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The Anatomical Variation of the Scapular Spine in A Chinese Population

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
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Background: The occurrence of fractures and risks following reverse total shoulder arthroplasty (rTSA) is common due to the variation of scapular spine (SS). Therefore, the consideration of the variable osteological features of SS prior to surgery may prove to be significant for the implementation of rTSA. This study aimed to propose a classification of SS through particular and quantitative parameters.

Material/Methods: In total, 354 intact dry scapulae were geometrical measured and classified on account of anatomical characteristics and the shapes of SS.

Results: Type I SS was found, and this was the most frequency was type (27.97%). The least common type was type II. The type of SS had a direct association with bone stock and bone mineral density. Type II represented an association with a much thinner spine and restricted cortical and cancellous bone; types II and V were also associated with a crooked SS, which had a more complex morphology.

Conclusions: This study offered a comprehensive classification of SS in the Chinese population. On the whole, this study indicates that knowledge of the morphological variations of SS can prompt the diagnosis of scapular fractures and can promote more successful rTSA procedures, and the relative clinical trial is necessary to support it.

MeSH Keywords: Anatomic Landmarks • Classification • Fractures, Bone • Scapula

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Background

Crossing obliquely the medial four-fifths of the scapula at its upper part, the scapular spine (SS) is a salient plate of bone. Reverse total shoulder arthroplasty (rTSA) is known to decrease pain, improve the range of motion and increase strength [1]. Therefore, it is frequently used in the disposition of shoulder fractures and other vulnera. However, for patients undergoing this procedure, it is considered normal that they experience pain several months after surgery [2,3]. Although frequent complications of stress fractures occurring in the acromion [4–10], SS [11–16], clavicle [17] and coracoid [1] following rTSA are not very common, the more usual subset of the aforementioned stress fractures occur in the SS and acromion in 3.1% to 10% [4–10,13,14,16] of patients following rTSA. A number of complications relating to SS are a result of a lack of knowledge of its anatomically morphological features. A single traumatic event and the tip of the metaglene screw are more likely to be the reason of SS fractures, which result in an increased risk of revision and dislocation and inferior clinical outcomes [4,13,18]. Acute pain can also occur without trauma, and the most common etiology during the initial postoperative years is a fracture of the SS [4,7,9,19,20]. Therefore, it is necessary to figure out the variations of SS, so as to decrease intraoperative risks and postoperative complications.

Instability is normally observed during the first year following rTSA, although late instability can be observed after several years as a result of polyethylene wear and the stretching of soft tissues [20–28]. Moreover, recurrent dislocations or subluxations have also been reported [7,22,23,25,29]. Surgical fixation offers better postoperative pulmonary function, more rapid verticalization and mobilization, and a better quality of life [30–34]. Thus, the implant is significant in order to improve stabilization and for better surgical fixation. However, there is an increasing hardware removal rate reaching 7.1% without anatomical knowledge due to implant-related discomfort and failure [35,36]. Understanding different types of SS can decrease implant-related discomfort and failure ratios. Currently, 3-dimensinal (3D) printing techniques are applied in a number of areas, such as research, implants and surgical planning [37]. Guarino et al. [34] found that 3D printing models could provide significant benefits in the areas of preoperative planning, intra-surgical navigation, and in the reduction of the operating time. In addition, knowing the variable morphology of SS can have an instructive effect on 3D printing implant during shoulder surgery. The classification of SS has instructional significance to 3D printing, which can lead to better accuracy for screw placement and may guide the customization of the shape of implant. Thus, the anatomical information about the variation of SS presented in this study may be important and useful.

A number of surgical management techniques have included SS [38–40]. Furthermore, the ease of collecting, minimal donor site morbidity and the credible blood supply to this bone may be the reason of SS being applied to a number of areas on the body [41–50]. The quantification of the anatomical information about this subject should be presented in detail in order to reduce the operative time and ensure better perceptions. The significance of the SS including quantitative and morphological variations of the SS seems to have been neglected so far [51–55]. Nevertheless, the detailed information of the SS was presented in present study. SSs were sorted into 6 types according to the osteological variations in the Chinese population and the thickness of the SS measured to examine the bone quality. This information can help surgeons to have a better and more extensive understanding of the complex anatomy of the SS. In this manner, less intra-operative blood loss, as well as less intra-operative radiation exposure can be achieved. In addition, a specific geometrical measurement method was proposed, which provides an auxiliary for surgical procedures.

