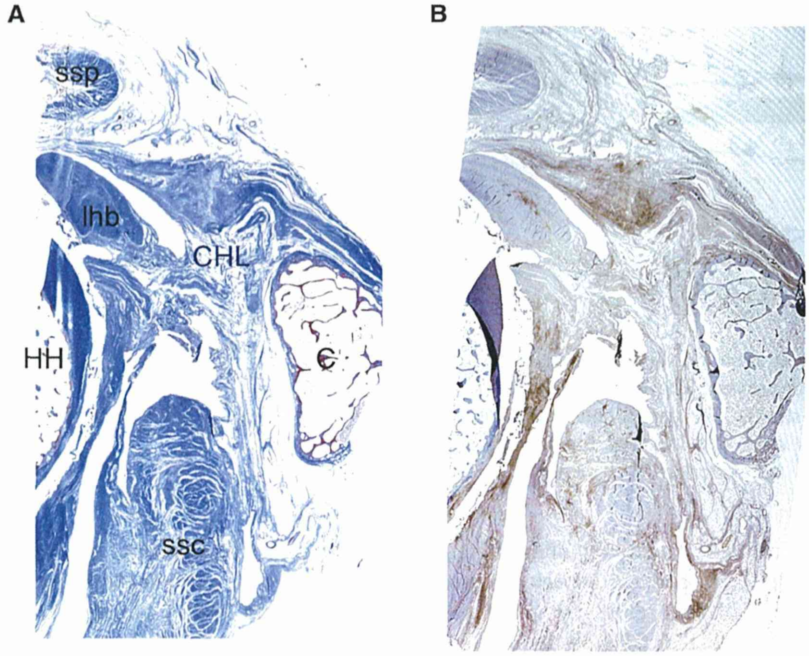

Figure 4 Histology of CHL. (**A**) The anterosuperior portion of the glenohumeral joint between the labrum and lesser tuberosity was sectioned vertically to the subscapularis tendon and stained with Masson trichrome. The CHL spread between the coracoid process (*C*) and supraspinatus (*ssp*) and between the coracoid process and subscapularis (*ssc*). The ligament consisted of irregular and sparse fibers. (**B**) The same section was stained with anti-human type III collagen antibody. The fibers of the CHL were stained more densely than the subscapularis or the long head of the biceps tendon. *HH*, Humeral head; *lhb*, long head of biceps brachii tendon.

This complexity among the subscapularis tendinous slip, the CHL, and the superior glenohumeral ligament at the most lateral rotator interval has drawn attention historically as the "reflection pulley."[1,22,23] The main function of the reflection pulley has been considered to be the maintenance of the position of the long head of the biceps tendon, and the superior glenohumeral ligament (a limited portion of the CHL according to our study) has been thought to be an important sustainer of the biceps tendon. On the basis of the macroscopic sagittal sections in this study, the CHL envelops the whole subscapularis insertion including the tendinous slip, and consequently, the CHL would likely function as a holder of the subscapularis insertion. Therefore, the CHL can be considered to spread into the narrow space between the biceps tendon and subscapularis insertion to function as both the sustainer of the biceps tendon and the holder of the subscapularis insertion.

The function of the CHL as suggested in our study as a holder of the subscapularis muscle and insertion would be very important from the clinical viewpoint. Even in the resting neutral position, the subscapularis tendon is pressed against the spherical surface of the anterior anatomic neck and bent vertically along the lesser tubercle because it inserts into the upper margin as well as the anterior aspect of the lesser tubercle.[2] Especially in the abducted and externally rotated position, the upper border of the subscapularis is coiled around the coracoid process and the humeral head becomes anteriorly prominent and pushes the subscapularis muscle forward and upward.[6] To maintain the whole subscapularis during such extreme morphologic changes, the enveloping structure of the CHL must be both strong and flexible.

