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An anatomic study on the origin of the long head of the triceps brachii

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Background: Posterior shoulder instability was reported to be more common than had been previously reported. However, the detailed morphology of the origin of the long head of the triceps brachii (LHT), which is located at the posteroinferior part of the glenohumeral joint and associated with the stability of the head of the humerus, has been unknown. The purpose of the current study was to clarify the detailed morphology of the origin of the LHT.
Methods: A total of 64 specimens from 36 cadavers (11 males and 25 females) were used. After dissecting the origin of the LHT in 54 specimens of 27 cadavers, the width of the origin of the LHT was measured with a caliper by 2 observers. The origin of the LHT was also investigated histologically in 18 specimens. Sections were analyzed with Masson's trichrome staining and Safranin O staining.
Results: Some fibers of the LHT originated more from the cranial area than from the infraglenoid tubercle and descended along the posterior rim of the glenoid cavity. The width of the origin on the dorsal surface of the scapula was 31.2 mm. The origin from the bone had a developed uncalcified fibrocartilage histologically. In addition, the LHT was fused with the glenohumeral joint capsule and was attached to the glenoid labrum directly.
Conclusions: The LHT could affect the glenohumeral joint capsule or the glenoid labrum because of their connections to each other and be associated with the posterior shoulder instability indirectly.

Shoulder instability causes shoulder pain or dysfunction in younger adults. The prevalence of anterior shoulder instability is significantly higher than the prevalence of posterior shoulder instability. However, Song et al[23] demonstrated that the rate of posterior instability in younger adults has been increasing more than previously reported. Posterior instability is regarded as one of the most commonly misdiagnosed or unrecognized shoulder pathologies.[19,24] Generally, posterior instability originates from an injury of the soft tissues including posterior capsule, posterior band of the inferior glenohumeral joint capsule, and posterior glenoid labrum, all of which play an important role as the static stabilizer.[7] On the other hand, dysfunctions of the dynamic stabilizer against the posterior instability mainly involve the rotator cuff, especially the teres minor and subscapularis, the deltoideus, the biceps tendon, and also all the muscles related to the scapulothoracic joint motion.[7] Thus, although many factors are considered to be associated with the posterior shoulder instability, its pathology has been inconclusive.

The long head of the triceps brachii (LHT) is also located at the posterior-inferior part of the glenohumeral joint. Although numerous textbooks have reported that the LHT consistently originates from the infraglenoid tubercle, Frohse et al[11] showed that the LHT is additionally connected to the glenohumeral joint capsule. Eiserloh et al[8] reported a consistent origin of the LHT from both the infraglenoid tubercle and the inferior glenohumeral joint capsule. Kapandji[17] explained that the LHT functionally opposes the inferior displacement of the head of the humerus.

However, the detailed morphology of the origin of the LHT, particularly how the LHT is attached to the bone, the glenohumeral joint capsule, and the glenoid labrum, has been unknown. The purpose of the current study was to clarify the detailed morphology of the origin of the LHT. We hypothesized that the anatomical relationship between the LHT and the surroundings of the glenohumeral joint would give us some clue to understand the pathologies of the posterior shoulder instability.

Our study complied with the Act on Body Donation for Medical and Dental Education in Japan established in 1983. No IRB approval was required for this study.

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Materials and methods

All of the cadavers used in the present study were donated to Tokyo Medical and Dental University. Before death, all of the donors had voluntarily expressed their will to donate their body for anatomical education and study according to the Act on Body Donation for Medical and Dental Education that was established in Japan in 1983. Our study completely complied with the law. At the time when this study was conducted, institutional review board approval was not required for cadaveric studies in our institution. A total of 64 specimens from 36 cadavers (11 males and 25 females) were used in this study. Both sides were dissected in 28 cadavers of all 36 cadavers. In contrast, only 1 side was assigned in the remaining 8 cadavers. The average age was 87 years (range, 73-101 years). Cadavers were fixed using 8% formalin and preserved in 30% ethanol. Specimens that had a medical history of shoulder operations were excluded.

In 54 specimens of 27 cadavers, the deltoideus, latissimus dorsi, teres major, short head of biceps brachii, coracobrachialis, and neurovascular structures were exposed and removed. Then, the teres minor and infraspinatus were reversed laterally, and the subscapularis was reversed medially. Eventually, the origin of the LHT was exposed and observed. To measure the width of the origin of the LHT, a line parallel to the lateral border of the scapula was adapted as the standard. The width from the most craniomedial point of the LHT to the most lateral end of the LHT was calibrated on the line parallel to the lateral border of the scapula with a caliper down to 0.01 mm. The measurements were conducted by 2 observers to evaluate the inter-rater reliability. Correlation coefficients for each value were calculated with Pearson's correlation coefficient and Spearman's correlation coefficient to evaluate the validity of the measurement within each group. Statistical tests were conducted by the statistical software "EZR" (Easy R), which is based on R and R commander. A score above 0.75 was considered to be excellent agreement.

