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Supination torque following single- versus double-incision repair of acute distal biceps tendon ruptures

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Background: Compared with single-incision (SI) distal biceps repair, double-incision (DI) repair has been described as permitting a more anatomic repair. We hypothesized that DI repair would result in greater terminal supination torque compared with SI repair for acute distal biceps ruptures.
Methods: Patients were included if they sustained an isolated, acute distal biceps rupture repaired between January 2012 and December 2017. Isometric forearm supination torque in 4 positions was measured using a validated uniaxial torque-testing device. Testing took place at least 12 months from surgery. The primary outcome was supination torque in the 60° supinated position. Secondary outcomes included supination torque in other forearm positions and functional outcome scores.
Results: The study included 37 patients: 15 underwent repair with the DI technique and 22 with the SI technique. The mean age was 47.3 years, the median follow-up time was 28.1 months, and demographic data were similar between cohorts. Mean supination torque, relative to the unaffected side, was 61% (95% confidence interval, 45%-77%) for DI repair vs. 80% (95% confidence interval, 69%-92%) for SI repair in the 60° supinated position ($P = .036$). In a multivariable linear regression model controlling for arm dominance, age, follow-up time, and workers' compensation status; SI repair was associated with greater mean supination torque than DI repair by 20% ($P = .015$).
Conclusions: Contrary to our hypothesis, we found a 20% mean improvement in terminal supination torque for acute distal biceps ruptures repaired with the SI technique compared with the DI technique. This finding may have clinical significance for the more discerning, high-demand patient.
Level of evidence: Level III; Retrospective Cohort Design; Treatment Study
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Keywords: Distal biceps rupture; single-incision repair; double-incision repair; supination strength; forearm torque; functional outcomes

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The ideal distal biceps tendon repair provides an anatomic reattachment of the tendon, preserves tuberosity shape and function, and preserves soft-tissue integrity to completely restore preinjury function.[14,25] The Boyd and Anderson technique modified by Morrey et al[18] is a popular double-incision (DI) technique that aims to reattach the ruptured tendon to its anatomic footprint, located slightly posterior to the radial tuberosity.[9] This muscle-splitting technique adequately reduced heterotopic ossification and synostosis that were issues with the original method.[6,8,12] However, fatty infiltration of the supinator muscle has been identified by magnetic resonance imaging (MRI) after DI repair. This finding was negatively associated with supination strength.[22] Alternatively, the single-incision (SI) EndoButton (Smith & Nephew, Andover, MA, USA) technique obviates posterior dissection. However, it has been associated with a higher rate of lateral antebrachial cutaneous (LABC) neurapraxia and has been criticized for the inability to accurately restore the distal biceps tendon to its anatomic footprint.[13,24]

The location and method of tendon reattachment have biomechanical implications. Ex vivo data suggest that a relative weakness in terminal supination may result from the SI technique if the tendon is reattached anterior to the anatomic insertion.[20,27] Regarding the DI technique, a mechanical disadvantage may result if the tuberosity height is decreased when creating a trough to dock the tendon.[23] The biomechanical data suggest that if a clinical difference exists in vivo, it should be most noticeable with forceful supination with the forearm in the supinated position.

Few comparative studies have been performed that were adequately powered to detect functional differences between repair methods. The largest prospective randomized trial to date found no difference in functional outcomes between SI and DI techniques.[12] Isometric supination torque was equivalent between groups, but this was tested in a neutral forearm position. Investigating supination torque specifically, Schmidt et al[22] used MRI and isometric torque testing to compare a prospective DI repair cohort with a retrospective SI cohort and included a cohort of normal uninjured volunteers as a reference. They found that a more anterior reattachment site, an SI anterior approach, and supinator fatty atrophy led to supination weakness tested in 60° of forearm supination. Notably, the DI group's tendons were directly reattached using intramedullary buttons without trephination. In addition, the SI group's average tendon insertion angle was almost 90° anterior to the apex of the radial tuberosity. This finding suggests that when using the SI approach, the tendon was not reattached to its anatomic insertion.