On the basis of our findings, we should consider these expected unique characteristics of the CHL: (1) As the CHL fibers converge to the coracoid process, the CHL can be thought to have sufficient stiffness to stabilize the subscapularis muscle, and the coracoid process functions as an important anchor of the CHL. (2) The histologic analysis showed that the CHL consisted of irregular and sparse fibers and that the proportion of type III collagen in the CHL was higher than that in the long head of the biceps tendon or in the intramuscular tendons of the subscapularis muscle. Because, in general, type III collagen is more pliable than type I collagen[12] and the proportion of type III to total collagen is roughly parallel to the extensibility of the tissue,[16] this finding means that the CHL consists of loose connective tissue and that it should be relatively flexible; therefore, the CHL can envelop the subscapularis muscle while maintaining the position of the insertion pressed against the humeral head.

From the clinical viewpoint, many surgeons suggest that the CHL should be cut and removed to release and mobilize the subscapularis tendon when performing subscapularis tendon repairs.[4,11,18] In such a pathologic situation,

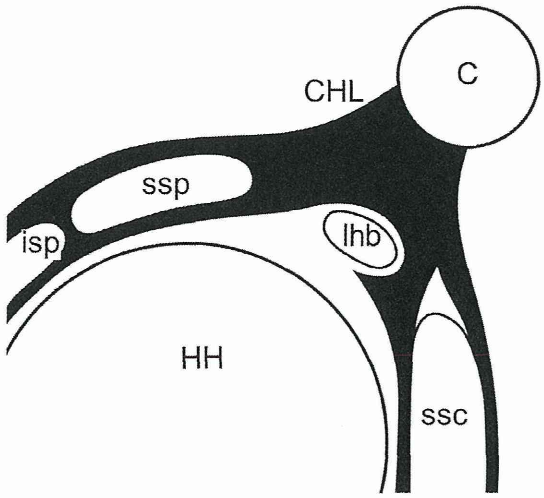

Figure 5 Functional anatomy of CHL. The CHL (*black area*) extends laterally from the base of the coracoid process (*C*). The anterior CHL likely holds the subscapularis muscle (*ssc*) and anchors the muscle to the coracoid process in a manner similar to that of the posterior CHL enveloping the supraspinatus (*ssp*) and infraspinatus (*isp*). The CHL is also a likely chief element in the reflection pulley and functions as a sustainer of the long head of the biceps tendon (*lhb*). *HH*, Humeral head.

inflammation around the torn subscapularis tendon might occur, and loose connective tissue composing the CHL can proliferate, leading to scar tissue formation. Adhesion to the surrounding structure may also occur. As a result, the CHL will lose its flexibility and may consequently hold the subscapularis muscle too tightly. This might be the reason patients benefit from removal of the CHL to allow the subscapularis muscle to slide correctly in subscapularis repair.

Macroscopically, the CHL was observed to be divided into two parts: one part spread fibers over the rotator interval to the posterior portion of the greater tuberosity, and the other part enveloped the superior portion of the subscapularis muscle. The anterior CHL holds the subscapularis muscle and anchors the muscle to the coracoid process in a similar manner to that of the posterior CHL enveloping the supraspinatus.[5] This finding suggests that the CHL plays a major role in the stabilization of the subscapularis, similar to the supraspinatus and infraspinatus (Fig. 5).

This study has several limitations. First, we used formalin-fixed specimens rather than fresh-frozen cadavers. Even with formalin fixation, the positional relationship among anatomic constructs does not change. Therefore, our study of morphologic observations has no disadvantage even though we did not use fresh-frozen cadavers. Second, the investigated cadavers were all of old age. Because, in Japan, the voluntary donor system of cadavers for education and study is widely adopted, as described earlier, it is inevitable that our specimens tend to be of high age. Consequently, the CHL may be affected by degeneration due to aging in a similar way to the rotator cuff. We, however, excluded 2 specimens with rotator cuff tears; therefore, we investigated morphologically intact shoulders only, and the structural characteristics should be maintained even in elderly specimens.

Although Edelson et al[10] already discussed that the CHL is a central element for suspending the humeral head because of its flexible strength and "strategic" position, further study will be needed for a comprehensive understanding of the mechanism by which the CHL holds the rotator cuff and maintains the global glenohumeral joint.

Conclusion

The CHL envelops the whole subscapularis muscle and insertion, and consequently, the ligament would function as a kind of holder for the subscapularis in the same way in which the ligament works for the supraspinatus muscle. The CHL is composed of irregular and sparse fibers and contains relatively rich type III collagen, which would suggest the flexibility of the ligament.