The origin of the LHT was also investigated histologically in a total of 18 specimens including 8 specimens observed macroscopically to analyze how the LHT was attached to the bone and peripheral structures. Eight specimens were sliced parallel to the lateral end of the LHT at 5 mm from the infraglenoid tubercle of the scapula to the glenoid labrum. Another 8 specimens were sliced on the coronal section. The 2 other specimens were sliced on the horizontal section parallel to the lateral border of the scapula. A diamond band pathology saw (EXAKT 312; EXAKT Advanced Technologies, Norderstedt, Germany) was used for the slicing. Blocks composing the glenoid cavity, the glenoid labrum, the glenohumeral joint capsule, and the LHT were harvested. After fixation in 8% formalin and decalcification in a solution containing aluminum chloride, hydrochloric acid, and formic acid, as described by Plank and Rychlo,[21] blocks were embedded in paraffin and sectioned at 5 μm. Sections were analyzed with Masson's trichrome staining and Safranin O staining.

In 2 specimens of the 54 specimens observed macroscopically, the cadaver was placed in a prone position to maintain the

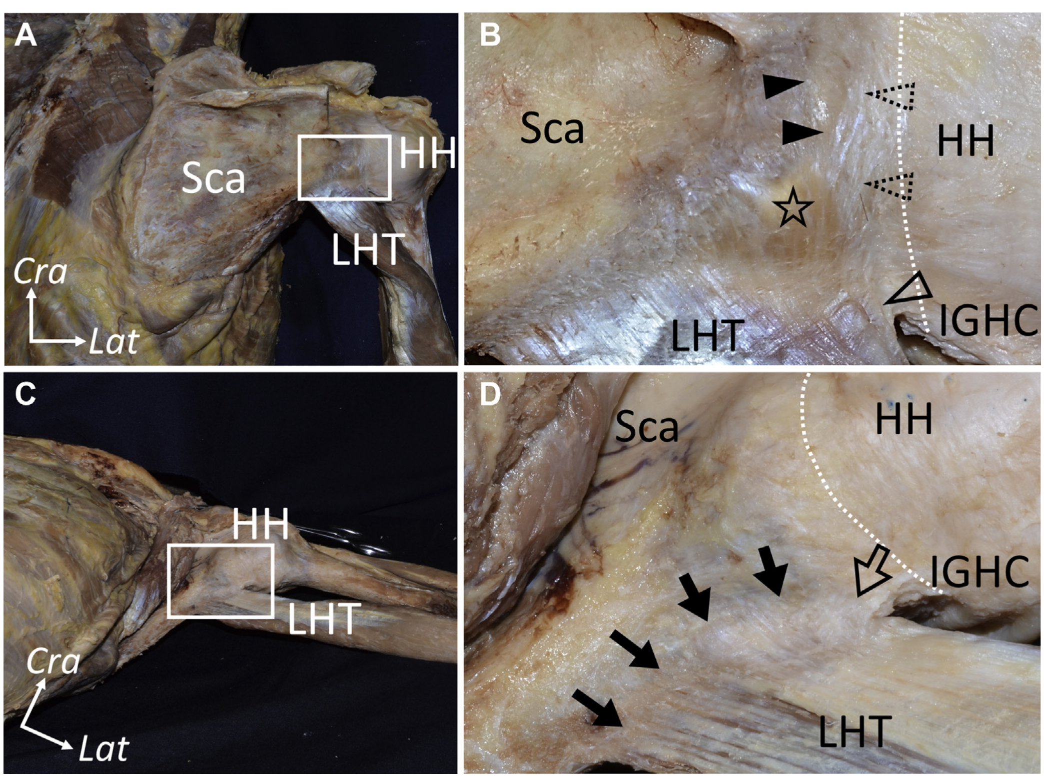

Figure 1 The origin of the long head of the triceps brachii (LHT). (**A**) The posterior aspect of the right glenohumeral joint is shown at the posterolateral view. (**B**) The magnified picture of the white square in picture (**A**). Some fibers of the LHT (►) originated from the more cranial area than from the infraglenoid tubercle (☆). In addition, some fibers of the LHT (◬) descended from close to the lateral border of the glenoid labrum (white dotted line). The lateral part of the LHT (△) had contact with the inferior glenohumeral joint capsule (IGHC). (**C**) The left glenohumeral joint at 90° abduction is shown from the inferolateral view. (**D**) The magnified picture of the white square in picture (**C**). The LHT also originated from the costal surface of the scapula (➔). The lateral part of the LHT (⇨) adjoined with the IGHC. *HH*, head of humerus; *Sca*, scapula; *Cra*, cranial; *Lat*, lateral.

glenohumeral joint at 90° flexion and 20° adduction. The positional relation between the LHT and the head of the humerus was observed at this position.

