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Research Article

Does biceps tenodesis screw with forked eyelet decrease the risk of Popeye deformity when compared to traditional closed eyelet screws?

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ABSTRACT

Objective: While many biomechanical studies have compared various biotenodesis materials for biceps tenodesis, there is a lack of research comparing different types of interference screws. This study aimed to compare the impact of a polyether ether ketone (PEEK) forked eyelet tenodesis screw with the traditional PEEK closed eyelet whipstitching technique. The focus was on evaluating the occurrence of Popeye deformity, which is an objective predictor of a successful arthroscopic suprapectoral long head of biceps tenodesis.

Methods: A retrospective analysis was conducted on patients who underwent arthroscopic rotator cuff repair and biceps tenodesis performed by a single surgeon between January 2010 and 2020 at a single center. The follow-up period was at least 1 year. Exclusion criteria included previous shoulder surgery and osteoarthritis. Patients were divided into 2 groups based on the type of tenodesis anchor used: forked eyelet tenodesis screw versus closed eyelet tenodesis screw. The occurrence of Popeye deformity was compared between the 2 groups.

Results: A total of 82 patients who underwent arthroscopic rotator cuff repair and biceps tenodesis were evaluated, with a mean follow-up of 24.5 ± 4 months. The patients operated on using forked eyelet tenodesis screw were labeled as Group I (n = 72) and those with traditional PEEK closed eyelet screw as Group II (n = 10). There were no significant differences between the groups in terms of age (Group I: 59.4 ± 5, Group II: 58.4 ± 4, $P = .896$), gender (both groups predominantly male, $P = .886$), and body mass index (Group I: 26.7 ± 2, Group II: 27 ± 3; $P = .896$). The overall rate of popeye deformity in all patients was 8% (n = 7). No significant difference in popeye deformity occurrence was observed between the 2 groups (Group I: 6/72 (8.3%), Group II: 1/10 (10%); $P = .998$).

Conclusion: The incidence of Popeye deformity after arthroscopic biceps tenodesis in patients undergoing concomitant rotator cuff repair is low. The choice of fixation anchor, whether a forked eyelet or closed eyelet PEEK anchor, does not significantly influence the occurrence of Popeye deformity.

Level of Evidence: Level III, Therapeutic study.

Introduction

Anterior shoulder pain often indicates an underlying pathology involving the long head of the biceps tendon (LHBT), which can manifest as tenosynovitis, tendinopathy, partial tears, and subluxation.[1] However, it is important to note that primary bicipital tendinitis is less common compared to secondary causes such as subacromial impingement, supraspinatus tendinitis, rotator cuff tears, frozen shoulder, and other conditions that can affect the biceps tendon.[2] Superior labrum-biceps complex (SLBC) lesions, including superior labrum anterior to posterior (SLAP) lesions, partial tears of the LHBT, complete ruptures of the LHBT, subluxations/dislocations of the LHBT, and biceps pulley lesions, are frequently associated with rotator cuff tears.[3-5]

The optimal approach for managing superior labrum-biceps complex (SLBC) lesions has long been a subject of debate. When conservative treatment for LHBT pathology fails to provide conclusive results, surgical intervention becomes necessary.[4] The 2 most common surgical procedures are biceps tenotomy and biceps tenodesis. Biceps tenotomy, performed as a standalone procedure, is a simpler approach that is easy to administer, requires fewer postoperative restrictions, and offers consistent pain relief. However, biceps tenotomy is less favorable for young and active patients due to the 4.3 times higher likelihood of developing a prominent lump formed by the collapsed biceps brachii muscle due to the loss of its tension. This easily discernible clinical finding can similarly be encountered in failed biceps tenodesis patients.[1,6,7]

