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Anatomic limitations of biceps tenodesis using an interference screw for Asian people: a cadaveric study

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Background: Biceps tenodesis using an interference screw has been commonly performed in clinical practice because of pathologic changes. Especially, the tenodesis distal to the bicipital groove, such as suprapectoral tenodesis (SPT) and subpectoral tenodesis (SBT), has been performed to avoid residual anterior shoulder pain. However, the techniques were developed based on research tested on Western population, and it is unknown whether they are applicable to Asian individuals, who have a smaller humerus than Western. The purpose of this study was to investigate the anatomic limitations of the biceps tenodesis using an interference screw for Asians.

Methods: We analyzed 22 fixed Japanese cadavers. We measured the length of the suprapectoral tenodesis zone (STZ), which is the area from the distal end of the lesser tuberosity to the proximal border of the insertion of the pectoralis major muscle tendon (PMMT) along the course of the biceps tendon, for the SPT. We also measured the bone tunnel depths (BTDs) for the SPT just distal to the lesser tuberosity along the course of the biceps tendon and, similarly, for the SBT just distal to the PMMT insertion. Finally, we analyzed the sexual differences and correlations of the measured values with the entire humeral length.

Results: In 9 shoulders (40.9%), the proximal border of the PMMT insertion was attached more proximally than the distal end of the lesser tuberosity, and the length of the STZ was negative. The mean BTDs in the SPT and SBT zones were 19.6 and 14.9 mm, respectively. In 11 shoulders (50%), the BTD in the SBT zone was shorter than 15 mm. The lengths of the STZ or BTDs in the SPT and SBT zones did not show statistical differences between sexes and were not correlated with the entire humeral length.

Conclusion: Asian patients would have anatomic limitations as follows for the biceps tenodesis regardless of their sex or body size. In anomalous PMMT cases, when the SPT was performed just proximal to the PMMT insertion, the bone tunnel entered into the bicipital groove. On the other hand, when the SPT was performed distal to the lesser tuberosity, a part of the PMMT insertion would be injured. Regarding the SBT, an interference screw with a length of $\geq$12 mm, which is commonly used in Western countries, is too long for Asians.

The long head of the biceps tendon (LHBT) is recognized as a common source of anterior shoulder pain due to idiopathic degeneration, instability of the LHBT, or superior labral detachment anterior and posterior (SLAP) lesions.[3,11,13–15,17,18,21,24,26,28] If conservative treatments, such as medication and physical therapy, fail, the LHBT tenodesis is likely to be performed, especially in active and young patients.[13,14,25,26,28]

Several studies have recommended that the tenodesis should be performed distal to the bicipital groove, because the tenodesis at the articular margin or within the bicipital groove is likely to occur residual postoperative anterior shoulder pain owing to persistent tenosynovitis.[5,6,11,12,14,15,17,21,23] The tenodesis distal to the bicipital groove has been performed in the suprapectoral position,[3,18,19,25,26,28] subpectoral position,[13,14,18,19,25,26,28] and others.[22,24,28] Moreover, several studies have reported that the tenodesis using an interference screw had biomechanical strengths equal to or higher than those of tenodesis using other fixation techniques.[1,7,18,27] As a result, the suprapectoral tenodesis and subpectoral tenodesis (SPT and SBT, respectively) using an interference screw have been widely performed in clinical practice.[3,11,13–15,26,28]

This study was approved by the Institutional Review Board of Kyoto University Graduate School and Faculty of Medicine, Ethics Committee (R0379-2).

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Surgical techniques of the SPT and SBT using an interference screw were based on Western patients,[3,11,17] and it has not been proved whether they could be applied in Asian individuals with a smaller humerus,[2,10] who may not have sufficient fixation area or humeral thickness.

Our study aimed to evaluate the anatomic limitations of the SPT and SBT using an interference screw in Japanese fixed cadavers.

Materials and methods

This study was approved by our Institutional Review Board. We used 23 Japanese cadavers for the study. The cadavers were embalmed using the modified Bradbury and Hoshino method, which used a solution of 50% ethylene glycol, 39% methanol, 8% formalin, 2% phenol, and 0.2% Cell Conditioner embalming fluid (Champion Co., Ltd., Springfield, OH, USA).[4] No individual information was available, including prior shoulder problems.