The aim of this study was to investigate differences in terminal supination torque between the SI EndoButton repair and the DI modified Boyd and Anderson method of acute distal biceps rupture repair. We hypothesized that the DI method would demonstrate greater terminal supination torque.

Materials and methods

Participants

We recruited participants from the practices of 3 fellowship-trained hand and upper limb specialists in a retrospective cohort study design. We included patients if they sustained an isolated, acute distal biceps rupture between January 2012 and December 2017 that was repaired using either an SI or DI technique. The exclusion criteria were (1) chronic rupture (>4 weeks earlier), (2) prior or subsequent injury to either arm, (3) inflammatory arthritis or collagen disorder, (4) less than 60°-60° prono-supination range of motion, or (5) complication requiring reoperation. Of 53 eligible patients, 37 consented to participate (Fig. 1).

Outcomes

The primary outcome was peak supination torque strength in terminal supination (60°), measured in newton-meters and converted to a percentage of the contralateral healthy limb. We chose this position as it minimizes the potential contribution from the brachioradialis muscle to supination torque and it is the forearm position in which the biceps reattachment site has been found to have the greatest effect on supination torque.[20,22,27] Objective secondary outcomes included peak torque strength in 45° of supination, neutral, 45° of pronation, and elbow range of motion. Subjective secondary outcomes included the American Shoulder and Elbow Surgeons elbow score[15]; Short Form 12 Physical and Mental Component Scores[29]; Disabilities of the Arm, Shoulder and Hand score[3]; visual analog scale score for pain; and VAS score for function (VAS-F). We tested participants at least 1 year postoperatively, the minimum time for strength and functional outcome scores to plateau following distal biceps rupture.[12]

Testing apparatus

The custom torque-testing apparatus was designed for testing forearm torque strength and has been shown to produce valid and reliable measurements.[17] It consists of a machined aluminum handgrip and an armrest. The handgrip is attached to a 6-axis load cell (±100 Nm for the prono-supination axis) (MC3A-1000; AMTI, Watertown, MA, USA), which is in turn mounted on a shaft that allows rotation through an arc of 180°. The handgrip is oriented perpendicular to the axis of rotation of the shaft. During the trials, the shaft is clamped to prevent rotation, allowing measurement of isometric torque at any angle of forearm rotation. The torque-testing apparatus is adjustable to facilitate a standardized testing position of 90° of elbow flexion with the humerus kept vertical. Load cell data are recorded at 20 Hz using a data acquisition system (SCXI-1000; National Instruments, Austin, TX, USA).

We tested 4 forearm rotation positions: 45° of pronation, neutral (0°), 45° of supination, and 60° of supination. We randomized testing positions to minimize any potential bias introduced by fatigue and/or learning. When instructed, the participant had 3 seconds to exert a maximal isometric supination torque at the designated forearm rotation position, and the peak torque measurement was recorded. Each position was tested 3 times and the average was taken, with a minimum 1-minute break between measurements.