Material and Methods

Ethics statement

Ethics approval was obtained from the Medical Ethics Committee of the School of Basic Medical Sciences, Southwest Medical University (SWMCTCM2017-0801). The related SS data and other data used to support the findings of this study are restricted by the Medical Ethics Committee of School of Basic Medical Sciences, Southwest Medical University.

Samples

A total of 354 intact dry Chinese scapulae were collected from the School of Basic Medical Sciences, Southwest Medical University, Luzhou, China. Inclusion criteria for the participation in this study were aged from 20 to 60 years old and belonged to the Chinese Han nationality. The scapulae with the following subjects was ruled out: 1) undeveloped complete scapulae from the patient that under 20 years old and the osteoporosis scapulae from the patient that over 60 years old; 2) congenital shoulder malformation; 3) have had a fracture. These included 193 right and 161 left scapulae; the age and gender of the donors were unknown.

Sample measurements

All scapulae were observed and measured. To avoid interobserver variations, each measurement was carefully observed by the same investigator, who performed the categorization. The investigator was a researcher who work at

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Figure 1. Different types of scapular spine in specimens. (**A**) Type I, tenuous-shape. (**B**) Type II, slender rod-shape. (**C**) Type III, thick shape. (**D**) Type IV, large fusiform-shape. (**E**) Type V, small fusiform-shape. (**F**) Type VI, S-shape.

the Department of Human Anatomy of Southwest Medical University of China for more than 5 years. The SS was classified based on its morphological features and size (shown in Figures 1, 2). Measurements were carried out using a Vernier caliper (SOMET™CN-25 1234, accurate to 0.1 mm) and recorded in millimeters.

Morphometric measurements

During the measurements, we selected 9 bony landmarks, which were related to areas of interest for scapula immobilization and reproducibility of the measurement among specimens. The parameters were measured using tpsDig and are shown in Figure 3.

AE (superior border of SS): straight-line distance measured from the medial edge of the scapula in which it encounters with the SS to the lateral edge of the acromion;
BC (lateral border of SS, spinoglenoid notch): height of the SS at the lateral edge
AC (base border of SS): straight-line distance measured from the medial edge of the scapula in which it encounters with the SS to the edge of the spinoglenoid notch;
AB: straight-line distance measured from the medial edge of the scapula in which it encounters with the SS to the point in which BC encounters with the spine;
AD: straight-line distance measured from the medial edge of the scapula in which it encounters with the SS to the corner of the acromion; FG and HI: height of the spine through point G and I; J, K, L are the midpoints of FG, HI, and BC, respectively.