Disclaimer

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SHOULDER

Anatomical study for SLAP lesion repair

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Abstract

Purpose The purpose of this study was to meticulously observe the structures around the origin of the long head of the biceps tendon (LHB) in order to propose a method of anatomical superior labrum anterior and posterior repair.
Methods Twenty-eight shoulders of 16 cadavers with intact LHB origin were macroscopically investigated. Among them, 20 shoulders with an intact superior labrum were additionally observed, to determine whether the anterior edge of LHB on the labrum (point ‘A’) was anterior to the supraglenoid tubercle. Serial sections vertical to LHB were observed using ordinary light and polarized microscopy in three glenoids and scanning acoustic microscopy in one.
Results The labrum had a meniscal appearance, and no LHB fibre was sent anterior to the anterior edge of the supraglenoid tubercle. ‘A’ was not located more posterior than the supraglenoid tubercle. All specimens had the so-called ‘the sheet-like structure’, in which the portion closer to the LHB origin tends to be stiffer. Fibres of the sheet-like structure ran vertically to LHB.
Conclusion Fibre orientation and the stiffness of the sheet-like structure suggest its support of LHB. As LHB fibres do not anteriorly cross over ‘A’, ‘A’ could be a landmark for the anterior border of LHB, independent from the sheet-like structure. Considering a previous report mentioning that the horizontal mattress suture maintains the meniscus-like structure which might be sufficient for proper motion of the normal superior labrum, the horizontal mattress suture not crossing over ‘A’ should be recommended from the viewpoint of functional anatomy.

Keywords Anatomical study · Shoulder joint · Long head of the biceps tendon · Superior labrum anterior and posterior lesion

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Introduction

Since the original descriptions [1, 17], the superior labrum anterior and posterior (SLAP) lesion has been thought to be an important clinical entity in shoulder injuries. Arthroscopic repair of the lesion has advanced and demonstrated successful results [6, 9] based on the classical concept that the attachment of the long head of the biceps tendon (LHB) should be firmly fixed to the glenoid incorporated into the superior labrum [8]. However, several authors have discussed that overhead athletes show an unsatisfactory return to their previous level of sports participation [3, 9, 14]. The reason that some patients have pain limiting overhead sports activities following SLAP repair is unknown, but a possible explanation might be that the superior labrum tends to be fixed to the glenoid too rigidly to allow dynamic movement of the labrum in shoulder motion [3]. The determination of what extent of labral movement is physiological and the identification of the ideal method of SLAP repair are difficult issues. To resolve these issues, it is critical to comprehend the detailed anatomy of the superior labrum. In particular, it is important to clarify the attachment area of LHB because traction of LHB is thought to be the primary element for labral movement [1, 5]. In our recent study, the superior labrum was found to consist of three components: (1) a semi-circular fibre component located along the circumference of the glenoid, (2) fibres of the 'sheet-like structure', and (3) LHB fibres which run posteriorly and become the primary component of the posterior portion of the superior labrum [2].

The sheet-like structure is a membranous structure which branches off the rotator interval and attaches anterior to the LHB origin. The superior glenohumeral ligament has been conventionally believed to run from the glenoid to humerus and create the reflection pulley on the humeral side [19]. Our recent observation, however, demonstrated that the ligament is not always continuous from the glenoid to humerus in cadaveric anatomy and clinical arthroscopy. The reflection pulley can consistently be observed but its fibres often stop at the rotator interval, and another membranous structure with different fibre orientation connects the rotator interval and anterosuperior labrum. This membranous structure is termed the sheet-like structure [2].

In that study [2], LHB was proven to send fibres posteriorly and it did not anteriorly penetrate the sheet-like structure. But the arthroscopic landmark of the anterior border of LHB attachment was still not clear. Furthermore, the function of the sheet-like structure was not shown, and thus, management of the sheet-like structure in SLAP repair has not been clarified. The purpose of the current study was to histoanatomically investigate LHB origin and the sheet-like structure, then define the anatomical landmark of the anterior border of LHB, and finally propose an ideal means of SLAP repair.