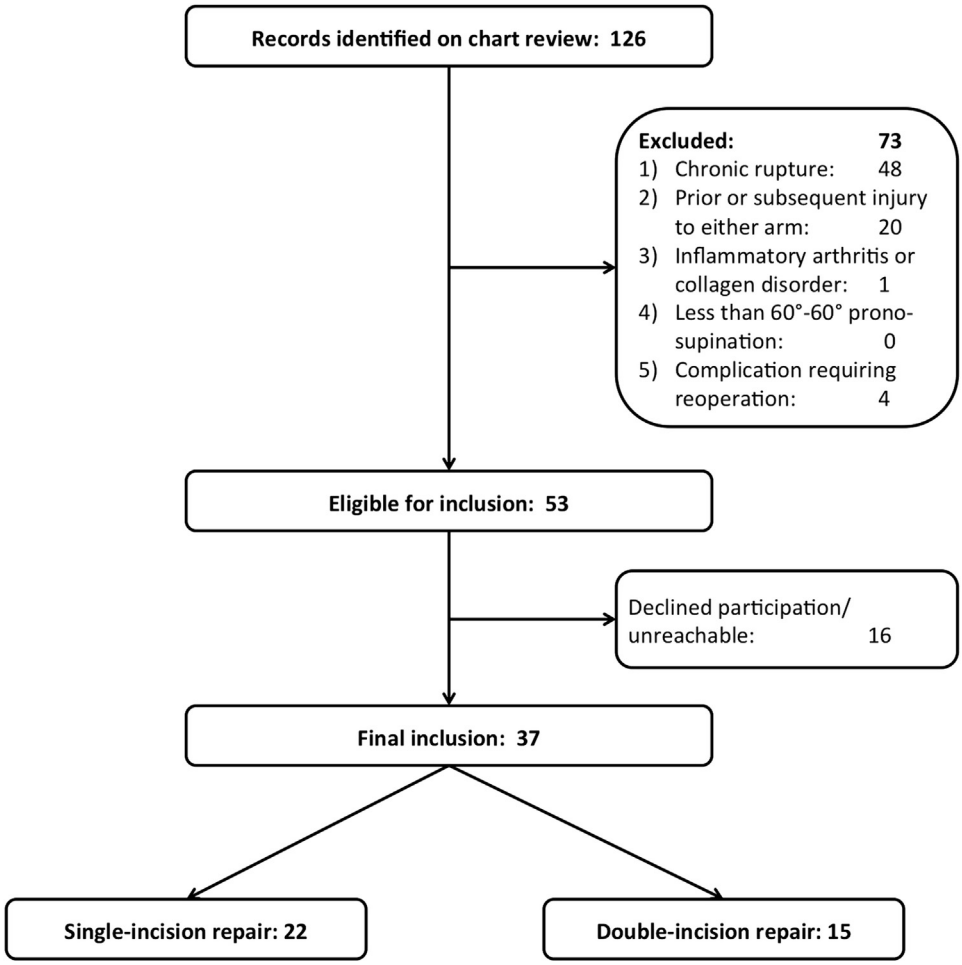

Figure 1 Participant recruitment flow diagram.

Surgical technique

The SI technique used was similar to that described by Bain et al[2] and was performed by two of the authors (J.M.P. and T.J.G.). Under tourniquet control through a transverse or longitudinal proximal volar forearm incision, the basilic veins and LABC nerve were identified and protected. The retracted biceps tendon was identified and the distal degenerative portion débrided. Two No. 2 FiberWire sutures (Arthrex, Naples, FL, USA) were placed in the tendon using a locking Krackow technique, incorporating the EndoButton into the distal end. With tendon preparation complete, the brachioradialis was retracted laterally and the pronator teres was retracted medially. The recurrent leash-of-Henry vessels were ligated using clips and divided to expose the bicipital tuberosity. Under maximal forearm supination, a 2.4-mm guide pin with an eyelet was drilled through the tuberosity in a radial and slightly proximal direction.[10] Efforts were made to ensure that the insertion point of the guide pin was at the center of the insertion footprint of the distal biceps tendon. The guide pin was angled to ensure adequate bone to allow reaming of a docking hole large enough to fit the sized tendon end. If the anatomic insertion was not easily identifiable, fluoroscopy was used to ensure the start point was at the apex of the tuberosity. The near cortex was drilled with a reamer sized to tendon width. The far cortex was drilled with a cannulated 4.5-mm drill, and copious saline solution irrigation was used to remove all bone fragments. The anconeus–extensor carpi ulnaris interval was identified on the dorsal forearm using surface landmarks, and the 2.4-mm guide pin was advanced through it, pulling the lead and trail sutures on the EndoButton. The EndoButton was flipped, and its position was confirmed with fluoroscopy. Direct inspection ensured that the distal tendon was completely docked in the tuberosity.