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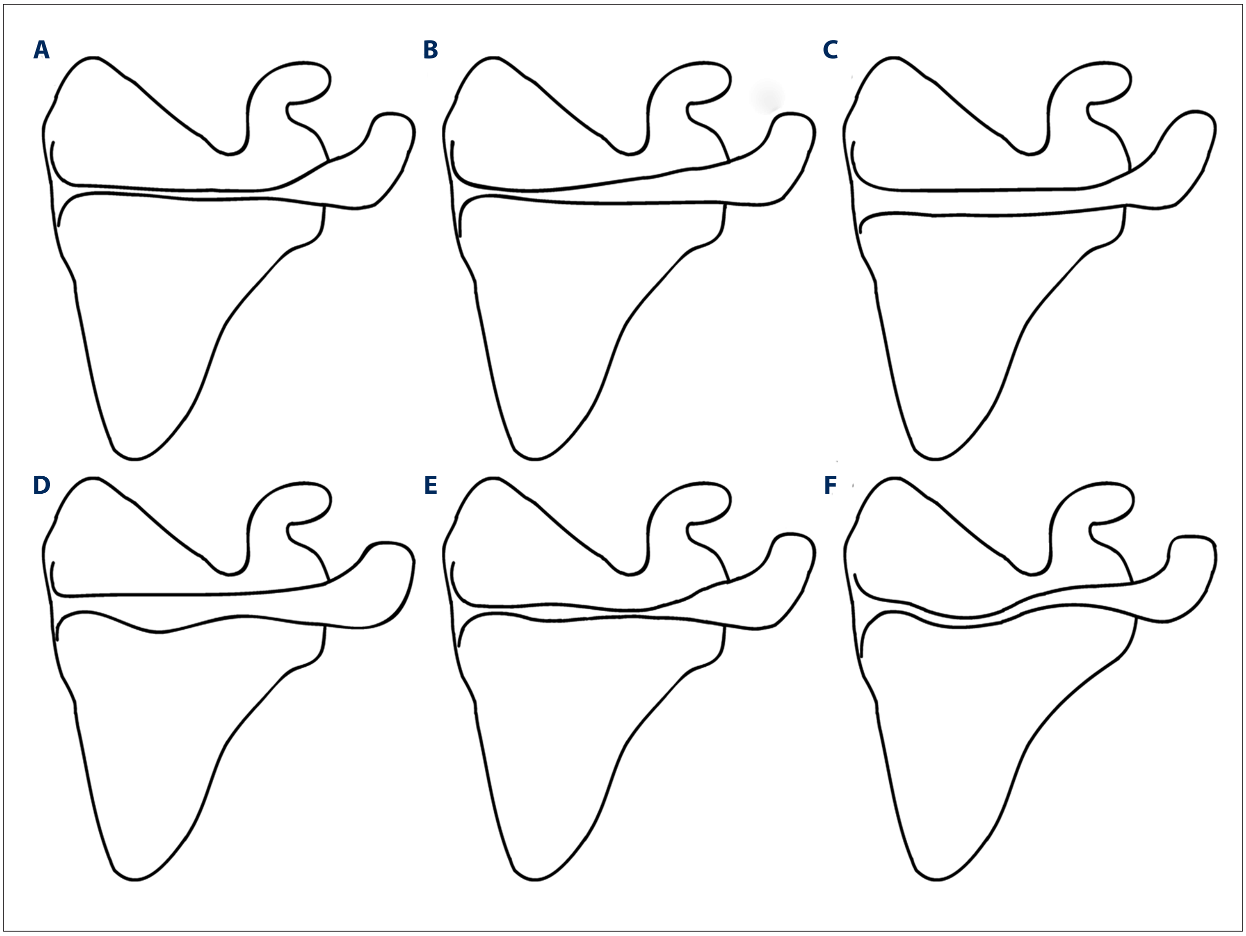

Figure 2. Sketches of different types of scapular spine shown in the diagram. (**A**) Type I, tenuous-shape. (**B**) Type II, slender rod-shape. (**C**) Type III, thick shape. (**D**) Type IV, large fusiform-shape. (**E**) Type V, small fusiform-shape. (**F**) Type VI, S-shape.