We removed the skin, subcutaneous tissues, and deltoid muscle around the shoulder. The pectoralis major muscle tendon (PMMT) was visualized and cut approximately 30 mm medial to its humeral insertion. We then carefully removed other soft tissues to disarticulate the glenohumeral joint. Subsequently, we identified the distal end of the bicipital groove, where the steep slope of the lesser tuberosity became more gradual. Additionally, we observed the 2 separated layers in the PMMT insertion, which included the anterior lamina originating from the clavicle and upper sternum, and the posterior lamina originating mainly from the sternum and attaching more proximal to the anterior lamina (Fig. 1, *A*), as previously reported.[8,9,16,29]

One shoulder was excluded because of a partial tear of the PMMT insertion, and 22 shoulders (13 male and 9 female specimens; 10 right and 12 left shoulders; the mean age 85.9 years [range, 52-101 years]) were examined in this study.

Regarding the SPT, we defined the suprapectoral tenodesis zone (STZ) according to a previous study[17] as the appropriate area for the SPT from the distal end of the lesser tuberosity to the proximal border of the insertion of the posterior lamina of the PMMT along the course of the LHBT (Fig. 1, *A* and *B*). We measured the length of the STZ with a digital caliper (Digital Nogisu 300 mm; Niigata Seiki, Niigata, Japan) (resolution, 0.02 mm). Additionally, we similarly defined the expansive STZ (ESTZ) as the area from the distal end of the lesser tuberosity to the proximal border of the insertion of the anterior lamina of the PMMT (Fig. 1, *A*) and measured its length.

For both SPT and SBT using an interference screw, the monocortical bone tunnels were created with a drill of 6.0 mm diameter. The locations of the bone tunnels were just distal to the lesser tuberosity along the course of the LHBT for the SPT and, similarly, just distal to the PMMT insertion for the SBT (Fig. 1, *A*). The bone tunnel depth (BTD) of each tunnel was measured with a digital depth gauge (digital depth gauge mini, 25 mm; Shinwa Sokutei, Niigata, Japan) (resolution, 0.2 mm).

In addition, as an indicator of the body size, we measured the entire humeral length (EHL), which is the distance from the proximal end of the greater tuberosity to the most lateral end of the lateral epicondyle.

Statistical analysis

Means and standard deviations were calculated for the EHL, lengths of the STZ and ESTZ, and BTDs in the SPT and SBT zones. We used the Wilcoxon rank sum test to compare the mean values of the EHL, lengths of the STZ and ESTZ, and BTDs in the SPT and SBT zones between sexes and to compare the mean values of the BTDs between the SPT and SBT zones. In addition, we used the Spearman rank correlation to examine the correlations between the EHL and lengths of the STZ and ESTZ, or BTDs in the SPT and SBT zones. All tests were considered statistically significant if the *P* values were <.05.