The DI repair (used by one of the authors [P.D.]) was performed via a muscle-splitting approach dorsally using the Morrey modification of the Boyd and Anderson technique.[5,18] Under tourniquet control and through a transverse antecubital incision, the biceps tendon was identified and the distal degenerative portion was resected. Two nonabsorbable sutures were passed through the distal part of the tendon using a locking Krackow technique. The biceps tuberosity was palpated with an index finger and a curved clamp passed just ulnar to it through the interosseous space, until it was palpated on the dorsal aspect of the proximal forearm in the anconeus–extensor carpi ulnaris interval. A second incision was made over the tip of the clamp, and the tuberosity was exposed using a muscle-splitting technique through the supinator with the forearm maximally pronated. The ulna was not

exposed. A burr was used to create a longitudinal trough in the ulnar aspect of the bicipital tuberosity through to the intramedullary cavity. Three 2.0-mm drill holes were placed 6 to 8 mm apart through the cortical margins of the tuberosity. The tendon sutures were passed through the holes with the elbow in 90° of flexion and the forearm in pronation. The biceps tendon was pulled into the bicipital tuberosity, and the sutures were tensioned and tied over bony bridges.

The postoperative protocol was similar in both cohorts. Light passive and active-assisted range of motion was prescribed until 6 weeks and unresisted active range of motion was prescribed until 10 to 12 weeks, followed by strengthening and a gradual return to unrestricted activity. One author (T.J.G.) prescribed active range of motion until 6 weeks, a graduated strengthening program until 12 weeks, and return to work after 3 months. Heterotopic ossification prophylaxis with indomethacin, 25 mg 3 times daily, was typically prescribed for 3 weeks unless contraindicated.

Statistical analysis

To detect a minimum 15% difference in peak supination torque strength between cohorts, assuming a variance of 15%,[22] an α of .05, and a β of .20, the calculated sample size was 32 patients (16 per group). We summarized demographic and outcome data that were normally distributed using means and 95% confidence intervals (CIs), skewed data using medians and interquartile ranges, and proportional data using fractions and percentages. We conducted bivariate analysis accordingly using independent *t* tests when the variable was parametric and the Wilcoxon rank sum test when nonparametric. We used the χ^2 test for differences in proportional variables. Statistical significance was set at $\alpha = .05$. As no minimal clinically important difference has been determined for forearm supination torque, we denoted clinical significance if the difference in means was greater than half the standard deviation.[19]

We built a multivariable linear regression model to test the adjusted effect of surgical technique on terminal supination torque. We examined relevant variables for confounding, mediation, effect modification, and collinearity, and the final model was tested to ensure that it met regression assumptions. Statistical analysis was performed using the R program (version 3.5.1; R Foundation for Statistical Computing, Vienna, Austria).

Results

The study included 37 participants with a mean age of 47.3 years (95% CI, 44.0-50.6 years) and median follow-up period of 28.1 months (interquartile range, 17.4-37.1 months). Of the 16 participants who were eligible but either declined participation or were unreachable, 9 underwent repair with the SI approach and 7 with the DI approach. All participants were men, the dominant arm was affected in 20 of 37 cases, 4 participants were smokers, and 6 patients had workers' compensation cases. Of the 37 participants, 12 experienced iatrogenic numbness in the distribution of the LABC nerve (9 of 22 in the SI group and 3 of 15 in the DI group); this persisted beyond 3 months in 3 patients (all from the SI group). No posterior interosseous nerve (PIN) palsies occurred in any patient screened from 2012-2017. The SI and DI cohorts showed no detectable differences in their descriptive characteristics (Table I).