Various techniques have been employed for performing biceps tenodesis in patients with superior labrum-biceps complex (SLBC) lesions accompanying rotator cuff tears. The commonly used methods include the interference screw (IS) and suture anchor (SA) techniques. While numerous biomechanical studies have compared these biotenodesis materials, there is a paucity of research available that directly compares the clinical aspects of different types of interference screws.[8-10]

In our study, we focused on implants featuring a specialized polyether ether ketone (PEEK) forked tip,

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which enables the biceps tendon to be guided into the bottom of the bone socket. Theoretically, introducing a loop of tendon into the bone socket provides twice the tendon-bone contact area compared to the traditional closed eyelet technique, which may contribute to tendon healing.[10] Moreover, without the need for externalization or whipstitching, the soft tissue support around the biceps tendon can be better preserved. Based on these considerations, the objective of this study was to compare the impact of the PEEK forked eyelet tenodesis screw with the traditional PEEK closed eyelet whipstitching technique on the occurrence of Popeye deformity after arthroscopic suprapectoral long head of biceps tenodesis. Our hypothesis was that the PEEK forked eyelet tenodesis screw would be more effective in reducing the risk of Popeye deformity compared to the traditional PEEK closed eyelet whipstitching technique. Additionally, we aimed to identify the risk factors associated with Popeye deformity following arthroscopic suprapectoral long head of biceps tenodesis.

Materials and methods

Following the acquisition of institutional review Koc University Ethical Committee on Human Research board approval and written informed consent (IRB NO: 2020.215.IRB1.065; Approval Date: 13.05.2020), we conducted a retrospective analysis of all the patients who underwent arthroscopic rotator cuff repair and biceps tenodesis performed by a single surgeon between January 2010 and January 2020 at a single center. Among 104 eligible patients, 82 who met the inclusion criteria and agreed to participate were enrolled in the study. The study included patients who had a minimum follow-up period of 1 year. The inclusion criteria consisted of: (a) confirmation of partial- or full-thickness rotator cuff tear along with inflammation of the biceps tendon through preoperative magnetic resonance imaging (MRI); (b) arthroscopic diagnosis of concomitant biceps lesions, including a partial tear of the long head of the biceps tendon (LHBT) of at least 50%, SLAP type II lesion, pulley lesion, or subluxation/dislocation of the LHBT, along with corresponding symptoms; and (c) arthroscopic suprapectoral biceps tenodesis performed in the bicipital groove in conjunction with rotator cuff repair. Among 104 patients, 3 patients were excluded due to early radiological findings of osteoarthritis; 1 had a concomitant active joint infection on her knee prosthesis; and 1 patient was documented to have traumatic deltoid paralysis 3 years after the index surgery. Five patients who underwent a subsequent shoulder surgery and 2 patients with repairable anterior-to-posterior superior labrum injuries were excluded from the analysis. Ten patients refused to provide the necessary photographs and to participate in the study.

The patients were categorized into 2 groups based on the type of tenodesis material used: Group I consisted of patients who received a PEEK forked eyelet tenodesis screw, while Group II comprised patients who underwent a PEEK closed eyelet tenodesis screw. Popeye deformity was defined as a structural failure characterized by a visible mass on the anterior aspect of the proximal upper arm, excluding cases with tenderness alone to ensure consistency. Clinical photographs were taken from the front view with the shoulder in full adduction, elbows flexed at 90 degrees, and forearm in a fully supinated position as previously described by Almeida et al[7] Side view photographs were captured with the shoulder abducted and externally rotated at 90 degrees. Both arms were photographed from the front and side to allow comparison with the non-operated shoulder. The evaluation of the photos was conducted by a researcher who was unaware of the surgical procedure and follow-up details. None of the patients reported experiencing Popeye deformity on the non-operated side.

HIGHLIGHTS

- Traditional PEEK closed eyelet whipstitching technique and the PEEK forked eyelet tenodesis screw are effective methods for biceps tenodesis.
- Fixation of the biceps tendon with forked eyelet or closed eyelet PEEK anchors has no influence on Popeye deformity incidence.
- Male gender is a risk factor for Popeye deformity after arthroscopic suprapectoral long head of biceps tenodesis.