Materials and methods

Anatomical study

This study used cadavers for practical anatomy class of medical students in our institute. All of the experimental procedures were performed after student dissection practices. These cadavers consisted of donors who voluntarily expressed that their body would be used as materials for education and study after their death. This voluntary donor system of cadavers guarantees the rights of donors, and it is universally spread throughout our country. Medical history of shoulder problems was not available.

All cadavers were fixed in modified solution of Bradbury and Hoshino's [4] method which contained 50 % ethylene glycol, 39 % methanol, 8 % formalin, and 2 % phenol and 0.2 % Cell Conditioner embalming fluid (Champion Co., Ltd., Springfield, OH, USA). After the deltoid and trapezius muscles were stripped from the shoulder girdle, the conjoined tendon was resected at the tip of the coracoid process. After cutting the long-head tendon of the triceps muscle near the glenoid, the clavicle was removed from the acromioclavicular joint. The humerus was cut at the proximal portion leaving LHB intact. The scapula spine was resected at its base being cautious to preserve the rotator cuff muscles. The scapula was vertically cut at the suprascapular notch with the rotator cuff muscles remaining attached, and the specimen was removed. After the posterior rotator cuff muscles were detached from the capsule and retracted, the posterior capsule was incised with great care so as not to damage the glenoid.

Thirty-two shoulders of 16 embalmed cadavers were examined, and 4 specimens in which LHB origin was severely degenerated or damaged were excluded. First, in 28 shoulders of 16 cadavers (6 men, 10 women, mean age of 85.3 years), we recorded whether LHB fibres extended across the anterior edge of the supraglenoid tubercle. Second, 8 shoulders in which the superior labrum was severely degenerated or damaged were additionally excluded, and in the remaining 20 shoulders of 12 donors (4 men, 8 women, mean age of 85.6 years), the glenoid with surrounding soft tissue was taken out. The lower half of each glenoid was approximated by a half circle of which anterior and posterior portions were even, and a line was drawn which was parallel to the bowstring of the half circle and passed through the centre of the bare spot. The reference we used in a previous study was set along the line, and the centre of the reference was put on the centre of the bare spot [2]. According to the reference, the clock time position of the following two points was recorded in units of 30 min: (1) crossing point of the labrum and anterior border of LHB (this point is determined as 'A') and (2) anterior edge of the supraglenoid tubercle. The anterior edge of the supraglenoid tubercle was viewed from the cranial side and its location was determined, because it could not be observed from simply the side of the glenoid surface hidden by soft tissue. These two points were recorded twice by the same examiner with a 2-week interval (Fig. 1).

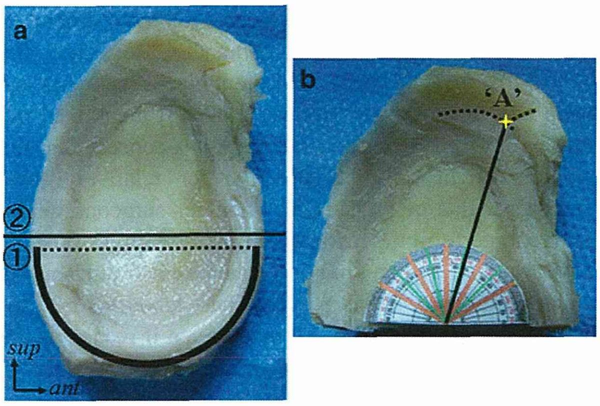

Fig. 1 Measuring method of the removed glenoid. **a** A glenoid specimen of the right shoulder. The lower half of the glenoid was approximated by a *half circle* of which the anterior and posterior portions were even (*1*). A line was defined which was parallel to the bowstring of the *half circle* and passed through the centre of the bare spot (*2*). **b** The glenoid was transversely divided on the defined line. According to an original reference which was set on the centre of the *bare spot*, the *clock time* position of the following two points was recorded in units of 30 min: (1) the crossing point of the labrum and anterior border of LHB (this point is determined as point 'A') (2) the anterior edge of the supraglenoid tubercle (behind the soft tissue)