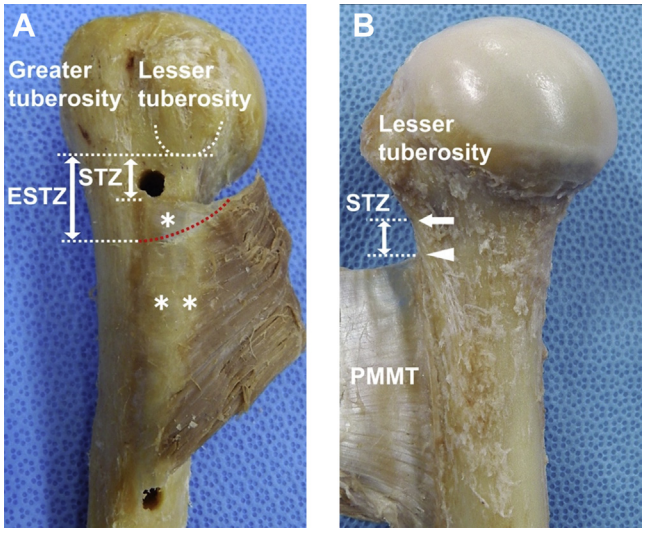

Figure 1 (**A**) The anterior view of the bicipital groove in the right proximal humerus. The border between the posterior (*) and anterior (**) laminae of the PMMT insertion is shown as a red dotted line. The STZ was the appropriate area for the SPT and defined as the distance from the distal end of the lesser tuberosity to the proximal border of the insertion of the posterior lamina along the course of the LHBT. The ESTZ was similarly defined as the distance from the distal end of the lesser tuberosity to the proximal border of the insertion of the anterior lamina. The mono-cortical bone tunnels were created just distal to the lesser tuberosity along the course of the LHBT for the SPT and, similarly, just distal to the PMMT insertion for the SBT. (**B**) The anteromedial view of the same humerus as in panel A. The PMMT insertion was reflected. The distal end of the lesser tuberosity (*white arrow*) and proximal border of the insertion of the posterior lamina of the PMMT (*white arrowhead*) are shown. *LHBT*, long head of the biceps tendon; *PMMT*, pectoralis major muscle tendon; *STZ*, suprapectoral tenodesis zone; *ESTZ*, expansive suprapectoral tenodesis zone; *SPT*, suprapectoral tenodesis; *SBT*, subpectoral tenodesis.

All measurements were performed by one examiner. The examiner made the same measurements twice with an interval of at least 1 week. A total of 4 measurements were carried out, and the values were averaged. The intraclass correlation coefficients between 4 separate measurement times of the same observer were 0.95, 0.79, 0.78, 0.95, and 0.92 for the EHL, lengths of STZ and ESTZ, and BTDs in the SPT and SBT zones, respectively.

The intraclass correlation coefficients were analyzed using R version 3.3.1 (R Foundation, Vienna, Austria), and the other data were analyzed using JMP, version 14.3. (SAS Institute Inc, Cary, NC, USA).

Results

The proximal border of the insertion of the posterior lamina of the PMMT was attached more proximally than the distal end of the lesser tuberosity in 9 of 22 shoulders (40.9% [5 male and 4 female specimens]; Fig. 2, *A* and *B*). In such anomalous cases, the lengths of the STZ were accordingly defined as negative values. Similarly, the proximal border of the insertion of the anterior lamina of the PMMT was attached more proximally than the distal end of the lesser tuberosity in 2 shoulders (9.1% [1 male and 1 female specimen]), and the lengths of their ESTZ showed negative values. The lengths of the STZ and ESTZ are demonstrated in Table I and Fig. 3 (STZ: 1.2 ± 8.3 mm, ESTZ: 13.2 ± 7.2 mm).

The BTDs in the SPT and SBT zones are shown in Table I (SPT: 19.6 ± 1.9 mm, SBT: 14.9 ± 1.6 mm). The BTD in the SPT zone was significantly longer than that in the SBT zone ($P < .01$). In the SPT