The surgeries were performed by the senior author of the study who has more than 25 years of experience in shoulder and elbow surgery. The procedures were conducted in the beach chair position under an interscalene block and general anesthesia.[11] A meticulous diagnostic arthroscopy was systematically performed. After confirming the presence of the superior labrum-biceps complex (SLBC) lesion arthroscopically, biceps tenotomy was carried out using arthroscopic scissors at the junction of the long head of the biceps tendon (LHBT) and the superior labrum within the glenohumeral joint. All rotator cuff repairs were executed using the knotless transosseous equivalent double-row repair technique, and the footprint and tendons were prepared before addressing the biceps tendon.[12] Biceps tenodesis was performed in the subacromial space with the arm positioned in elevation and external rotation to achieve a perpendicular access to the bicipital groove through the anterolateral portal. The bicipital groove, including the upper part of the transverse humeral ligament, was identified using a radiofrequency probe, aiming for the lowest possible position. A 25-mm bone tunnel was created using a reamer, and the drill hole was tapped to prepare for the screw. It is noteworthy that the depth of the bone socket was consistent at 25 mm in both groups, and there were no differences between the groups in terms of anchor diameters (Group I: 7.48 mm, Group II: 7.32 mm; $P=.932$). Subsequently, biceps tenodesis was performed at the bicipital groove using either the PEEK forked eyelet tenodesis screw (SwiveLock System, Arthrex, Munich, Germany) or the traditional PEEK closed eyelet whipstitching technique (SwiveLock System, Arthrex, Munich, Germany). Care was taken during the screw insertion to restore the original length of the tendon at the tenodesis site, avoiding both over and under-tensioning. For this purpose, the intraarticular portion of the biceps tendon was estimated and the length of the tendon that is seated into the tunnel was calculated as "one screw length" for interference screw and "two screw lengths" for the forked eyelet, since the tendon dives and goes out of the tunnel which spans 2 times the screw length. The excessive portion of the tendon was cut out before stitching for the interference screw group, and the adequate apex point to place the forked eyelet to seat the tendon into the tunnel was estimated accordingly. The proximal portion that remained out of the tunnel after securing the anchor was cut out. In almost all patients, subacromial decompression was performed to remove inflamed bursal tissue. Acromioplasty was performed using a high-speed burr to create a flat undersurface of the acromion.

A standardized postoperative rehabilitation program was implemented for all patients.[13] Following surgery, the patients were provided with an arm sling equipped with an abduction pillow. During the first postoperative month, only tabletop activities without the sling were permitted, starting immediately after the procedure. Early initiation of periscapular and core stability exercises was also encouraged. The arm sling was worn for a duration of 4 weeks postoperatively. In the fourth to fifth weeks after surgery, active assisted range of motion exercises were initiated within pain limits. Once the full range of motion was restored, typically around the 10th week

postoperatively, strengthening and active resistive exercises were introduced. Progressive resistive exercises were gradually incorporated after the initial 3-month period. At the 6-month mark, patients were given the green light for a full return to activities, including sports and heavy work.

Statistical analyses were performed using SPSS software version 28 (IBM SPSS Corp.; Armonk, NY, USA). The variables were investigated using visual (histogram, probability plots) and analytical methods (Kolmogorov–Smirnov/Shapiro–Wilk's test) to determine whether they were normally distributed. The Mann–Whitney *U* test was used to examine differences between the abnormally distributed variables. Fisher's exact test was used to assess independence between groups. Associations between non-normally distributed variables were assessed using Spearman's correlation coefficients and their significance. A 5% type-I error level was used to infer statistical significance.

Results

Among the 82 patients, a PEEK forked eyelet tenodesis screw was used in 72 (group I) and PEEK closed eyelet tenodesis screws were used in 10 (group II). The mean follow-up period was 24.5 ± 4 months (range, 12-37 months). Patient demographics are given in Table 1.