Histological study

After the anatomical observation was completed, three superior-half glenoid specimens were randomly selected. They were decalcified for 2 weeks in a solution containing formic acid and sodium citrate, as described by Morse [15]. After dehydration and embedding in paraffin, serial sections with 3 μm thickness and 500-μm interval were made vertical to LHB fibres. They were observed using an ordinary microscopy with haematoxylin-eosin (HE) staining and polarized microscopy in order to clarify the fibre orientation of the sheet-like structure. In addition, one specimen was selected whose cross section of LHB and the sheet-like structure at LHB attachment had a similar morphology to its 3 mm distal site, and those two sites were evaluated by scanning acoustic microscope (SAM). SAM characterizes biological tissues by assessing the elastic parameters based on sound speed [10]. With SAM, the stiffness of the sheet-like structure at the two sites was examined separately.

Mechanical property analyses by SAM

When an acoustic wave is directed from a transducer to a specimen, it is reflected. Considering the formula that sound speed is proportional to the square root of Young's elastic modulus, sound speed of the reflection is considered to be a good parameter to characterize its elasticity. By measuring the speed of the reflected sound, SAM has an advantage for evaluating tissue elasticity on slide glass in situ. Higher sound speed means that the directed portion of the tissue is stiffer. In addition, SAM works as a microscope as it delineates the tissue border based on the marked changes in tissue properties.

The total system used in this study has been reported elsewhere [11] and thus is briefly described as follows. Reflections from the tissue surface and from the interface between tissue and glass are received by the same transducer. The central frequency is 80 MHz. Frequency domain analysis of the reflection enables the separation of these two components and calculation of tissue thickness and intensity by Fourier transformation the waveform [12]. Normal light microscopic images corresponding to the stored acoustic images are captured. A region of analysis by SAM was set at the two sites of the sheet-like structure. In the region, the sound speed of the structure was calculated with a grey scale using commercially available image analysis software (Photoshop CS2, Adobe Systems Inc., San Jose, CA, USA). SAM images with a gradation colour scale were also produced for clear visualization of the sound speed.

Results

Anatomical study

In all 28 glenoids which had an intact origin of LHB, LHB sent fibres only posterior to the anterior edge of the supraglenoid tubercle. In 20 glenoids which also had an intact superior labrum, point 'A' did not come posterior to the anterior edge of the supraglenoid tubercle, although the results of the first and second measurement using the original reference were not completely identical (Table 1). These results showed that 'A' was located either in more anterior portion or at the comparable position to the anterior limit of the LHB origin (Fig. 2).

Histological study

Ordinary light microscopy of serial sections vertical to LHB fibres with HE staining showed the cross sections of LHB and the superior labrum. Near the supraglenoid tubercle, borders of soft tissues were vague, but in polarized microscopy, fibres with vertical orientation to LHB were observed, which were located where the sheet-like structure existed macroscopically (Fig. 3). In SAM, the sound speed of the sheet-like structure at LHB attachment tended to be higher than its 3 mm distal portion. The average of the sound speed of two sites was 1,632.0 and 1,598.3 m/s (Fig. 4).

Table 1 The location of point 'A' compared to the anterior edge of the supraglenoid tubercle

Case	1st measurement	2nd measurement
1R	Same	Same
L	Same	Same
2R	Same	0:30 anterior
L	Same	Same
3L	0:30 anterior	Same
4R	Same	Same
L	0:30 anterior	Same
5R	0:30 anterior	Same
L	Same	Same
6R	Same	Same
L	Same	Same
7R	0:30 anterior	Same
8R	Same	Same
10R	Same	Same
L	0:30 anterior	Same
11R	Same	Same
L	Same	Same
13R	0:30 anterior	Same
L	0:30 anterior	0:30 anterior
17L	0:30 anterior	0:30 anterior