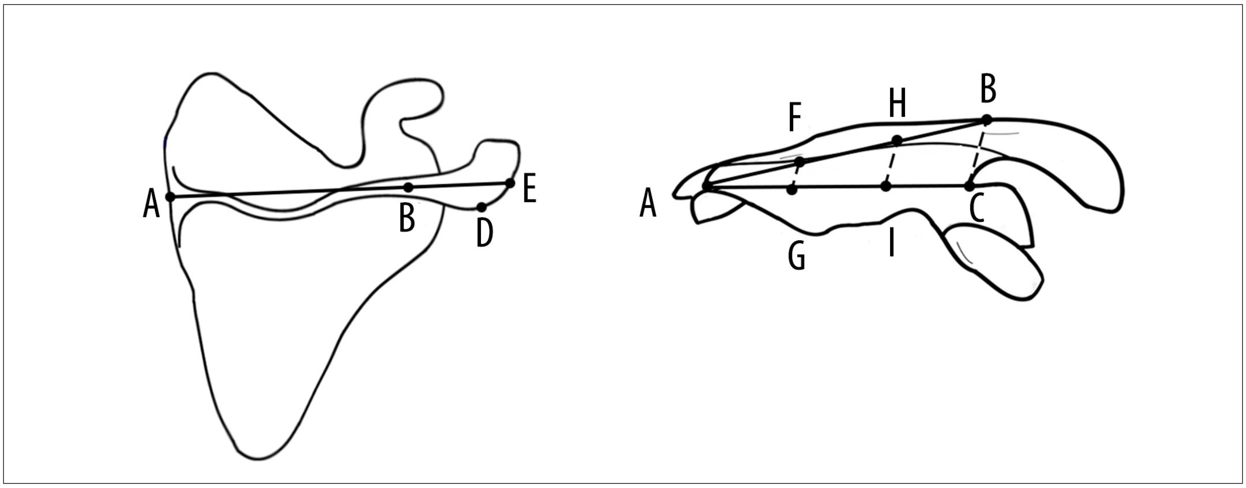

Figure 3. Morphometric measurements. AE (superior border of SS): length of SS measured from the medial edge of the scapula where it meets with the SS to the lateral edge of the acromion; BC (lateral border of SS, spinoglenoid notch): height of the spine at the lateral edge; AC (base border of SS): distance from the medial edge of the scapula where it meets with the SS to the edge of the spinoglenoid notch; AB: length of SS measured from the medial edge of the scapula where it meets with the SS to point where BC meets with the spine; AD: length of SS measured from the medial edge of the scapula where it meets with the SS to the corner of the acromion; FG and HI: height of the spine at point G and I; J, K, L, midpoints of FG, HI, and BC.

Table 1. Comparison of the height and length of the scapular spine in mm (n=354).

Type	N, %	AE	AD	AB	AC	BC	HI	FG
Type I	52, 14.69%	119.99±7.45	107.11±5.98	88.56±9.91	74.17±6.52	28.01±3.47	23.57±3.32	12.50±3.18
Type II	80, 22.60%	128.72±5.76[a]	113.83±7.10[a]	91.24±7.67a	80.36±5.94[a]	27.43±3.42	20.49±3.37[a]	14.08±2.38[a]
Type III	99, 27.97%	131.60±8.56[a,b]	115.84±8.26[a]	95.55±7.02[a,b]	84.23±5.74[a,b]	27.13±4.17	19.50±3.50[a,b]	14.39±2.77[a]
Type IV	29, 8.19%	132.18±5.95[a,b]	117.03±7.20[a,b]	96.99±5.83[a,b]	84.51±4.18[a,b]	32.35±4.90[a,b,c]	25.62±2.61[a,b,c]	15.56±1.89[a,b,c]
Type V	83, 23.47%	129.29±7.46[a,c]	113.09±6.15[a,c,d]	91.77±6.74[a,c,d]	77.65±6.50[a,b,c,d]	32.11±2.68[a,b,c]	21.84±3.73[a,b,c]	11.66±2.28[b,c,d]
Type VI	11, 3.11%	129.15±10.68[a]	108.85±4.36[b,c,d]	93.20±7.77	79.78±8.99[a,c,d]	31.54±2.49[a,b,c]	19.80±3.56[a]	13.93±3.64[e]
Average	354	128.67±8.33	113.34±7.63	92.71±7.94	80.22±7.05	29.06±4.24	21.40±3.89	13.48±2.88

[a] Versus Type I, *P*<0.05; [b] versus Type II, *P*<0.05; [c] versus Type III, *P*<0.05; [d] versus Type IV, *P*<0.05; [e] Type V, *P*<0.05.

Table 2. Comparison of the thickness of the scapular spine in mm based on classification (n=354, mm).