Among the patients, the supraspinatus tendon was found to be torn in 28 individuals (34.2%), the subscapularis tendon in 8 individuals (9.8%), and the infraspinatus tendon in 6 individuals (7.3%). Additionally, more than 1 tendon was affected in 40 patients (48.7%). No significant association was observed between the affected tendon and the occurrence of Popeye deformity (*P*=.761). Furthermore, the presence of Popeye deformity was found to be independent of the number of affected tendons (*P*=.72). The overall rate of Popeye deformity in the entire patient cohort was 8% (n=7). Importantly, there were no significant differences in the occurrence of Popeye deformity between the 2 groups (Group I: 6/72 (8.3%), Group II: 1/10 (10%); *P*=.987). In terms of the tenodesis procedure, the bone socket depth was consistent at 25 mm in both groups, and there were no differences in anchor diameters between the groups (Group I: 7.48 mm, Group II: 7.32 mm; *P*=.932).

Notably, within the PEEK forked eyelet group, 2 patients were diagnosed with implant pull-out; however, only 1 of them exhibited Popeye deformity.

Discussion

Our study sought to investigate the effectiveness of 2 different types of tenodesis screws, namely PEEK forked eyelet tenodesis screw and the traditional PEEK closed eyelet whipstitching technique, in preventing the occurrence of Popeye deformity after biceps tenodesis, and our results demonstrated that there is no significant difference between the 2 implants. Additionally, our findings identified male sex as a risk factor for the occurrence of Popeye deformity.

Table 1. Patient characteristics according to group distribution

	Group I (n=72)	Group II (n=10)	*P*
Age	59.4 (19-68)	58.4 (21-64)	.896
Gender (female/male)	17/55	3/7	.886
Side (right/left)	55/17	4/6	.43
Preoperative symptoms (months)	6.8 ± 1.9	22.4 ± 3.7	.346
More than one ruptured rotator cuff tendons	36	4	.131
Smoking	13	2	.738
Popeye deformity	6	1	.514
Acromioplasty	66	7	.94
Preoperative VAS	6 ± 2.1	7 ± 0.8	.54
Comorbidity	24	4	.622
Body mass index	26.7 ± 1.1	27.3 ± 0.3	.896

Current literature lacks consensus on whether biceps tenotomy or tenodesis is more effective in preventing the occurrence of Popeye deformity. Frost conducted a literature review on the long head of the biceps and found a wide range in the reported risk of Popeye sign, ranging from 3% to 70%.[14] In their cadaveric biomechanical analysis in 2005, Wolf et al reported a significantly lower load to failure and a significant risk of distal biceps tendon migration in the tenotomy group.[5] Similarly, MacDonald et al, in a follow-up study at the second year, documented a lower rate of Popeye deformity in their tenodesis group (10%) compared to the tenotomy group (33%).[15] While numerous studies have suggested an increased incidence of cosmetic deformity in the literature, there is a scarcity of research comparing different tenodesis materials and the few comparative studies primarily focus on suture anchors and interference screws.[16-19] For example, a randomized prospective study by Park et al reported no difference between these 2 materials in terms of arm cosmesis.[4]

The majority of studies comparing interference screws with suture anchors primarily focus on biomechanical analyses, which consistently demonstrate higher ultimate load to failure and an increased risk of stiffness in patients treated with screws.[5,10] This is supported by Kuan et al's recent study, emphasizing that increased contact area and exposure to marrow-derived endogenous stem cells provide improved incorporation in screw techniques.[20] The surface area of the tendon-bone interface is the major factor that differentiates forked eyelet screws from closed eyelets. The contact area between the tendon and the bone is theoretically doubled in patients with forked eyelets since the tendon is pushed down into the tunnel and then comes out, making the total contact area twice the length of the screw. Contrarily, closed eyelet screws seat only one screw-length of tendon since only the tensioning whipstitch comes out of the tunnel. (Figure 1) Greater stiffness and a higher mean load required for failure in the interference screw group were also documented by Golish et al[21] Patzer's cadaveric studies further supported these previous findings.[22]