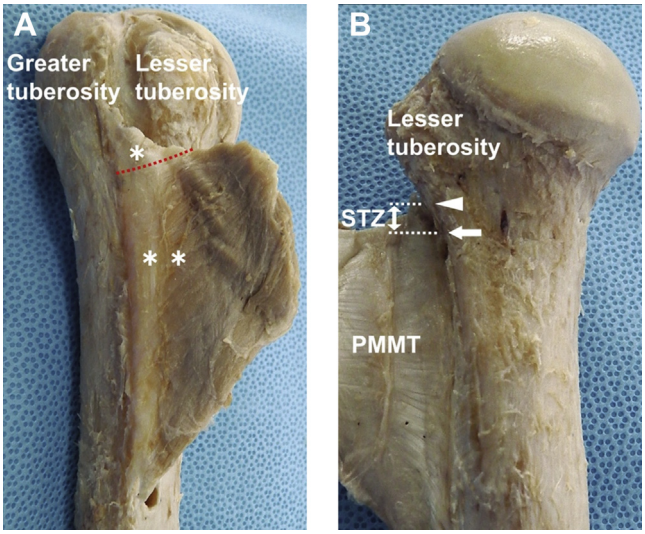

Figure 2 (**A**) An example of the anomaly, with the anterior view of the bicipital groove in the right proximal humerus. The proximal border of the insertion of the posterior lamina of the PMMT ascended and passed over the lesser tuberosity. The border between the posterior (*) and anterior (**) laminae is shown as a red dotted line. (**B**) The anteromedial view of the same humerus as in panel A. The PMMT insertion was reflected. The proximal border of the insertion of the posterior lamina of the PMMT (*white arrowhead*) was attached more proximally than the distal end of the lesser tuberosity (*white arrow*). In such anomalous cases, the length of the STZ was defined as negative. *PMMT*, pectoralis major muscle tendon; *STZ*, suprapecoral tenodesis zone.

zone, no shoulders had BTDs <15 mm, 5 of 22 shoulders (22.7% [2 male and 3 female specimens]) had BTDs <18 mm, and 12 shoulders (54.5% [7 male and 5 female specimens]) had BTDs <20 mm (Fig. 4). On the contrary, in the SBT zone, 11 shoulders (50% [5 male and 6 female specimens]) had BTDs <15 mm and 20 shoulders (90.9% [11 male and 9 female specimens]) had BTDs <18 mm (Fig. 4).

There were no statistically significant differences between sexes in the lengths of the STZ and ESTZ or BTDs in the SPT and SBT zones ($P > .05$), although statistically significant differences were found in the EHL ($P < .001$) (Table I). Moreover, there were no correlations between the EHL and lengths of the STZ and ESTZ or BTDs in the SPT and SBT zones (Table II).

Discussion

Our study aimed to evaluate the anatomic limitations in relation to the SPT and SBT using an interference screw in 22 Japanese fixed cadaveric shoulders, with humerus smaller than those of Western patients.[2,10] We demonstrated 3 important findings. First, the proximal border of the insertion of the posterior lamina of the PMMT was attached more proximally than the distal end of the lesser tuberosity in 9 shoulders (40.9%). As a result, when the SPT was performed just proximal to the insertion of the posterior lamina of the PMMT in these shoulders, the bone tunnel entered into the bicipital groove. In contrast, when the SPT was performed distal to the lesser tuberosity, a part of the PMMT insertion, mainly posterior lamina, would be injured. Second, 11 shoulders (50%) had BTDs <15 mm in the SBT zone, suggesting that an interference screw with a length of ≥12 mm, which is commonly used in Western countries and requires a BTD of ≥15 mm,[11,13,14,20] is too long for Asian patients. Third, there were no significant differences in the lengths of the STZ and ESTZ or BTDs in the SPT and SBT zones between sexes. In addition, the EHL had no correlation to any items described above either. These results suggested that the lengths of the STZ and ESTZ or BTDs in the SPT and SBT zones do not depend on the patients' sex or apparent body size.

In our study, the length of the STZ of the Japanese cadavers was 1.2 ± 8.3 mm. In a previous Western cadaveric study, Neviaser et al[17] reported that the mean length of the STZ was 29.6 mm (range, 15.4-44.0 mm) in 12 shoulders. The large discrepancy between the results would be explained as the difference in the anatomic landmark for measurements. In both studies, the definition of the distal end of the bicipital groove appeared the same, but the interpretation of the proximal border of the PMMT insertion might be different; the quality of the proximal border of the PMMT insertion is thin and wide tendon tissues (Figs. 1 and 2).[8,9,29] Neviaser et al[17] might thus regard only the insertion of the anterior lamina of the PMMT as the proximal border of the PMMT insertion. In this situation, the length of the STZ should be equivalent to the length of the ESTZ in our study. Nevertheless, there is still an unneglectable difference in the results, as the length of the ESTZ in our study was 13.2 ± 7.2 mm, which was much shorter than Neviaser et al's STZ length.[17] With respect to the results of both observations, further studies and discussions are necessary.