Type	B	H	F	L	K	J	C	I	G
Type I	10.60±2.28	8.47±2.33	7.50±1.62	8.75±1.98	6.30±1.55	6.11±1.52	9.97±2.37	8.04±1.58	7.59±1.46
Type II	12.43±1.74[a]	10.85±1.26[a]	8.78±1.49[a]	9.13±1.22	8.20±1.26[a]	7.02±1.19[a]	11.08±1.26[a]	10.03±1.24[a]	9.19±1.22[a]
Type III	12.57±2.36[a]	11.83±1.34[a,b]	11.06±1.79[a,b]	9.63±1.56[a,b]	9.54±0.98[a,b]	8.99±1.53[a,b]	11.96±2.11[a,b]	11.15±1.90[a,b]	12.28±1.75[a,b]
Type IV	14.97±1.51[a,b,c]	10.07±1.57[a,b,c]	11.29±1.33[a,b]	8.52±0.82[c]	6.76±1.06[b,c]	7.53±1.27[a,c]	11.42±1.42[a]	10.78±1.42[a,b]	11.46±1.54[a,b,c]
Type V	13.34±2.40[a,b,c,d]	7.12±1.68[a,b,c,d]	6.70±1.10[a,b,c,d]	8.40±1.12[c]	3.97±1.23[a,b,c,d]	4.50±1.05[a,b,c,d]	12.09±1.79[a,b,c]	8.15±1.90[b,c,d]	8.42±1.21[a,b,c,d]
Type VI	16.53±2.17[a,b,c,d,e]	7.73±1.73[b,c,d]	8.82±1.43[c,d,e]	9.04±0.94	6.41±1.53[b,c,e]	5.32±1.66[b,c,d]	11.61±1.49[a]	9.40±1.06[a,c,d,e]	8.86±1.50[a,c,d]
Average	12.75±2.51	9.74±2.46	8.95±2.34	8.99±1.48	7.13±2.42	6.84±2.13	11.44±1.97	9.65±2.10	9.81±2.30

[a] Versus Type I, *P*<0.05; [b] versus Type II, *P*<0.05; [c] versus Type III, *P*<0.05; [d] versus Type IV, *P*<0.05; [e] Type V, *P*<0.05.

Statistical analysis

All data were categorized according to morphology and the measured side of the body (left or right). Statistical differences on the measured side of the body were assessed using independent sample *t*-tests. One-way ANOVA and a non-parametric test were used to analyze the statistical differences in the morphology of the body. The parameters were expressed as the mean ± standard deviation. All statistical analyses were fulfilled using SPSS version 17.0 software (SPSS Inc.), the inspection level was bilateral α=0.05, and a *P*-value <0.05 was regarded to represent a statistically significant difference.

Results

In total, 6 types of variable SS based on morphological classifications were found and are shown in Figure 1. The thick type was the most common (27.97%), followed by a small fusiform-shape (23.47%), a slender rod-shape (22.60%), and a tenuous type (14.69%). The incidence of large fusiform-shape and S-shape was fairly small, at 8.19% and 3.11% respectively. The various types of SS based on morphological classifications are shown in Figures 2 and 3. The average lengths of landmarks of AE, AC, and BC were 128.67±8.33 mm, 80.22±7.05 mm, 29.06±4.24 mm, respectively. AB was the longest and significantly different in the large fusiform-shape type compared to

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Table 3. Comparison of the height and length of the scapular spine based on body sides.

Type	N, %	AE	AD	AB	AC	BC	HI	FG
Right	193, 54.52%	128.45±8.33	113.17±7.83	92.86±7.32	80.67±7.11	29.48±4.26	21.69±3.95	13.49±3.01
Left	161, 45.48%	128.67±8.33	113.54±7.39	92.51±8.64	79.68±6.96	28.55±4.19	21.00±3.80	13.55±2.92
Average	354	128.55±8.32	113.34±7.63	92.71±7.93	80.22±7.05	29.06±4.24	21.38±3.89	13.51±2.97

There is no statistically significant differences.

Table 4. Comparison of the thickness of the scapular spine based on body side.

Type	B	H	F	L	K	J	C	I	G
Right	12.69±2.50	9.41±2.57	8.85±2.40	8.83±1.43	6.79±2.38	6.61±2.07	11.41±2.15	9.48±2.16	9.71±2.36
Left	12.82±2.51	10.13±2.78	9.06±2.26	9.18±1.51	7.54±2.41*	7.11±2.19*	11.48±1.75	9.86±2.01	9.93±2.23
Average	12.75±2.51	9.74±2.46	8.95±2.34	8.99±1.48	7.13±2.42	6.84±2.13	11.44±1.97	9.65±2.10	9.81±2.30

* Versus right, $P<0.05$.

other types, while the S-shape type was the longest. The large fusiform-shape type had the longest length of AB, HI, and FG among the tenuous type and slender rod-shape type. An integrate description and summary of this results is shown in Table 1. The thickness of the landmarks of H, F, L, K, and J was the shortest and differed significantly between the small fusiform-shape type compared to the other 5 types (S-shape type was exclusive). However, the thick type was the thickest in most of the landmarks. An outline of the results is shown in Table 2. There is no statistically significant difference between the left and right measured sides of the length of the scapula, as presented in Table 3. As for the thickness of the landmarks of K and J, the left side was larger than the right side. There is no statistically significant difference between the left and right measured sides of the body in the other thick of landmarks, as presented in Table 4.