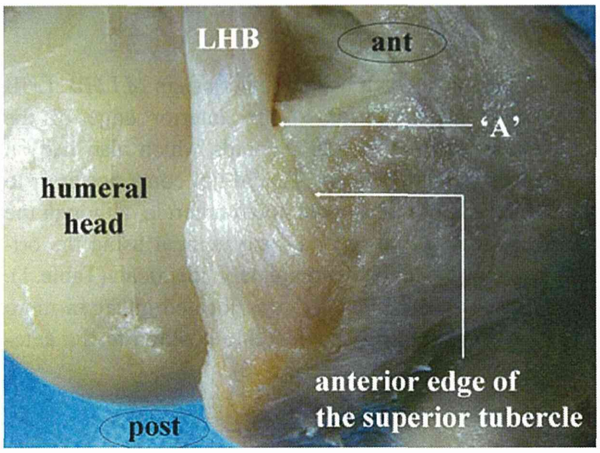

Fig. 2 The attachment site of LHB. LHB fibres did not anteriorly cross over the anterior edge of the superior tubercle. Point 'A' was not located posterior to the anterior edge of the supraglenoid tubercle. Therefore, 'A' was located either in more anterior portion or at the comparable position to the anterior limit of the LHB origin

Discussion

The most important findings of the present study were that LHB does not send fibres anteriorly beyond the anterior edge of the supraglenoid tubercle and that 'A' can be a landmark indicating the anterior limit of LHB fibres in shoulder arthroscopy. They are considered to be crucial to repair the superior labrum anatomically. Regarding the surgical treatment of the SLAP lesion, biceps tenodesis has drawn attention recently. Boileau et al. [3] mentioned the efficacy of biceps tenodesis, but there is a concern that the tenodesis might only be effective for relatively low-demand patients of higher age. Shoulder surgeons would hesitate to perform the tenodesis in the first surgery for the SLAP lesion of a young major league baseball pitcher or a young Wimbledon tennis player. Thus, tenodesis has not completely replaced the SLAP repair even if results of the SLAP repair are unstable for throwing or overhead athletes. Therefore, SLAP repair should be refined further.

In order to consider the ideal SLAP repair, it is critical to comprehend the detailed anatomy of LHB origin. Vangsness et al. [18] described that about half of fibres of LHB attachment were derived from several portions of the labrum, entirely posterior portion 22 %, almost posterior portion 33 %, equally anterior and posterior portions 37 %, and almost anterior portion 8 %, but there was no description of the anterior and posterior distance of extension of the LHB fibres. Several studies have already demonstrated that LHB fibres continue to the posterior portion of the superior labrum and that the posterosuperior labrum was substantially composed of LHB fibres [2, 13, 16], and therefore, there should be no posterior limit of LHB origin. In contrast, the anatomical landmark to indicate the anterior limit of LHB origin has not yet been described. The current study demonstrated macroscopically that the anterior limit of LHB fibres was the anterior edge of the supraglenoid tubercle, but this anterior edge cannot be recognized in arthroscopic surgeries. In this study, we proposed point 'A', which is the crossing point of the labrum and anterior border of LHB, as the landmark. 'A' was not completely consistent with the anterior limit of LHB origin, but it is easy to confirm in arthroscopy, and it can be a good tool to indicate that there is no LHB fibre in more anterior portion.

The sheet-like structure which branched off the rotator interval as a kind of membranous structure attached anterior to the LHB origin [2], and its fibres existed anterior to 'A'. In this study using polarized microscopy, the fibres of the sheet-like structure ran vertically to the LHB fibres. According to biomechanical principles, the orientation of the fibres of soft tissues reveals the direction of the tensile stresses they must resist [20]. According to the fibre orientation of the sheet-like structure, it should support the shearing stress of LHB. A previous study showed that the fibres of the sheet-like structure converge near the LHB origin [2], and the current study demonstrated that the sheet-like structure in the portion near the LHB origin tended to be stiffer than the distant portion. Such findings should indicate that the sheet-like structure has the