A considerable proportion of biceps tendon pathologies accompanying rotator cuff tears are typically degenerative in nature. Consequently, the already frayed tendon can incur further damage between the teeth of the screw and the cortical bone.[20] Additionally, the direction of tension in the biceps tendon is not aligned with the 90-degree insertional angle of the interference screw (Figures 2-3). The importance of maintaining the appropriate length-tension relationship in biceps tenodesis has been emphasized in previous literature. Furthermore, it is recognized that overtensioning can occur when inserting the folded tendon into the drilled bone, leading to a phenomenon known as double-drop. The impact of the tension during biceps tenodesis has been investigated by Dedeoğlu et al in a large clinical series where they evaluated the forearm position during the tenodesis. They concluded that better functional scores and lower pain were achieved when the tenodesis was performed in forearm pronation and elbow extension, which is the highest possible tension at the distal biceps insertion.[23] These factors contribute to certain biomechanical issues associated with the interference screw technique and underscore the importance of selecting the most suitable type of screw for this specific patient group to mitigate potential risks. Future studies may introduce new surgical techniques or screw designs that

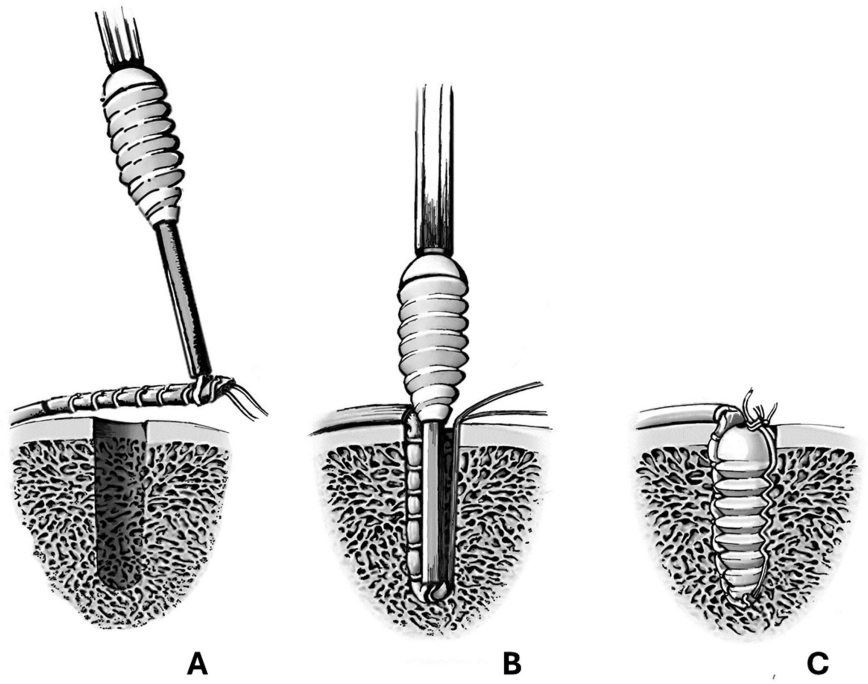


Figure 1. The traditional closed eyelet interference screw with biceps tendon whipstitch suturing. A: The tendon is secured using Krackow sutures that are passed through the eyelet of the interference screw. B: The biceps tendon is introduced into the pre-drilled bone tunnel, and the interference screw is inserted to secure the tendon. Note that the tendon – bone contact is present only at the distal half of the bone tunnel. C: Final appearance of the biceps tenodesis: The guiding fiberwires are knotted and cut. Note that the tendon is compressed to the bone tunnel only through the distal half, contrary to the forked eyelet screw where the tendon is compressed on both proximal and distal sides, surrounding the implant.

allow for a more anatomical insertion of the biceps tendon, leading to improved outcomes.