We showed that the proximal border of the insertion of the posterior lamina of the PMMT was attached more proximally than the distal end of the lesser tuberosity in 9 shoulders (40.9%). When the SPT was performed just proximal to the insertion of the posterior lamina of the PMMT in these shoulders, the bone tunnel entered into the bicipital groove. Taking into consideration the diameter of an interference screw, keeping the bone tunnel distal to the bicipital groove could be difficult in a large number of cases. According to several studies, the LHBT tenodesis at the articular margin or within the bicipital groove is likely to occur residual postoperative anterior shoulder pain owing to persistent tenosynovitis.[5,6,11,12,14,15,17,21,23] Therefore, the SPT just proximal to the insertion of the posterior lamina of the PMMT may be a cause of persistent anterior shoulder pain. On the other hand, when the SPT was performed just distal to the lesser tuberosity, a part of the PMMT insertion, mainly posterior lamina, would be injured. The proximal part of the insertion of the posterior lamina, however, mostly consists of thin tendinous tissue,[8,9,29] and it seems to only play a limited role in the stabilization of the total PMMT insertion. Thus, it might not be so critically important in a clinical viewpoint.

Table I
Anatomically measured values in the LHBT tenodesis

	Total, mean ± SD (n = 22)	Male, mean ± SD (n = 13)	Female, mean ± SD (n = 9)	Difference between sexes, *P* value
Length of STZ, mm	1.2 ± 8.3	2.1 ± 8.7	0.0 ± 8.1	.14
Length of ESTZ, mm	13.2 ± 7.2	15.1 ± 7.0	10.3 ± 6.8	.08
BTD in SPT zone, mm	19.6 ± 1.9	19.9 ± 2.1	19.1 ± 1.8	.46
BTD in SBT zone, mm	14.9 ± 1.6	15.2 ± 1.9	14.5 ± 1.1	.46
EHL, mm	271.7 ± 16.1	282.2 ± 6.2	256.5 ± 13.5	<.001*

LHBT, long head of biceps tendon; *STZ*, suprapectoral tenodesis zone; *ESTZ*, expansive suprapectoral tenodesis zone; *BTD*, bone tunnel depth; *SPT*, suprapectoral tenodesis; *SBT*, subpectoral tenodesis; *EHL*, entire humeral length.
* Statistically significant ($P < .001$).

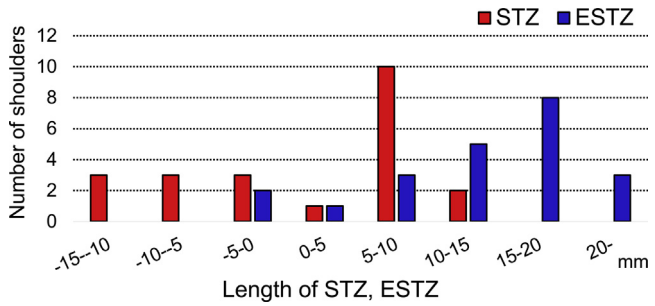

Figure 3 The distribution of the lengths of the STZ and ESTZ. In 9 shoulders, the length of the STZ had a negative value because the proximal border of insertion of the posterior lamina of the PMMT was attached more proximally than the distal end of the lesser tuberosity. Similarly, in 2 shoulders, the length of the ESTZ was negative because the proximal border of insertion of the anterior lamina of the PMMT was attached more proximally than the distal end of the lesser tuberosity. *STZ*, suprapectoral tenodesis zone; *ESTZ*, expansive suprapectoral tenodesis zone; *PMMT*, pectoralis major muscle tendon.

Nevertheless, further investigations focusing on the clinical effect of the minor injuries in the PMMT insertion will be needed.

In our study, the BTD in the SBT zone was 14.9 ± 1.6 mm, and 11 shoulders (50%) had BTDs shorter than 15 mm. On the other hand, a previous clinical study from a Western country reported that the BTD in the SBT zone was 17.5 mm (range, 10-23 mm), and only 4 of 66 shoulders (6%) had BTDs shorter than 15 mm.[14] Our study demonstrated obviously shorter BTDs and a higher frequency of BTDs <15 mm. In the SBT zone, interference screws with a length of ≥12 mm, which are commonly used in Western countries and require BTDs of ≥15 mm,[11,13,14,20] would be too long for Asian patients. Moreover, it could lead to persistent anterior shoulder pain and fixation failure owing to the formation of a proud screw head and insufficient strength fixation, respectively,[14,20] in Asian patients. Thus, it would be safer to avoid using an interference screw for the SBT.