The SI technique was associated with greater mean forearm supination torque, both statistically and clinically, in the terminally supinated forearm position (Table II). The SI technique had also higher mean forearm torque in the 45° and neutral starting positions, but these findings were not significant. No statistically significant difference in terminal supination torque was noted between the 2 surgeons who performed the SI technique ($P = .722$). In absolute values, SI mean forearm torque was 5.5 Nm (95% CI, 4.4-6.6 Nm) in terminal supination and sequentially increased to 11.7 Nm (95% CI, 10.2-13.2 Nm) in 45° of pronation. DI mean forearm torque was 4.2 Nm (95% CI, 3.1-5.2 Nm) in terminal supination and sequentially increased to 10.6 Nm (95% CI, 8.8-12.5 Nm) in 45° of pronation.

Secondary outcomes are reported in Table III. The SI technique was associated with a marginally higher mean flexion-extension arc and showed a mean 0.8-cm improvement in the VAS-F score, but no statistically significant differences in subjective or objective outcomes were found otherwise.

In the multivariable linear regression model (adjusted $R^2 = 0.40$), SI repair was associated with a 20% greater terminal supination torque ($P = .015$), controlling for arm dominance, age, time to follow-up, and workers' compensation status. Arm dominance was a significant confounder in our model ($P = .002$), with injury to the nondominant arm associated with a 31% weaker terminal supination torque. Age, time to follow-up, and workers' compensation status were not statistically significant confounders in our model.

Discussion

The importance of reattaching the biceps to restore supination is well recognized, but the majority of clinical studies have only reported supination testing in a neutral forearm position.[7,11,12] Biomechanical[20,27] and preliminary clinical data[13,22,24] through the range of forearm rotation have suggested that DI distal biceps repair likely results in improved supination torque over the SI technique, most apparent in the terminally supinated position. Our finding that the SI repair was associated with a 20% greater mean terminal supination torque was unexpected. The SI repair cohort achieved a mean terminal supination torque of 80% of the unaffected forearm, which provides evidence that an adequate functional result is attainable through an SI anterior approach. Furthermore, our results indicate a clear trend, favoring SI repair over DI repair, that begins at neutral forearm rotation and becomes statistically significant at terminal supination (Fig. 2).

The first clinical study to call into question the ability of the SI repair to restore terminal supination torque was

Table I Descriptive characteristics of participants

Variable	Single incision (n = 22)	Double incision (n = 15)	*P* value
Age (95% CI), yr	47.8 (42.7-53.0)	46.5 (42.4-50.6)	.679
Time to follow-up (IQR), mo	29.6 (19.5-36.4)	19.5 (13.8-39.4)	.272
Dominant arm affected (%)	12 of 22 (54.5)	8 of 15 (53.3)	1.000
Occupation requires lifting >22.7 kg (>50 lb) (%)	9 of 22 (40.9)	4 of 15 (26.7)	.589
Workers' compensation (%)	2 of 22 (9.1)	4 of 15 (26.7)	.332
Smoker (%)	3 of 22 (13.6)	1 of 15 (6.7)	.896

CI, confidence interval; *IQR*, interquartile range.

published by Schmidt et al[24] in 2012. Although the surgeons attempted to reattach the biceps tendon to the center of the tuberosity, the insertion angle determined by MRI was 97° (±23°) anterior to the apex of the tuberosity. The authors proposed that this anterior reattachment site was the likely cause of the 33% loss of isometric supination torque at 60° of supination. This was followed up by a comparative study that included a cohort of patients who underwent repair with the DI technique.[22] At terminal supination, isometric strength measured 67% for the SI group vs. 81% for the DI group ($P < .001$). The weaker SI group's result was again attributed to a more anterior reattachment and higher insertion angle: 89° (±23°) vs. 24° (±8°) in the normal control group.