A limited number of studies have investigated the factors associated with the occurrence of Popeye deformity, with age, sex, and body mass index being among the most commonly studied factors. Woodmass et al reported a 7-fold higher risk for developing Popeye deformity in men (OR: 7.33, 95% CI: 0.87-61.91, P=.067).[19] Similarly, Lim et al found a 10-fold higher risk in men following biceps tenotomy (OR: 10.2, P < .001).[24] Kelly et al documented an increased incidence of Popeye deformity in patients who underwent arthroscopic biceps tendon release (OR: 8.40, P=.008).[25] Our study supports these previous findings, as male sex was indeed identified as a risk factor for the occurrence of Popeye deformity. One possible explanation for this is the balance between the pulling strength of the biceps brachii muscle and the resistive force that prevents distal migration. Moreover, Popeye deformity can be more easily perceived in males despite comparable incidences to females due to larger muscle mass and lower subcutaneous fat.[19] Nevertheless, it is reasonable to assume that male musculature can generate a strength that overpowers the pullout tension. Conversely, Osbahr et al did not find a significant impact of sex on the occurrence of Popeye deformity.[26] This discrepancy may be attributed to the questionnaire-based design of their study, where patients self-identified the deformity as subjective assessments by patients can differ from objective findings.[27] In our study, we implemented clinical photographs of patients evaluated by

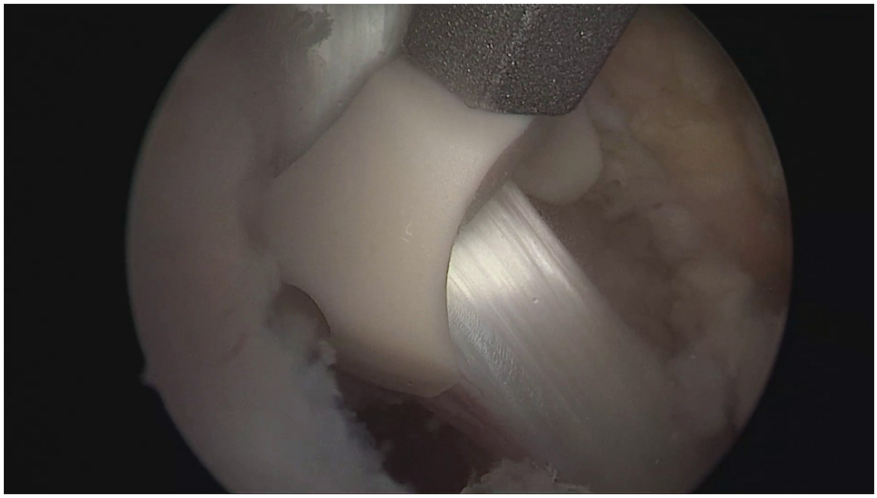


Figure 2. Arthroscopic anterolateral portal view showing a forked eyelet screw pushing the biceps tendon into the tunnel. The forked eyelet holds the tendon, letting it glide on the eyelet into the tunnel until the final fixation position.