Results

The attachment to the bone

One specimen was excluded because of a shoulder operation. A total of 53 specimens of 27 cadavers were dissected for macroscopic investigation. The LHT originated from not only the infraglenoid tubercle but also from both the dorsal and costal surfaces spread from the lateral border of the scapula cranially (Fig. 1). In addition, the origin of the LHT also extended along the lateral border of the scapula medially. On both dorsal and costal surfaces, the lateral end of the LHT was connected to the axillary pouch of the inferior glenohumeral joint capsule.

Histological examination also demonstrated that the LHT had the dorsal and costal origins (Fig. 2). These origins combined with each other to form a V-shaped origin. The origin of the LHT was deeply stained with Masson's trichrome on a slice including the infraglenoid tubercle. Based on a detailed observation of the attachment to the bone, the calcified fibrocartilage and uncalcified fibrocartilage were discriminated by a tidemark on both dorsal and

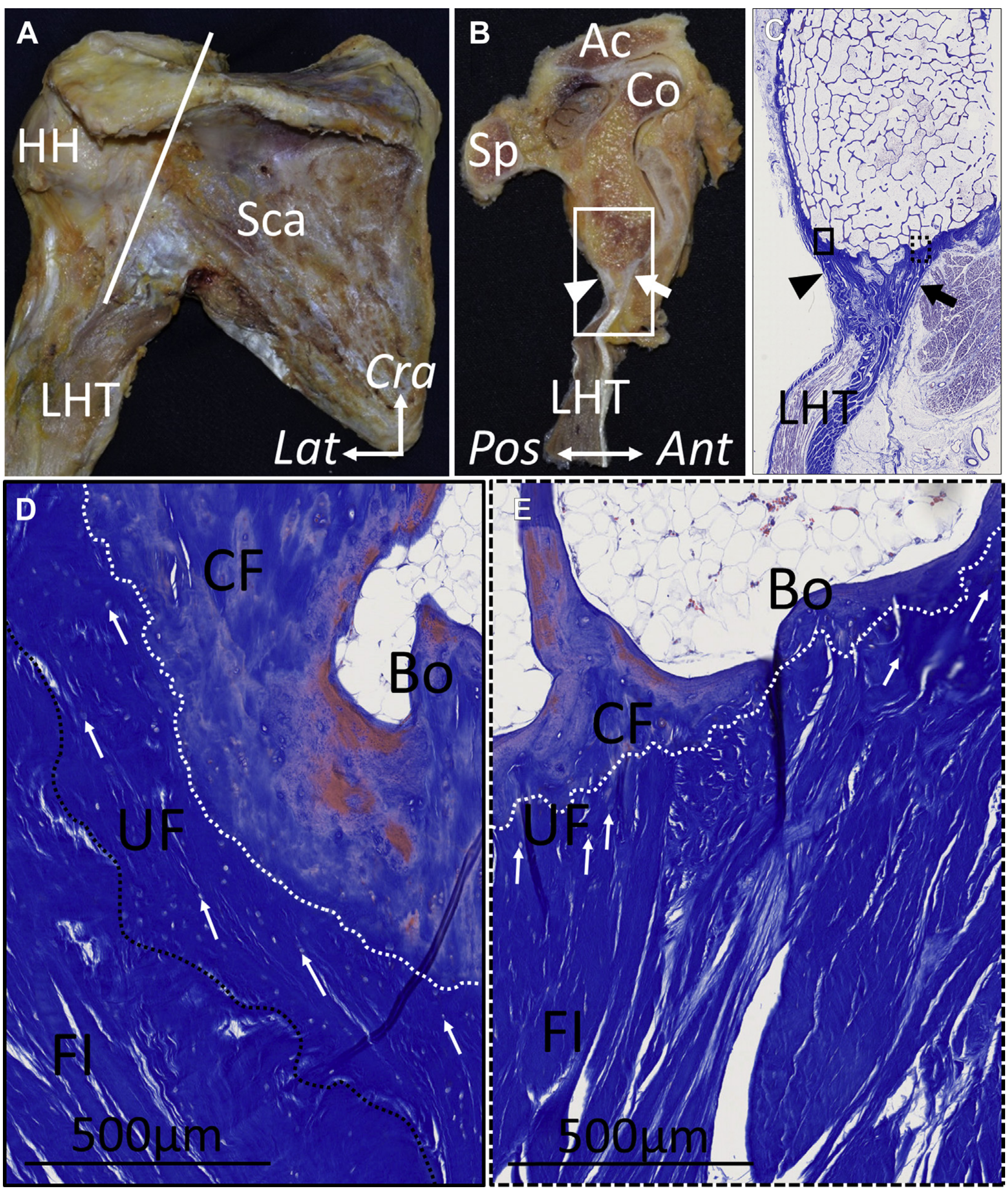

Figure 2 Histological analysis of the origin of the long head of the triceps brachii (LHT). (**A**) Slicing location is shown in the overview of the posterior aspect of the left glenohumeral joint. The location is parallel to the lateral end of the LHT. (**B**) A slice at the white line in picture (**A**). The dorsal and costal origins are indicated by the arrowhead and arrow, respectively. (**C**) The square area of slice (**B**) stained with Masson's trichrome. (**D**, **E**) Magnified images at the (□) and (⬚) areas in section (**C**), respectively. Tidemark of the boundary between the calcified fibrocartilage (CF) and uncalcified fibrocartilage (UF) is shown by the white dotted line. Oval-shaped large fibrocartilage cells (arrows) were observed in the area of the UF. The black dotted line (-—-) indicates the boundary between the UF and the fibers (FI) of the LHT. *Ac*, acromion; *Bo*, bone; *Co*, coracoid process; *HH*, head of humerus; *Sca*, scapula; *Sp*, spine of scapula; *Ant*, anterior; *Cra*, cranial; *Lat*, lateral; *Pos*, posterior. Scale bar = 500 µm.

Table I
The width of the origin of the long head of the triceps brachii

Locations of the measurement*	Average ± standard deviation (mm)
From the most craniomedial point (o) to the most lateral border (p) on the dorsal surface	31.2 ± 4.2
From the most craniomedial point (s) to the most lateral border (t) on the costal surface	24.0 ± 2.7

* Locations of the measurement are shown in Figure 3.