Unexpectedly, our study did not show a statistically significant difference in the lengths of the STZ and ESTZ or BTDs in the SPT and SBT zones between sexes, although significant differences were found in the EHL. Moreover, there were no correlations between the EHL and the lengths of the STZ and ESTZ or BTDs in the SPT and SBT zones. These results suggested that it is difficult to determine based on the patients' sex or apparent body size only whether a patient has the sufficient lengths of the STZ and ESTZ or BTDs in the SPT and SBT zones. On the other hand, our study showed several anatomic limitations of the tenodesis for Asian people, who have a smaller humerus compared to Western patients.[2,10] These

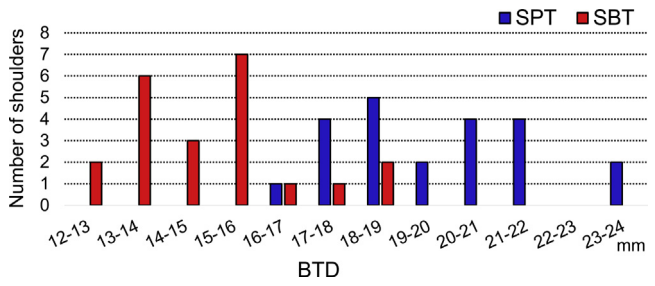

Figure 4 The distribution of the BTDs in the SPT and SBT zones. No shoulders had BTDs shorter than 15 mm in the SPT zone, but there were 11 shoulders (50%) with BTDs shorter than 15 mm in the SBT zone. *BTD*, bone tunnel depth; *SPT*, suprapectoral tenodesis; *SBT*, subpectoral tenodesis.

Table II
Correlations between the EHL and the lengths of the STZ and ESTZ or BTDs in the SBT and SBT zones

	P value	Correlation coefficient
Length of STZ	.71	−0.08
Length of ESTZ	.36	0.21
BTD in SPT zone	.47	0.16
BTD in SBT zone	.88	0.04

EHL, entire humeral length; *STZ*, suprapectoral tenodesis zone; *ESTZ*, expansive suprapectoral tenodesis zone; *BTD*, bone tunnel depth; *SPT*, suprapectoral tenodesis; *SBT*, subpectoral tenodesis.

differences in our results suggested that the anatomic limitations for Asian people might be caused by the racial differences between Asians and Westerns, not be caused by the body size differences. However, this finding is inconclusive, and further studies and discussions are necessary. Clinically, preoperative computed tomography (CT) should be performed to measure the expected BTD to avoid the formation of a proud screw head and insufficient strength fixation in Asian patients, regardless of their sex and body size.

Based on the results, the following recommendations should be considered when performing the LHBT tenodesis using an interference screw in Asian patients. It would be safer to select the SPT, as the BTD in the SBT zone could be too short. In the SPT, it would be better to perform the tenodesis just distal to the lesser tuberosity to avoid the screw from entering into the bicipital groove under the limited length of the STZ. In addition, obtaining a preoperative CT scan would be mandatory to determine the sufficient BTD for the tenodesis device.

There were 2 limitations in this study. First, the mean age of the specimens was 85.9 years (range, 52-101 years), although the LHBT tenodesis is likely to be performed in young patients. The anatomic features investigated in this study were unchanging with age, and the results that we have obtained should be applicable to younger generations. Second, the demographic data of the cadavers, such as the height, body weight, and BMI, were not available. We measured the EHL as an indicator of the body size instead of these data.

Conclusion

Asian patients would have anatomic limitations as follows for the biceps tenodesis regardless of their sex or body size. When the SPT was performed just proximal to the PMMT insertion, the bone tunnel may enter into the bicipital groove. On the other hand, when the SPT was performed distal to the lesser tuberosity, a part of the PMMT insertion may be injured. Regarding the SBT, an interference screw with a length of ≥12 mm, which is commonly used in Western countries, is too long for Asians.