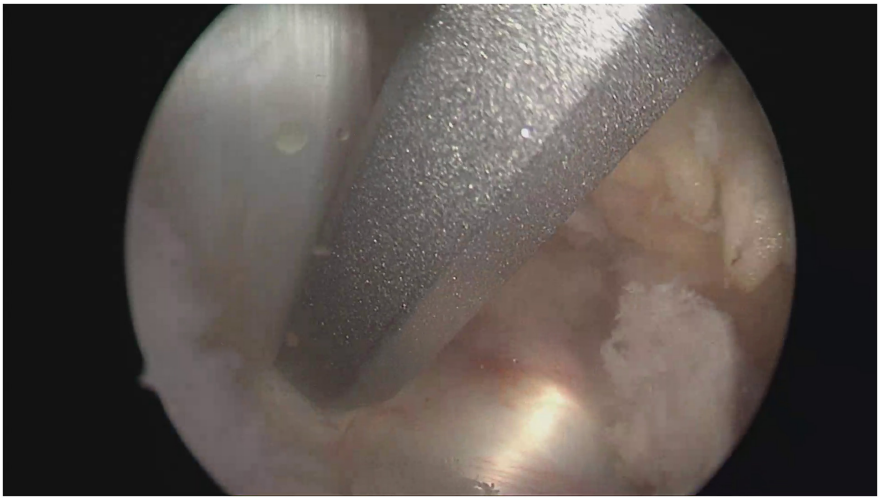


Figure 3. Arthroscopic anterolateral portal view showing the forked eyelet pushing the biceps tendon into the bone tunnel. Note that the tendon lies on both proximal and distal sides of the screw, providing 2 times of bone – tendon contact.

fellowship-trained shoulder surgeons, achieving excellent interobserver consistency. It is possible that thicker subcutaneous tissue in women may conceal a Popeye sign, which could explain why this deformity is more frequently documented in men. Under these circumstances, an inverse correlation between body mass index and the incidence of Popeye deformity might have been expected, but our study did not find any correlation between body mass index and the diagnosis of Popeye deformity.

Our study is subject to several limitations. First, the number of patients in the closed eyelet group is relatively low compared to the forked eyelet group. The main reason for this is that this implant was no longer available in our country, and we included all available patients who were operated using the closed eyelet screw. Secondly, we were unable to invite our patients for a final follow-up to include important clinical and radiological findings in our study. However, the present study focuses on the occurrence of the Popeye deformity, which is an obvious visual finding, independent of the range of motion or strength. We contacted all our patients to instruct them on how to adequately obtain photographs of their arms, and our excellent interobserver ratio supports the effectiveness of the method we implemented in documenting the biceps tenodesis failure. Third, it is a cross-sectional study, which means that we are unable to observe time-dependent changes in the rate of occurrence of this problem. It remains unclear whether the deformity manifests as a long-term result of degenerative changes. Previous literature reported that the structural failure of fixation is associated with an unhealed tendon-bone interface rather than a degenerative process.[28] Another limitation is that patients with a high body mass index (BMI) may have a bulky upper arm, which could hinder the identification of the mass associated with Popeye deformity. Additionally, despite demographic similarities, there is a notable disparity in the number of patients within our study groups. This discrepancy was inevitable as the traditional PEEK closed eyelet whipstitching technique has not been employed since 2012, and PEEK forked eyelet tenodesis screws have been used exclusively thereafter. Considerable efforts were made to include patients operated on before 2012 to create a statistically comparable PEEK closed eyelet group. Lastly, due to the unfortunate restrictions imposed by the pandemic, we were unable to perform a strength test on patients.

As a conclusion, both the traditional PEEK closed eyelet whipstitching technique and the PEEK forked eyelet tenodesis screw are effective methods for preventing Popeye deformity in biceps tenodesis patients, without any difference in terms of the occurrence of Popeye deformity.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics committee approval: This study was approved by the Ethics Committee of Koc University (Approval No: 2020.215.IRB1.065; Date: 13.05.2020).

Informed consent: Written informed consent was obtained from the patients who agreed to take part in the study.

Peer-review: Externally peer reviewed.

Author contributions: Concept – K.B., M.D.; Design – E.C., K.B., İ.E.; Supervision: M.D.; Resources – K.B., M.D.; Materials – M.D.; Data Collection and/or Processing-K.B., L.A., İ.E., O.B., E.C.; Analysis and/or Interpretation – E.C., İ.E., O.B.; Literature Search – K.B., E.C.; Writing – E.C., O.B., İ.E.; Critical Review – M.D.

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