costal surfaces. Especially on the dorsal surface, more oval-shaped large fibrocartilage cells were observed than that on the costal surface.

Descending fibers passing through the posterior rim of the glenoid cavity and the posterior glenoid labrum

On the dorsal surface of the scapula, descending fibers originated from a more cranial and lateral area than the highest prominence of the infraglenoid tubercle (Fig. 1). Some fibers originated from the more cranial area than the highest prominence of the infraglenoid tubercle, descended along the posterior rim of the glenoid cavity, and combined with the LHT. Other fibers originated from close to the lateral edge of the glenoid labrum, descended on the posterior glenoid labrum, and also integrated with the LHT.

The width of the origin of the LHT on the dorsal surface was on average 31.2 mm (standard deviation, 4.2 mm), and the width of the origin of the LHT on the costal surface was on average 24.0 mm (standard deviation, 2.7 mm). As a result of the calculation of the correlation coefficients, all scores were greater than 0.95 (range, 0.96-0.98). The data and locations of the measurement are shown in Table I and Fig. 3.

The attachment to the glenohumeral joint capsule and the glenoid labrum

Observation from the inferolateral view revealed that the LHT originating from the axillary pouch extended in a fan-like fashion from the LHT to the inferior glenohumeral joint capsule (Fig. 4). Macroscopically, the boundary between the LHT and the inferior glenohumeral joint capsule was not able to be discriminated. According to histological examination on the horizontal section, some fibers that were continuous from the LHT passed through the posterior glenoid labrum and combined with the glenohumeral joint capsule (Fig. 5). On the coronal section, a space between the lateral end of the LHT and the glenohumeral joint capsule was occupied with loose connective tissues (Fig. 6). In addition, some fibers that were mingled with the glenohumeral joint capsule connected to the glenoid labrum directly (Fig. 6).

The positional relation between the LHT and the head of the humerus

A simulated position at the glenohumeral joint position of 90° flexion and 20° adduction was used to observe the positional relation between the LHT and the head of the humerus (Fig. 7). At this position, the descending fibers, which passed through the posterior rim of the glenoid cavity and the posterior glenoid labrum, and the lateral end of the LHT formed a bowl-shaped structure. The head of the humerus became stuck in the bottom of the bowl-shaped structure. It seemed the head of the humerus was suspended.