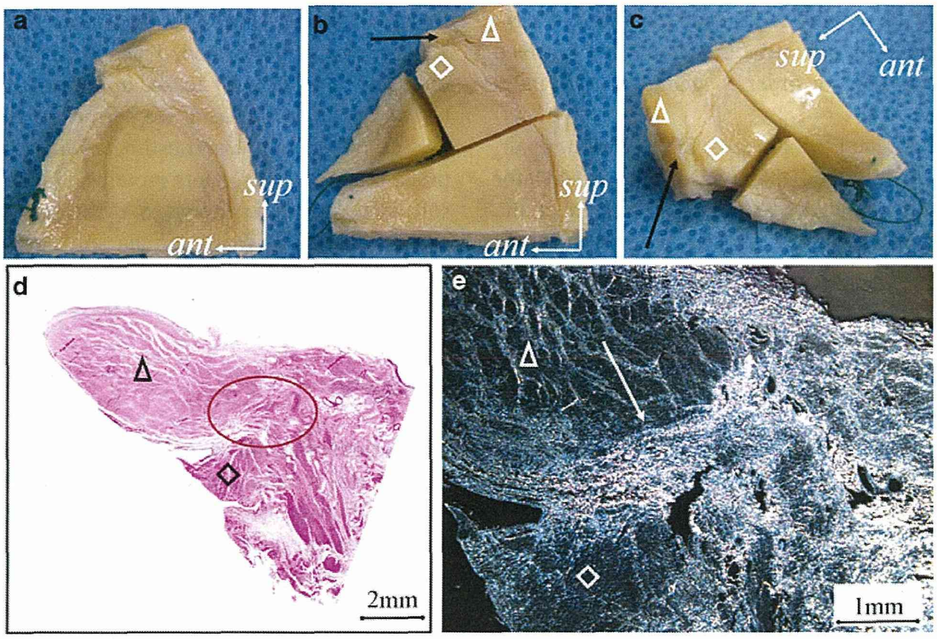

Fig. 3 Histological sections vertical to LHB fibres. **a** superior-half glenoid of the left shoulder after decalcification. **b** A block for examination viewed from the lateral side. The *triangle* and *square* symbols indicate LHB and the superior labrum. The *arrow* indicates the sheet-like structure. **c** The same specimen as (**b**) viewed from superior side. The sheet-like structure is located between LHB and the superior labrum. **d** A cross section near the supraglenoid tubercle with HE staining showed LHB and the superior labrum. In the *oval* area, the borders of the soft tissues were vague. Original magnification ×1. **e** A cross section with polarized microscopy showed fibres *vertical* to LHB between LHB and the superior labrum. Those fibres corresponded to the sheet-like structure observed in (**b**) and (**c**). Original magnification ×20

