological anatomy, biomechanics experiment and clinical practice can we obtain the best conclusion with referral use. Hence, it is necessary to carry on biomechanical research of lengthened sacroiliac screw to support clinical practice and to formulate concrete indications for this therapeutic tool.

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