Discussion

In the current study, we demonstrated 3 findings. First, the LHT was attached to the bone via the developed uncalcified

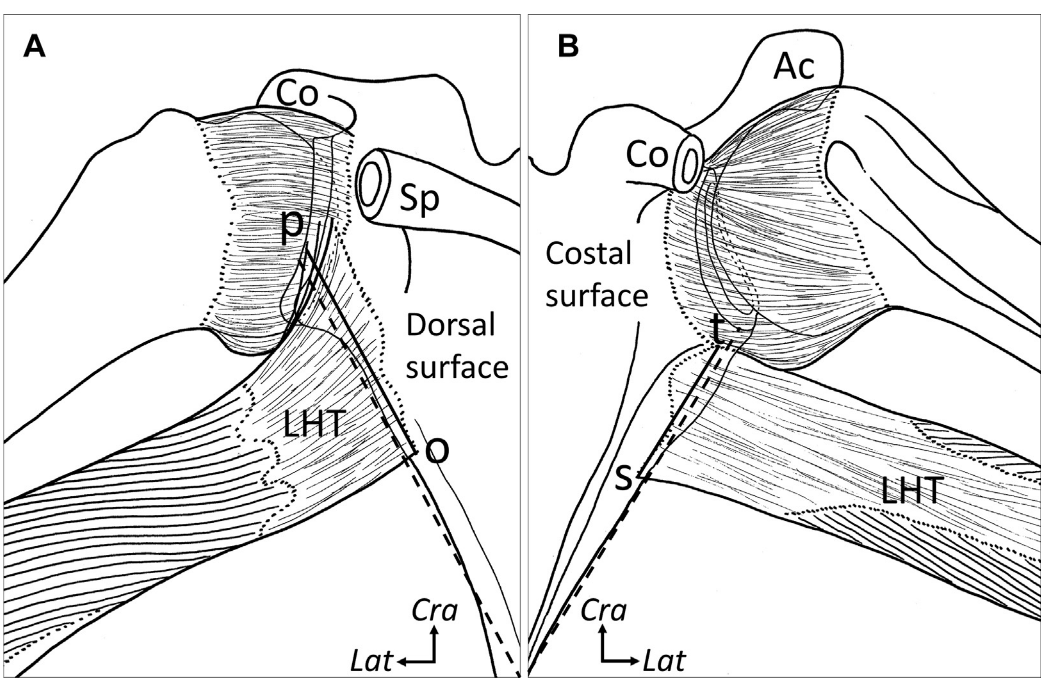

Figure 3 The dimension on the width of the origin of the long head of the triceps brachii (LHT). Illustrations show the locations of measurement (data are listed in Table I). (**A**) The posterior aspect of the left glenohumeral joint. A solid line parallel to the lateral border of the scapula (––) is shown. The width of the origin was measured from the most craniomedial point (o) to the most lateral border (p). (**B**) The anterior aspect of the left glenohumeral joint. A solid line parallel to the lateral border of the scapula (––) is shown. The width of the origin was measured from the most craniomedial point (s) to the most lateral border (t). *Ac*, acromion; *Co*, coracoid process; *Sp*, spine of scapula; *Cra*, cranial; *Lat*, lateral.

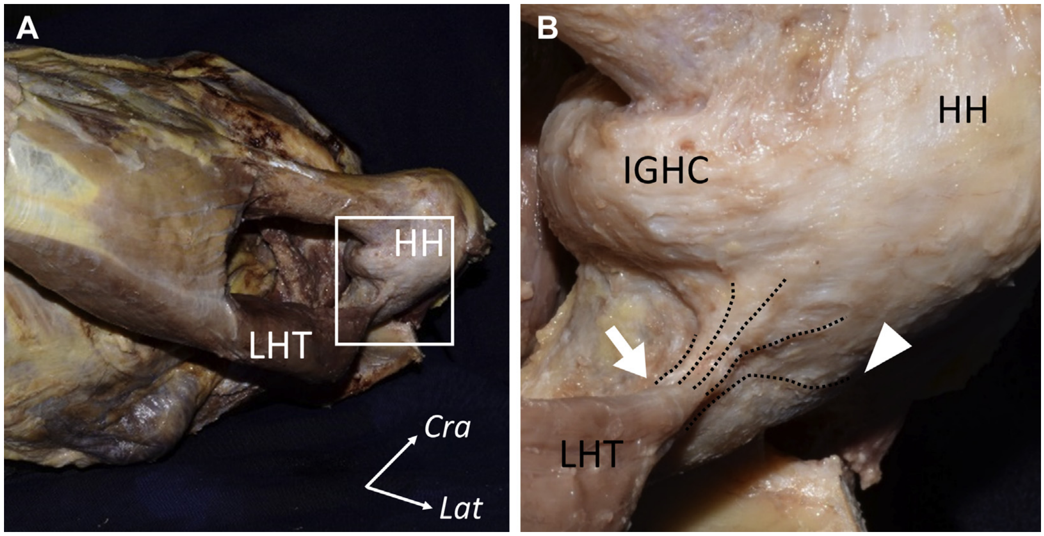

Figure 4 The attachment to the axillary pouch of the long head of the triceps brachii (LHT). (**A**) The left glenohumeral joint at 20° adduction is shown from the inferolateral view. (**B**) The magnified picture of the white square in picture (**A**). The LHT extended in a fan-like fashion (----) to the inferior glenohumeral joint capsule (IGHC). The closed arrow and closed arrowhead indicate the lateral border of the costal and dorsal origins from the bone, respectively. *HH*, head of humerus; *Cra*, cranial; *Lat*, lateral.