The only identifiable difference in the SI repair technique used in our study that might explain the improved mean terminal supination torque is the location and direction of guide pin insertion. At least 3 cadaveric studies have advocated aiming the guide pin in an ulnar manner (up to 30°) and perpendicular to the longitudinal axis of the radius, with the forearm in full supination, to avoid the PIN.[16,21,28] In our experience, it is not possible to aim in an ulnar manner from the anatomic insertion site on the tuberosity. To place the tendon at the anatomic insertion and to allow for adequate bone for the tunnel (ie, to avoid blowout), it is necessary to aim radially. Previous cadaveric work has warned against aiming radially, but the combination of aiming radially and proximally is yet untested. Unpublished cadaveric work by our group demonstrates that aiming radially and 30° proximal results in a mean distance to the PIN of 13.3 mm.[10] Furthermore, the safety of that trajectory is underscored by the fact that not one PIN palsy was encountered in the 126 patients screened for enrollment between January 2012 and December 2017.

The performance of the DI cohort deserves equal scrutiny. One explanation that has been put forth previously to partially explain supination torque loss is the MRI-assessed fatty infiltration that occurs in the supinator muscle after it has been split following the posterior approach to the radius.[22] Although we do not know the relative contributions of the biceps brachii and supinator muscles, fatty infiltration of the supinator muscle could plausibly weaken supination force. Another factor involves the trephination of the radial tuberosity for preparation of the docking site in the modified Boyd and Anderson approach. In the static, isometric testing conditions of our experiment, the proximal radius and biceps unit can be modeled as a lever with a mechanical advantage that is increased by the cam effect of the tuberosity. It follows that if the trough is not carefully placed on the dorsal aspect of the tuberosity such that the apex is preserved, the moment arm may be reduced. Indeed, in a cadaveric study by Schmidt et al,[23] specimens with trough repair had a 27% lower supination moment arm at terminal supination vs. controls ($P = .036$). On inspection, trephination in that study was performed in a manner that reduced biceps tuberosity height.

The objective secondary outcome measures demonstrated in this study are comparable to those reported in other comparative studies.[4,6,7,12,22] We did find a statistically significant difference in the flexion-extension arc favoring the SI technique, but the magnitude of the difference was 1.2% and is likely clinically insignificant. Although the

Table II Affected forearm supination strength as percentage of unaffected side

Starting position	Single incision, %		Double incision, %		*P* value
	Mean	95% CI	Mean	95% CI	
60° supinated	80	69-92	61	45-77	.036*
45° supinated	82	72-91	67	49-85	.102
Neutral	98	92-104	89	75-102	.170
45° pronated	103	97-110	105	91-118	.862

CI, confidence interval.
* Statistically significant at $P < .05$ and clinically significant.

Table III Secondary outcomes

Outcome	Single incision	Double incision	*P* value
Objective outcome, mean (95% CI)			
Flexion-extension arc, % of unaffected side	101 (100-101)	99 (99-100)	.007*
Supination, °	78 (76-81)	80 (77-84)	.385
Supination, % of unaffected side	96 (93-98)	96 (93-98)	.968
Pronation-supination arc, % of unaffected side	96 (94-98)	96 (94-98)	.974
Grip strength, % of unaffected side	101 (97-105)	99 (91-107)	.641
Subjective outcome, median (IQR)			
ASES pain score (0, no pain)	0.5 (0-3.0)	3.0 (0-7.0)	.328
ASES function score (36, no difficulties)	36.0 (35.0-36.0)	35.0 (34.5-36.0)	.553
DASH score (0, no difficulties)	1.3 (0-4.0)	2.5 (0.4-6.7)	.344
DASH work (0, no difficulties)	0 (0-0)	0 (0-0)	.176
DASH sports/arts score (0, no difficulties)	0 (0-12.5)	8.9 (0-17.2)	.340
SF-12 PCS (US norm mean of 49.4 for ages 45-54 yr)	55.4 (54.1-57.5)	55.9 (53.7-56.9)	.914
SF-12 MCS (US norm mean of 49.9 for ages 45-54 yr)	55.4 (51.7-57.8)	54.6 (49.5-56.9)	.567
VAS score for function (0, full function)	0.5 (0.0-1.3)	1.3 (0.6-2.0)	.023*
VAS score for pain (0, no pain)	0.3 (0.0-0.4)	0.2 (0.1-0.4)	.692

CI, confidence interval; *IQR*, interquartile range; *ASES*, American Shoulder and Elbow Surgeons; *DASH*, Disabilities of the Arm, Shoulder and Hand; *SF-12*, Short Form 12; *PCS*, physical component score; *MCS*, mental component score; *VAS*, visual analog scale.
* Statistically significant at $P < .05$ and clinically significant.

chosen method of determining clinical significance[19] indicated that the result was clinically meaningful, we suggest that this statistical method loses its utility when values are closely clustered around a mean.