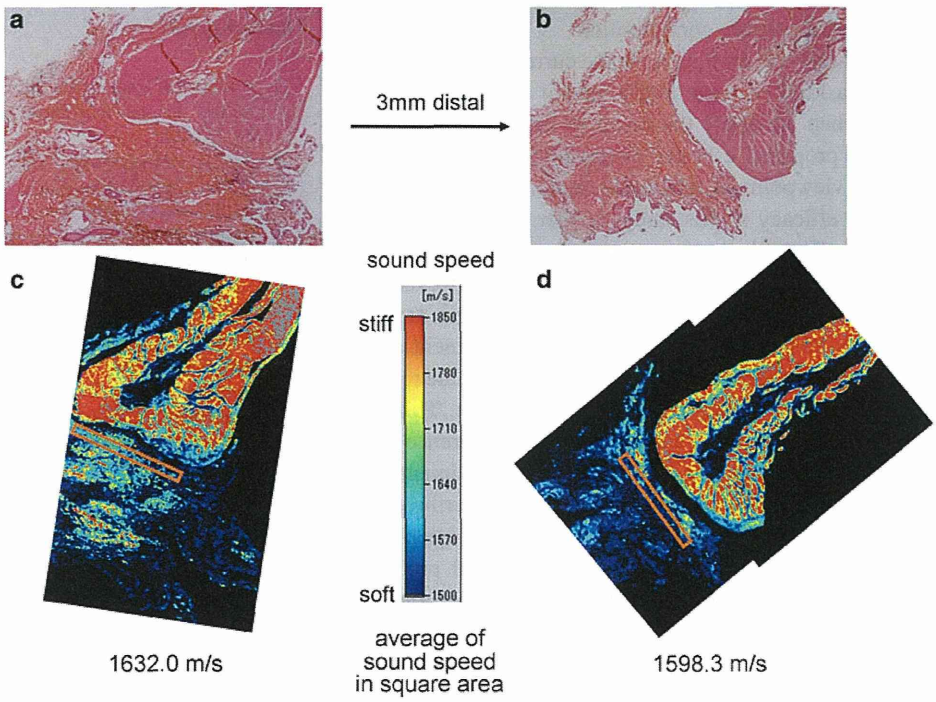

Fig. 4 Stiffness of the sheet-like structure as examined by SAM. **a**, **b** HE section of the LHB attachment and its 3 mm distal site. Original magnification ×1. **c**, **d** Images obtained by SAM at the two sites. Both images showed LHB as a relatively *red* area and the sheet-like structure as a relatively *blue* area. The sheet-like structure in (**c**) looked paler than in (**d**). This finding means that the sheet-like structure in (**c**) tended to be stiffer than in (**d**). The average of sound speed within the *red rectangle* in (**c**) and (**d**) was 1,632.0 m/s and 1,598.3 m/s, respectively

requisite property to support LHB near its origin. Therefore, LHB and the sheet-like structure should not be fixed in the same suture knot in order to maintain their independent functions.

Regarding the surgical technique of SLAP lesion repair, Boileau et al. [3] described that one of the reasons for unsuccessful results might be a too rigid fixation of the superior labrum to the glenoid; it might lose the medial role of the biceps anchor during abduction/external rotation. Dines and Elattrache reported that the horizontal mattress suture creates the normal meniscus-like free edge of the superior labrum, which traditional SLAP repair techniques do not form [7]. It is still unclear as to what extent the superior labrum changes appearance in shoulder motion, but repair configuration with a greater free edge should result in more flexibility of the superior labrum, which can recreate the normal mechanics of the superior labrum. At the sufficiently posterior portion from the LHB origin, however, the labrum was composed of parallel LHB fibres [2, 13] and its change of shape would be minimal. In this portion, the rigidity of labral fixation should be more important than its flexibility; consequently, the simple suture configuration vertical to the labrum fibres, which provides a stronger initial fixation than horizontal mattress suture [21], would be appropriate. In summary of the SLAP repair, (1) the origin of LHB should be fixed in horizontal mattress configuration in order to create a free edge of the superior labrum, (2) the horizontal mattress suture should not cross over ‘A’ so as not to fix both the LHB and the sheet-like structure together, and (3) the sufficiently posterior portion where the appearance of the labrum does not change with shoulder motion should be fixed in simple suture configuration.

There are some limitations in the current study. First, this study is a kind of basic study, and it is important to be careful when we apply the result to true clinical practice. We have proposed a better means of SLAP lesion repair from the viewpoint of functional anatomy, but in order to prove the efficacy of this study, further clinical studies are necessary. Second, the investigated cadavers were all of high age. According to Huber and Putz [13], however, with macroscopically intact joints, the internal fibrous architecture of the labrum and the nature of its attachment do not change with age. Therefore, we can assume that the result of this study is consistent even in younger people. Third, the measurement of location using the original reference might be crude. This study was undertaken with the intention to determine an anatomical landmark to facilitate arthroscopic surgeries; consequently, the method of determination of the location around the glenoid mimics the actual procedure performed in arthroscopy. As in arthroscopic surgeries, it is thought to be difficult to define and to adjust in more detail than the 30 min of clock time position (15°), we adopted the current method. Fourth, we mentioned the LHB supporting function of the sheet-like structure, but biomechanical testing was not performed. The sheet-like structure is very tiny, and it is difficult to set up and apply a mechanical testing apparatus. Instead, we performed histological analysis described above and estimated the function. Fifth, as tissue fixation always clots proteins and the stiffness of the soft tissue might be altered, SAM might not represent the actual stiffness of living human soft tissue. The stiffness, however, should be maintained even after embalming, and the result of SAM is thought to be reliable.

Conclusion

Fibre orientation and the stiffness of the sheet-like structure suggest that it should support LHB. As LHB fibres do not anteriorly cross over ‘A’, ‘A’ could be a landmark of the anterior border of LHB independent from the sheet-like structure. Considering a previous report which stated that the horizontal mattress suture can maintain the meniscus-like structure and thus it might be sufficient for proper motion of the normal superior labrum, it should be recommended in view of functional anatomy that the horizontal mattress suture does not cross over point ‘A’.

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