Discussion

Reverse shoulder arthroplasty (RSA) is a common therapeutic method which has been applied to a mass of etiologies and populations. However, it is related with an enhancive number of complications and postoperative discomforts [15,20,22,56–60]. In particular, the occurrence of SS fractures has a prevalence ranging from 0.8% to 10.2% [6,13,14,16,20,22,56,58,60–68]. As far as we know, few studies have put forward the variable anatomy of SS [51–54]. However, the findings of this study present that it is a common occurrence for the morphological variation of SS. Of the 354 scapulae examined, sorted into 6 types according to morphological features. Spines were classified as thick type (type I), small fusiform-shape type (type II), slender rod-shape type (type III), tenuous type (type IV), large fusiform-shape type (type V), and S-shape type (type VI). Similarly, suprascapular notch and lateral angle were classified to different types by dimensions of scapula [69–72]. Among our classification, type I (27.97%) was the most common, followed by type VI (23.47%), type III (22.60%), and type IV (14.69%). Type VI had the lowest incidence (3.11%). According to the study by Wang et al. [73], the fusiform-shape type was most frequent, and the slender rod-shape type was the least frequent. In previous studies, the average lengths of AE, AC, and BC were 133.6±11.8 mm, 85.5±8.7 mm and 46.1±6.3 mm, respectively [51–54]. This study yielded similar results in the average lengths of AE, AC, and BC at 128.67±8.33 mm, 80.22±7.05 mm and 29.06±4.24 mm, respectively.

As we can see from this study, type V was associated with a far longer length of AB, AD, HI, and FG and small type II was associated with a lesser thickness of many landmarks. Wang et al. demonstrated a similar result [51]. The results indicate that types II and V are associated with a crooked SS, which has more complex morphological characteristics compared to the other 4 types (type VI was exclusive), eventually causing a worse condition with the occurrence of trauma, particularly a fracture. The 2 types were more prone to an increased intraoperative risk and postoperative complications [51]. There are more difficulties in bending and rotating the plate to adapt the

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shape of these 2 types in surgery. Therefore, during surgery with these 2 types, the duration of the surgery is more apt to be lengthened, which leads to increased overlying tissue irritation, and results in complications in the configuration of the bone-plate construct [36]. Wang et al. demonstrated a similar result [73]. However, some differences between types II and V were found in this study. Type V was associated with a longer length of many landmarks and a lesser thickness of many landmarks compared with type II. Thus, type V is associated with a large ease for the occurrence of fractures, so that the internal fixation is not recommended due to fragility. Similarly, type IV is associated with thinner SS, which may not be suitable for inner fixation and care should be taken during plate implantation. Moreover, there is an increasing hardware removal rate reaching 7.1% due to implant-related discomfort and failure [36,41]. Thus, knowledge of the morphologically variable characters of SS may help to improve preoperative planning. This information may guide the shape of a more compatible precontoured locking plate using 3D printing technology, which can reduce the material loss ratio.

The SS is a salient plate of the scapula, which has the adequate bone stock. The SS is thought to be an ideal area to bear screws, pins, or wires for stability of fracture fixation [51,73]. Nevertheless, the thickness of 9 landmarks was presented in this study. As regards the thickness of H, F, L, K, and J, type II was the thinnest among the 5 types (type VI was excluded). On the contrary, type I was the thickest. This indicates type II may have association with poor remaining bone stock following surgery, and thus the likelihood of fractures is greater. Type I was more stable and thus more able to withstand fixtures. Moreover, fragility related to the SS, the voluntary contraction of the muscle and avulsion of ligaments attached to the scapula are regarded as the main cause of trauma in some studies [62,74,75]. Types II, V and VI were associated with a crooked and thin SS, while type I was associated with a relatively straight and thick SS; type III had an association with a thinner SS. Type IV was associated with a wider inner and outer narrow SS. Thus, more care needs to be taken with type IV when placing the screw. High tensile, AC-joint reaction force, and compressive stresses in the cranial and caudal part of SSs had a contribution to the bending effects of the spine [76]. Furthermore, it is believed that increased screw pull-out strength has a direct connection with increased cortical thickness [77,78]. Thus, it may be more difficult to evaluate internal fixation to a direct or indirect trauma of type II. This result offers guidance for surgeons as regards surgical planning and improving preoperational diagnosis.