Regarding our absolute measures of isometric supination torque, the values that we found in the neutral position (9.3 Nm [95% CI, 8.2-10.4 Nm] for SI vs. 8.2 Nm [95% CI, 6.7-9.8 Nm] for DI) were comparable to normative values

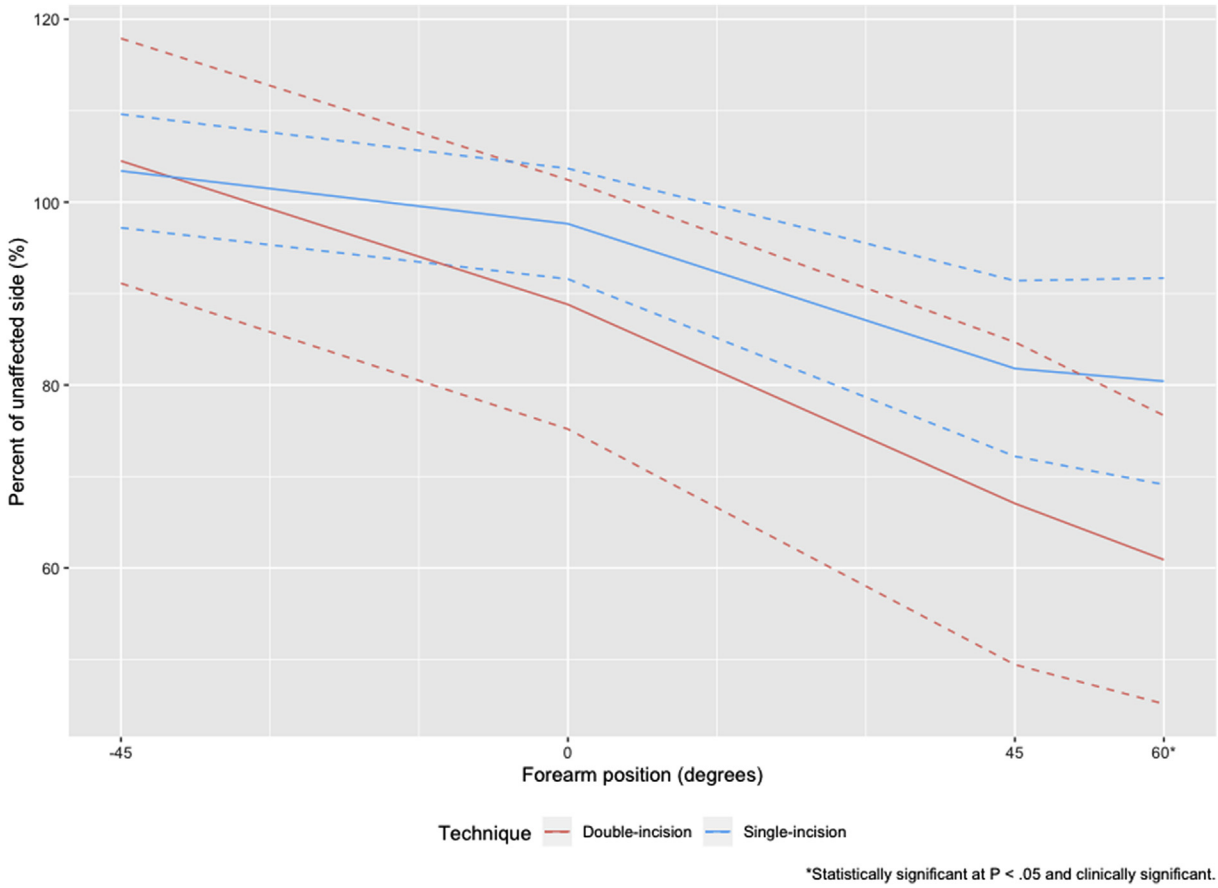

Figure 2 Effect of distal biceps repair technique on forearm isometric supination torque strength. *Solid lines* represent mean values, with *dashed lines* representing 95% confidence intervals. A negative direction denotes pronation; positive denotes supination.

established using the Baseline dynamometer (Fabrication Enterprises, White Plains, NY, USA) by Axelsson et al[1] in Sweden. They found that normal isometric supination torque for male individuals was 9.1 Nm (95% CI, 8.9-9.4 Nm) for the right arm and 8.9 Nm (95% CI, 8.6-9.2 Nm) for the left. This finding supports the external validity of our testing apparatus.

Major complications are rare with the described procedure; therefore, large sample sizes are needed to accurately describe their incidence and associated predictors. Two recent studies have investigated this, one with a sample of 956 patients[8] and another with a sample of 784 patients.[6] Clinically significant heterotopic ossification is rare, with a slightly higher incidence with the DI technique. LABC neurapraxia was the most frequently encountered complication, with an increased incidence with the SI technique. Our study was not powered to compare complication rates, although we do note that 3 cases of persistent LABC palsy were observed in the SI group, none of which were bothersome to the patients.

The purpose of our study was to study the population of patients with distal biceps ruptures who had uncomplicated recoveries. Because we excluded patients with serious complications (LABC neurapraxia was not deemed serious), the functional outcome measures were impressive and, in some cases, better than those of age-matched norms.[3,29] This may be a function of the population of the Canadian west coast, which is generally quite active and healthy. One functional outcome for which an improved score was not detected for the SI group over the DI group was the VAS-F score. This score has been rarely used in the distal biceps literature, but we included it in our outcomes because it asks specifically about forearm function in isolation. This finding suggests that the relative weakness of the DI technique may be clinically perceived by patients. However, the median score for the group was still well within an acceptable range.