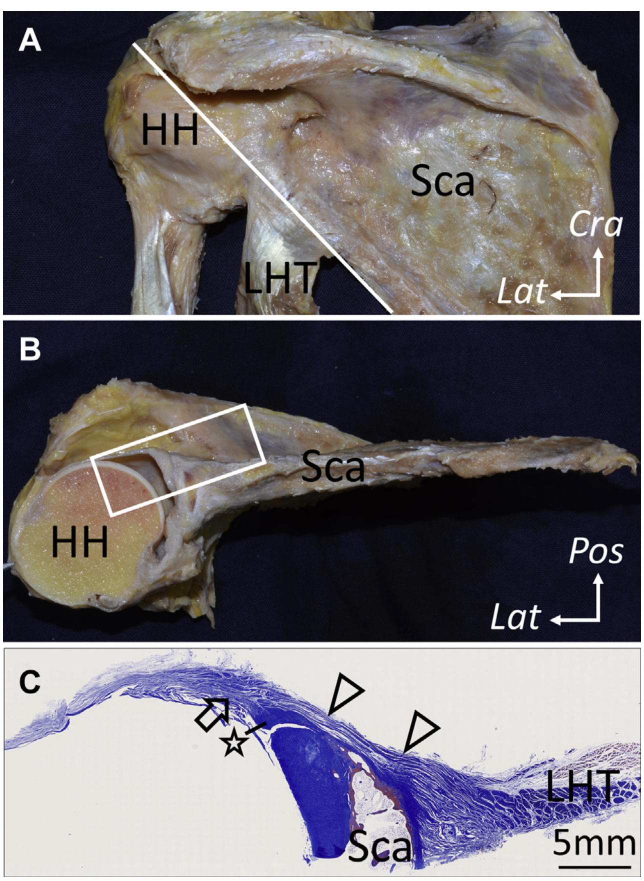

Figure 5 Some fibers continuous to the glenohumeral joint capsule. (**A**) Slicing location is shown on the posterior aspect of the left glenohumeral joint. The location is parallel to the lateral border of the scapula. (**B**) A slice at the white line in picture (**A**) is shown in the inferior view. (**C**) The square area of slice (**B**) was stained with Masson's trichrome. Some fibers of the LHT (△) were continuous to the complex of the glenohumeral joint capsule (⇨) and the glenoid labrum (☆). *HH*, head of humerus; *Sca*, scapula; *Cra*, cranial; *Lat*, lateral; *Pos*, posterior.

fibrocartilage. Second, descending fibers passed through the posterior rim of the glenoid cavity and the posterior glenoid labrum, and they were combined with the LHT. Third, the LHT was fused with the glenohumeral joint capsule and was attached to the glenoid labrum directly. These findings indicate that the LHT might contribute to posterior shoulder stability more significantly than people have believed until now.

First, the LHT originated from the infraglenoid tubercle and the dorsal and costal surfaces spread from the lateral border of the scapula cranially. The histological examination also revealed the dorsal and costal origins of the LHT. We found the uncalcified fibrocartilage at both origins. Especially on the dorsal surface, the LHT was attached to the bone via the developed uncalcified fibrocartilage. Benjamin et al[3] described that the stress concentration at the site of tendon and ligament origin to the bone causes the development of uncalcified fibrocartilage, termed "entheses." On the basis of Benjamin's description,[3] we consider that the area with the developed uncalcified fibrocartilage of the origin of the LHT results from mechanical stress, such as repeated loads or excessive traction associated with joint motion. Some researchers[4,10,15] reported cases with infraglenoid tubercle avulsion fracture and argued that it could be caused by contraction of the LHT. As far as the knee joint is concerned, at the area where Segond's avulsion fracture is triggered, the developed uncalcified fibrocartilage is found.[20] We consider that although the origin of the LHT on the bone endures mechanical stress within an acceptable range, an overloaded traction could affect the infraglenoid tubercle resulting in an avulsion fracture.