Disclaimer

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References

1. Baleani M, Francesconi D, Zani L, Giannini S, Snyder SJ. Suprapectoral biceps tenodesis: A biomechanical comparison of a new "soft anchor" tenodesis technique versus interference screw biceps tendon fixation. Clin Biomech (Bristol, Avon) 2015;30:188–94. https://doi.org/10.1016/j.clinbiomech.2014.12.001.
2. van Zanden JL, Baten J, d'Ercole MM, Rijpma A, Smith C, Timmer M, editors. How was life?: Global well-being since 1820. OECD Publishing; 2014. https://doi.org/10.1787/9789264214262-en.
3. Boileau P, Krishnan SG, Coste JS, Walch G. Arthroscopic biceps tenodesis: A new technique using bioabsorbable interference screw fixation. Arthroscopy 2002;18:1002–12. https://doi.org/10.1053/jars.2002.36488.
4. Bradbury SA, Hoshino K. An improved embalming procedure for long-lasting preservation of the cadaver for anatomical study. Acta Anat (Basel) 1978;101:97–103. https://doi.org/10.1159/000144954.
5. Crenshaw AH, Kilgore WE. Surgical treatment of bicipital tenosynovitis. J Bone Joint Surg Br 1966;48:1496–502.
6. Froimson AI, O I. Keyhole tenodesis of biceps origin at the shoulder. Clin Orthop Relat Res 1975:245–9.
7. Golish SR, Caldwell PE 3rd, Miller MD, Singanamala N, Ranawat AS, Treme G, et al. Interference screw versus suture anchor fixation for subpectoral tenodesis of the proximal biceps tendon: A cadaveric study. Arthroscopy 2008;24:1103–8. https://doi.org/10.1016/j.arthro.2008.05.005.
8. Jennings GJ, Keereweer S, Buijze GA, De Beer J, DuToit D. Transfer of segmentally split pectoralis major for the treatment of irreparable rupture of the subscapularis tendon. J Shoulder Elbow Surg 2007;16:837–42. https://doi.org/10.1016/j.jse.2007.03.030.
9. Klepps SJ, Goldfarb C, Flatow E, Galatz LM, Yamaguchi K. Anatomic evaluation of the subcoracoid pectoralis major transfer in human cadavers. J Shoulder Elbow Surg 2001;10:453–9. https://doi.org/10.1067/mse.2001.117125.
10. Matsumura N, Oki S, Ogawa K, Iwamoto T, Ochi K, Sato K, et al. Three-dimensional anthropometric analysis of the glenohumeral joint in a normal Japanese population. J Shoulder Elbow Surg 2016;25:493–501. https://doi.org/10.1016/j.jse.2015.08.003.
11. Mazzocca AD, Cote MP, Arciero CL, Romeo AA, Arciero RA. Clinical outcomes after subpectoral biceps tenodesis with an interference screw. Am J Sports Med 2008;36:1922–9. https://doi.org/10.1177/0363546508318192.
12. Mazzocca AD, McCarthy MB, Ledgard FA, Chowaniec DM, McKinnon WJ Jr, Delaronde S, et al. Histomorphologic changes of the long head of the biceps tendon in common shoulder pathologies. Arthroscopy 2013;29:972–81. https://doi.org/10.1016/j.arthro.2013.02.002.
13. Mazzocca AD, Rios CG, Romeo AA, Arciero RA. Subpectoral biceps tenodesis with interference screw fixation. Arthroscopy 2005;21:896. https://doi.org/10.1016/j.arthro.2005.04.002.
14. Mirzayan R, Takara T, Batech M, McCrum CL. In vivo analysis of biceps tendon characteristics in subpectoral tenodesis. Arthroscopy 2017;33:1495–502. https://doi.org/10.1016/j.arthro.2017.03.024.
15. Moon SC, Cho NS, Rhee YG. Analysis of "hidden lesions" of the extra-articular biceps after subpectoral biceps tenodesis: The subpectoral portion as the optimal tenodesis site. Am J Sports Med 2015;43:63–8. https://doi.org/10.1177/0363546514554193.