The findings of this study were subject to certain limitations. Our suspicions regarding the reason behind the excellent outcome in the SI group would be greatly strengthened by cross-sectional imaging. We chose isometric torque as our primary outcome to investigate the position at which any potential difference should be most apparent. However, isokinetic torque and muscular endurance were not tested in this study, and it is possible that the effect of repair type may be different depending on the strength parameter tested. Isometric forearm torque has also been found to vary depending on body size,[1] but we minimized this potential confounder by expressing torque values relative to the contralateral healthy arm. Although there were statistically insignificant differences between the cohorts, there were 2 more workers' compensation patients in the DI group. This may have negatively biased the DI group toward a lower supination torque. Finally, in the DI group, we were 1 patient short of meeting the sample size that we calculated a priori. However, our observed standard deviation was smaller than anticipated, and the difference detected was 20%. Post hoc power analysis indicated that our study was well powered to detect a difference of this magnitude.

Recent biomechanical and clinical studies on the treatment of acute distal biceps rupture have promoted the concept that an anatomic onlay method of reattachment using a DI technique is likely the most reliable way of restoring supination torque.[20,22-24,26,27] Our study shows that similarly favorable results can be obtained using an SI approach. In addition, the DI approach may be limited in its ability to restore supination torque.

Conclusions

Contrary to our hypothesis, we found a 20% mean improvement in terminal supination torque for acute distal biceps ruptures repaired with the SI technique compared with the DI technique. Patients did well with either technique; however, this finding may have clinical significance for the more discerning, high-demand patient. The accepted recommendation regarding guide pin trajectory in the SI technique may need to be revisited to better restore supination torque.

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