Second, we showed that descending fibers passed through the posterior rim of the glenoid cavity and the posterior glenoid labrum, and they were combined with the LHT. In addition, the LHT also extended along the lateral border of the scapula medially. Handling et al[13] reported that the width of the LHT on the dorsal surface of the scapula was 26.9 mm. However, the current study reported the origin of the LHT averaged 31.2 mm in width. This difference in width could reflect whether the fibers that descended on the posterior rim of the glenoid cavity and the posterior glenoid labrum were included or not. In addition, we proved that the

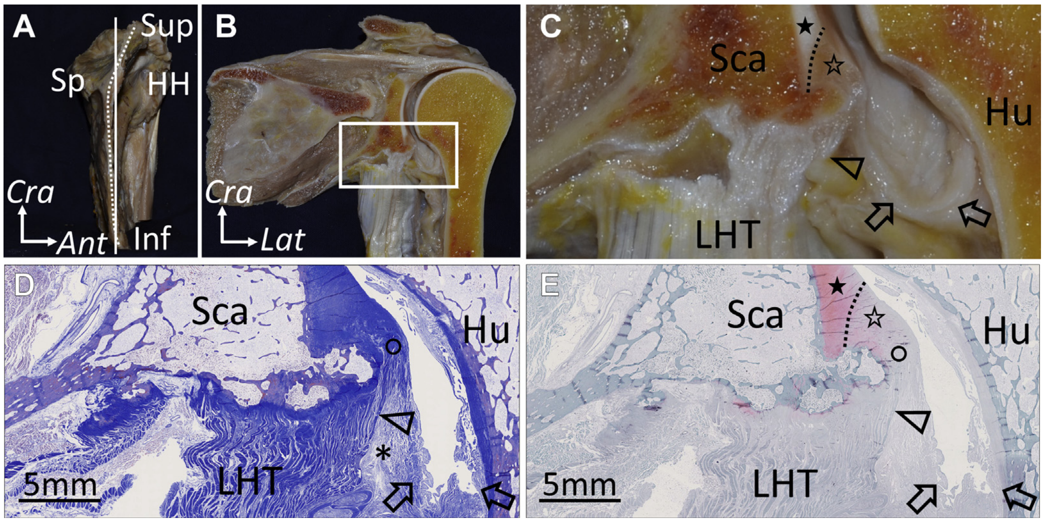

Figure 6 Some fibers of the long head of the triceps brachii (LHT) connecting to the glenoid labrum. (**A**) Slicing location is shown in the medial view of the scapula and humerus. The white dotted line indicates the medial border of the scapula. (**B**) A slice at the white line in picture (**A**). (**C**) The magnification of the white square of picture (**B**). The boundary between the glenoid labrum (☆) and the articular cartilage (★) is indicated by the dotted line (‑‑‑). (**D**) A section of the white square of picture (**B**) stained with Masson's trichrome. A space between the lateral end of the LHT (△) and the glenohumeral joint capsule (⇨) was occupied with loose connective tissues (*). At the area close to the glenoid labrum, the tissues were mingled with each other (◯). (**E**) A section of the white square of picture (**B**) stained with Safranin O. The mingled fascicle (◯) was connected to the glenoid labrum (☆) directly. *HH*, head of the humerus; *Hu*, humerus; *Inf*, inferior angle of the scapula; *Sca*, scapula; *Sp*, spine of scapula; *Sup*, superior angle of the scapula; *Ant*, anterior; *Cra*, cranial; *Lat*, lateral.

descending fibers formed a bowl-shaped structure with the lateral end of the LHT at the glenohumeral joint position of 90° flexion and 20° adduction. Eiserloh et al[8] demonstrated that the LHT would prevent inferior displacement of the head of the humerus. Furthermore, we consider that the behavior of the LHT could be attributed to this bowl-shaped structure including the descending fibers.

Bennett[2] reported a deposit of bone develops on the posterior inferior border of the glenoid cavity because of the excessive use of the arm and the tremendous pull on the posterior capsule and the triceps tendon. This condition is a bony spur called the Bennett lesion. However, the etiology of the Bennett lesion has been