16. Nelson GN, Namdari S, Galatz L, Keener JD. Pectoralis major tendon transfer for irreparable subscapularis tears. J Shoulder Elbow Surg 2014;23:909–18. https://doi.org/10.1016/j.jse.2013.12.035.
17. Neviaser AS, Patterson DC, Cagle PJ, Parsons BO, Flatow EL. Anatomic landmarks for arthroscopic suprapectoral biceps tenodesis: A cadaveric study. J Shoulder Elbow Surg 2018;27:1172–7. https://doi.org/10.1016/j.jse.2018.01.007.
18. Patzer T, Santo G, Olender GD, Wellmann M, Hurschler C, Schofer MD. Suprapectoral or subpectoral position for biceps tenodesis: Biomechanical comparison of four different techniques in both positions. J Shoulder Elbow Surg 2012;21:116–25. https://doi.org/10.1016/j.jse.2011.01.022.
19. Richards DP, Burkhart SS. A biomechanical analysis of two biceps tenodesis fixation techniques. Arthroscopy 2005;21:861–6. https://doi.org/10.1016/j.arthro.2005.03.020.
20. Salata MJ, Bailey JR, Bell R, Frank RM, McGill KC, Lin EC, et al. Effect of interference screw depth on fixation strength in biceps tenodesis. Arthroscopy 2014;30:11–5. https://doi.org/10.1016/j.arthro.2013.08.033.
21. Sanders B, Lavery KP, Pennington S, Warner JJ. Clinical success of biceps tenodesis with and without release of the transverse humeral ligament. J Shoulder Elbow Surg 2012;21:66–71. https://doi.org/10.1016/j.jse.2011.01.037.
22. Scheibel M, Schroder RJ, Chen J, Bartsch M. Arthroscopic soft tissue tenodesis versus bony fixation anchor tenodesis of the long head of the biceps tendon. Am J Sports Med 2011;39:1046–52. https://doi.org/10.1177/0363546510390777.
23. Taylor SA, Fabricant PD, Bansal M, Khair MM, McLawhorn A, DiCarlo EF, et al. The anatomy and histology of the bicipital tunnel of the shoulder. J Shoulder Elbow Surg 2015;24:511–9. https://doi.org/10.1016/j.jse.2014.09.026.
24. Verma NN, Drakos M, O'Brien SJ. Arthroscopic transfer of the long head biceps to the conjoint tendon. Arthroscopy 2005;21:764. https://doi.org/10.1016/j.arthro.2005.03.032.
25. Werner BC, Brockmeier SF, Gwathmey FW. Trends in long head biceps tenodesis. Am J Sports Med 2015;43:570–8. https://doi.org/10.1177/0363546514560155.
26. Werner BC, Evans CL, Holzgrefe RE, Tuman JM, Hart JM, Carson EW, et al. Arthroscopic suprapectoral and open subpectoral biceps tenodesis: a comparison of minimum 2-year clinical outcomes. Am J Sports Med 2014;42:2583–90. https://doi.org/10.1177/0363546514547226.
27. Werner BC, Lyons ML, Evans CL, Griffin JW, Hart JM, Miller MD, et al. Arthroscopic suprapectoral and open subpectoral biceps tenodesis: a comparison of restoration of length-tension and mechanical strength between techniques. Arthroscopy 2015;31:620–7. https://doi.org/10.1016/j.arthro.2014.10.012.
28. Werner BC, Pehlivan HC, Hart JM, Carson EW, Diduch DR, Miller MD, et al. Increased incidence of postoperative stiffness after arthroscopic compared with open biceps tenodesis. Arthroscopy 2014;30:1075–84. https://doi.org/10.1016/j.arthro.2014.03.024.
29. Wirth MA, Rockwood CA Jr. Operative treatment of irreparable rupture of the subscapularis. J bone Joint Surg Am 1997;79:722–31. https://doi.org/10.2106/00004623-199705000-00012.