It is noteworthy that an abnormal type of SS (3.11%) was found, which was similar to an 'S' shape. This type had a coarse surface and tortile features. The incidence of stress and ossification of the tendon and tendinous fibers of the trapezius muscles may be the reasons [73]. The S-shape type had the shortest AB. The thickness of many landmarks associated with this type was much thinner. Therefore, postoperative complications and fractures are more prone to occur in patients with SS of type VI. Taking this anatomical information into account may provide a more satisfactory results for patients with the long-term return of strength and function.

Some studies have proved that osteoporosis is a main reason of the increased risk of scapular fractures following reverse shoulder arthroplasty [6,15,18]. Several studies have recommended conservative treatment for patient with osteoporosis, particularly among the elderly [6,13]. In order to enhance the stability of the glenoid construct, through the SS longer posterior glenoid screw can be applied to [79–81]. However, the result can be easily influenced by an evident variability in bone quality and size. In this study, an additional longer posterior glenoid screw for type II is not recommended due to the congenital thin spine, which supplements this research. Furthermore, the thickness of the SS can affect the osteomyocutaneous flap. Fixation stability having a direct connection with the increased cortical thickness of the SS had been demonstrated in previous studies. In addition, cancellous bone density is directly associated with the mechanical support of the implant fixture [77,78]. Type II was related to a much thinner spine and restricted cortical and cancellous bone in this study. This would be negative factor in osseointegration and would weaken the support force.

The SS acts as an osteomyocutaneous flap, which was previously applied to reconstruct a composite flaw of the mandible [41]. This reconstructed method has also been extended to other complex and fickle flaw such as maxilla, face, head, pharyngeal, humerus, neck, femur defects, trauma and congenital malformations [42,44–46,81]. Tubbs et al. [48] found that the SS was very fit for posterior spinal fusion transplantation. The SS had been successfully used to posterior lumbar interbody fusion surgery. Due to the ease of gathering, minimal donor site morbidity, and credible blood supply to the bone, the SS is widely applied to in many regions of the body [49,50]. Long and strong bone healing and contours are needed for an optimal osteomyocutaneous flap to reconstruct complex three-dimensional bone flaw [42,81]. Furthermore, it is critical to estimate bone availability and familiarity with the morphological features of the spine for the proper contouring of the bone graft and for fitting defects to ensure optimal functional outcomes. Thus, the results of this study may be of significance for the application of SS in many areas.

Some limitations in this study. A total of 354 Chinese specimens were gathered from a university, but the age and gender of donors were unknown. The result of SS development was only speculative in this study, and we only used manual

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measurements. CT and 3D scanning technology could have enriched our findings and might have produced more precise results. In addition, we lacked sufficient clinical data to make the connection between the rTSA and SS, and we do not know whether all participants were asymptomatic because this was an anatomical research rather than a clinical trial.

Conclusions

SS was sorted into 6 types according to the anatomical features among the Chinese SS specimens; types II, IV, V and VI of SS were more fragile due to more complex morphologies, which indicated that inner fixation and screw implantation needs to be considered. This study provides comprehensive and significant information about the SS in the Chinese population; these results might enhance the diagnostic accuracy and aid in the specific targeting of the site of intervention.

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Data availability

The related SS data and other data used to support the findings of this study are restricted by the medical ethics committee of School of Basic Medical Sciences, Southwest Medical University. Data are available from Lei Zhang (email: zhanglei870722@126.com) for researchers who meet the criteria for access to confidential data.

Conflict of interests

None.

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