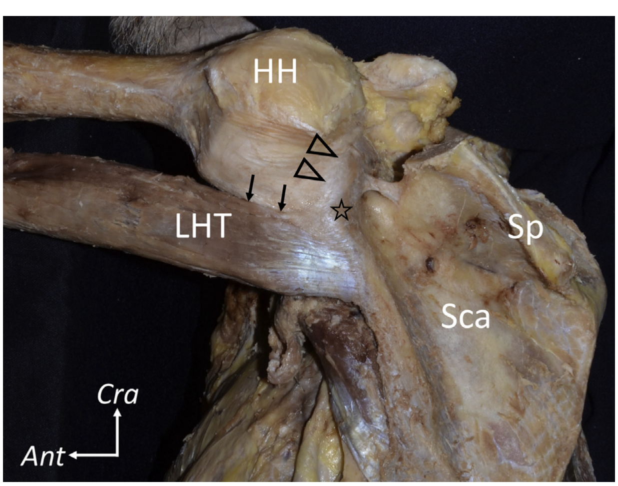

Figure 7 The positional relation between the long head of the triceps brachii (LHT) and head of the humerus (HH) at the glenohumeral joint position of 90° flexion and 20° adduction. The (☆) indicates the origin of the LHT from the highest prominence of the infraglenoid tubercle. Descending fibers (△) and the lateral end of the LHT (→) form a bowl-shaped structure. *Sca*, scapula; *Sp*, spine of scapula; *Ant*, anterior; *Cra*, cranial.

controversial. Lombard et al[18] speculated that the ossification might be caused by the impingement between the head of the humerus and the rim of the glenoid cavity. Some researchers[1,6,9] have reported that the Bennett lesion does not have its origin in the region of the triceps brachii but at a junction of the posterior capsule with the posterior labrum and adjacent glenoid rim. However, we suppose that the Bennett lesions could be triggered by a complex structure including the LHT because some fibers of the LHT descended on the posterior rim of the glenoid cavity and the posterior glenoid labrum.

Third, the LHT also originated from the axillary pouch. It extended in a fan-like fashion from the LHT to the inferior glenohumeral joint capsule. The connection to the glenoid joint capsule has been described by Frohse et al.[11] Eiserloh et al[8] also reported a consistent origin of the LHT from the inferior glenohumeral capsule. Gohlke et al[12] explained that the axillary pouch arises from an intermingling of radial and circular fibers of the glenohumeral joint capsule. We believe that the fan-like fibers of the LHT to the axillary pouch follow the same track as the collagen fibers of the glenohumeral joint capsule and strengthen it. On the other hand, adhesion at the space between the LHT and the axillary pouch, which was occupied with loose connective tissues, could result in a limitation of the range of motion at the glenohumeral joint.

Histological analysis of the horizontal sections demonstrated that some fibers of the LHT passed through the posterior glenoid labrum and connected to the glenohumeral joint capsule. Simons et al[22] and Yu et al[25] reported the posterior labrocapsular periosteal sleeve avulsion (POLPSA) lesion. In this lesion, the periosteum is detached from posterior glenoid with the intact posterior glenoid labrum. The POLPSA lesion creates a redundant recess in the joint and causes posterior instability of the shoulder. We think that the extension force transmitted through some fibers of the LHT that were connected to the glenohumeral joint capsule might be associated with initiation of the POLPSA. In addition, histological analysis of the coronal sections revealed that a part of the LHT was attached to the glenoid labrum directly. Hertz et al[14] and Huber and Putz[16] reported that fibers from the LHT ran backward and forward into the glenoid labrum. They revealed that the LHT was one of the parallel collagen fibers that surrounded the entire circumference of the glenoid cavity. However, we found that the fibers of the LHT were directly attached to the glenoid labrum. This finding is a new point in our study. Cooper et al[5] reported that the inferior part of the glenoid labrum consisted of a round fibrous elevation at the glenoid rim. The LHT might sustain the inferior glenoid labrum and reinforce the inferior capsulolabral complex.

Díaz Heredia et al[7] reported that the posterior capsule, posterior band of the inferior glenohumeral ligament, and posterior labrum provide greater support posteriorly, and some injuries of these posterior structures often result in posterior instability. Our findings that the LHT had some connections with the posterior structures indicate that the LHT could have had some effects on them. Clinically, these connections mean not only that the LHT could support the posterior structures but also that the LHT could have some negative effect on the posterior structures under excessive loads because of the connection. Therefore, these detailed morphologies of the origin of the LHT could be useful to understand unrecognized shoulder pathologies on the posterior instability. However, the functional interaction between the LHT and the posterior structures warrants further investigation.

This study has the following limitations: first, the age of the materials was imbalanced because all of the cadavers came from elderly people. Second, the specimens were mixed with the use of both sides and only use of 1 side. Third, this was purely an anatomical study and did not include a biomechanical examination. More research is required to clarify the functional interaction between the LHT and the posterior structures and the mechanism of how the LHT sustains the inferior displacement of the head of the humerus biomechanically.

Conclusions

The LHT originated from the infraglenoid tubercle via the developed uncalcified fibrocartilage and had some connections with the glenohumeral joint capsule and glenoid labrum. Based on the findings in the current study, the LHT might be indirectly associated with the posterior shoulder instability. Further investigation is required to clarify the functional interaction between the LHT and the posterior structures and the mechanism of how the LHT sustains the inferior displacement of the head of the humerus biomechanically.

Disclaimer

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