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Biomechanical Analysis of Single Interference Screw vs Interference Screw With Cortical Button for Flexor Hallucis Longus Transfer

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Abstract

Background: Flexor hallucis longus tendon transfer (FHL) with a cortical button tension slide is an innovative addition that has not been measured against traditional methods.

Methods: 12 pairs (n=24) of fresh-frozen cadaveric tibia-to-toe samples were used and randomized to receive one of the operative FHL techniques. Specimens underwent bone density analysis. Biomechanical loading was applied between 20 and 60 N at 1 Hz for 100 cycles. Post–cyclic load to failure occurred at 1.25 mm/s. Cyclic displacement, structural stiffness, and ultimate load were derived from load-displacement curves. Student *t* tests evaluated significant effects between both FHL techniques. Linear regression analysis assessed interactions between bone density and strength of FHL technique.

Results: Average tendon diameter was 5.44 ± 0.46 mm. Average bone density was 1.06 ± 0.08 g/cm^2. Addition of a cortical button to FHL transfer did not significantly affect cyclic displacement (0.78 ± 0.52 mm vs 0.87 ± 0.80 mm) or structural stiffness (162.11 ± 43.34 N/mm vs 167.57 ± 49.19 N/mm). Cortical button addition to FHL transfer resulted in significantly increased ultimate load (343.72 ± 68.93 N) compared with interference screw alone (255.62 ± 77.17 N) (P = .0002). Linear regression analyses did not reveal any significant interactions between bone density and FHL tendon transfer technique.

Conclusion: Enhanced strength can be achieved with FHL tendon transfer to calcaneus using an interference screw and cortical button tension slide technique as compared to an interference screw alone. Cortical buttons in the setting of FHL tendon transfer to the calcaneus offers an additional level of support.

Clinical Relevance: Operative cases presenting with poor bone quality due to osteoporosis or osteopenia could benefit from cortical button fixation during FHL transfer. Clinical studies are needed to determine if the increased construct stability conferred from the additional use of a flip button results in fewer FHL transfer failures or better clinical outcomes.

Level of Evidence: Level V, Controlled Laboratory Study.

Keywords: flexor hallucis longus, FHL transfer, Achilles, interference screw, cortical button, tension-slide technique

Introduction

Operative intervention is an effective option to treat Achilles tendon rupture or degenerative pathology.[6] Neglected injuries and conservative management may result in continued symptoms and decreased ankle plantarflexion strength.[12] Restoration of functional plantar flexion of the ankle joint following chronic Achilles injury is achieved through transfer of the flexor hallucis longus tendon (FHL). FHL transfer to the calcaneus has undergone several iterations from the first introduction by Wapner et al[19] in 1993. Clinical results suggest that FHL transfer for Achilles pathology has a low complication rate and no failures.[1] The FHL transfer

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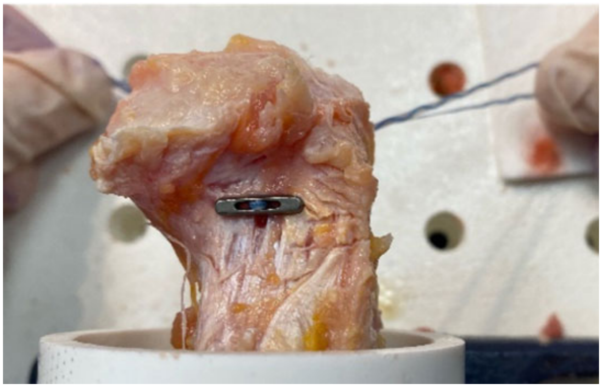

Figure 1. Cortical button fixation. A 2.6 × 12-mm cortical button (BicepsButton; Arthrex, Inc) was used for the interference screw with cortical button flexor hallucis longus (FHL) transfer group. The cortical button was passed through the pilot hole and positioned on the underside of the plantar surface in the midline and adjusted perpendicular to the long axis of the calcaneus. The FHL was tensioned through the tunnel, and 8 consecutive half-hitch knots were tied. The tenodesis screw was introduced to the construct and inserted until flush.

Figure 2. Samples were imaged using fluoroscopy. All specimens underwent bone density analysis following interference screw or interference screw and cortical button placement (A). Specimens were placed on the scanning platform with the medial side facing upward and scanned with a 55-kV C-arm (Fluoroscan InSight FD, Hologic).

technique is a well-established method for augmenting degenerative Achilles tendinopathy, tendon rupture, and revision surgery.[3]

Several methods for securing tendon to bone have been introduced[4]; however, modern operative repair techniques for FHL transfer use interference screws.[6,16] Incorporation of an interference screw was introduced by Cohn et al.[5] Several technique variations have been described, including an endoscopic approach[12] and integration of a cortical button.[16] Owing to the novelty of FHL transfer augmentation with the cortical button, there is a paucity of clinical data available. Combination of the interference screw with the cortical button for FHL transfer results in a repair construct with increased failure load and decreased displacement, properties that are characteristic of the 2 repair techniques.[16] These biomechanical characteristics clinically translate to a more robust repair construct that will allow for early weightbearing and accelerated rehabilitation.

Fortification of the flexor hallucis longus transfer with a cortical button tension slide is an advancement that has not been measured against traditional methods. The purpose of this study is to evaluate the biomechanical differences between a single interference screw vs interference screw with cortical button tension slide technique for the fixation of FHL transfer. The authors hypothesize that the combination of interference screw with cortical button tension slide technique will have superior strength of fixation and improved biomechanical properties compared to single interference screw for fixation of the FHL in chronic Achilles pathology.

Methods

Specimens

Twelve pairs (n=24) of fresh-frozen cadaveric tibia-to-toe samples (6 male, 6 female) were used to assess the biomechanics of FHL tendon transfer fixation using a single interference screw or interference screw with a cortical button tension slide technique. Each pair of cadaveric samples were randomized to receive one of the operative FHL treatment techniques. Soft tissue was removed with exception of the FHL tendon and calcaneus. FHL tendons were identified and preserved in a saline solution for biomechanics testing. Mean age of the samples was 58.08 years.

Operative Technique

Calcaneus specimens were potted in a 5-cm-diameter cylindrical PVC section for mechanical testing. FHL tendons were harvested at the posteromedial aspect of the ankle and marked 3 cm from the musculotendinous junction. Additionally, the FHL tendon was marked 1 and 2.5 cm superior to this point for whip-stitching and prepared for insertion into the calcaneal bone.

A Haglund deformity, typically removed during surgery, was created with a diagonal cut anterior to posterior. A guide pin was aimed anterior to the plantar weightbearing surface. Specifically, a spade-tip drill pin was inserted 1 cm anterior to the Achilles tendon insertion on the superior calcaneus and aimed 1 cm anterior to exit the plantar surface in the midline of the calcaneus. A drill guide handle (Arthrex, Inc, Naples, FL) assisted guide pin placement. A through-all hole

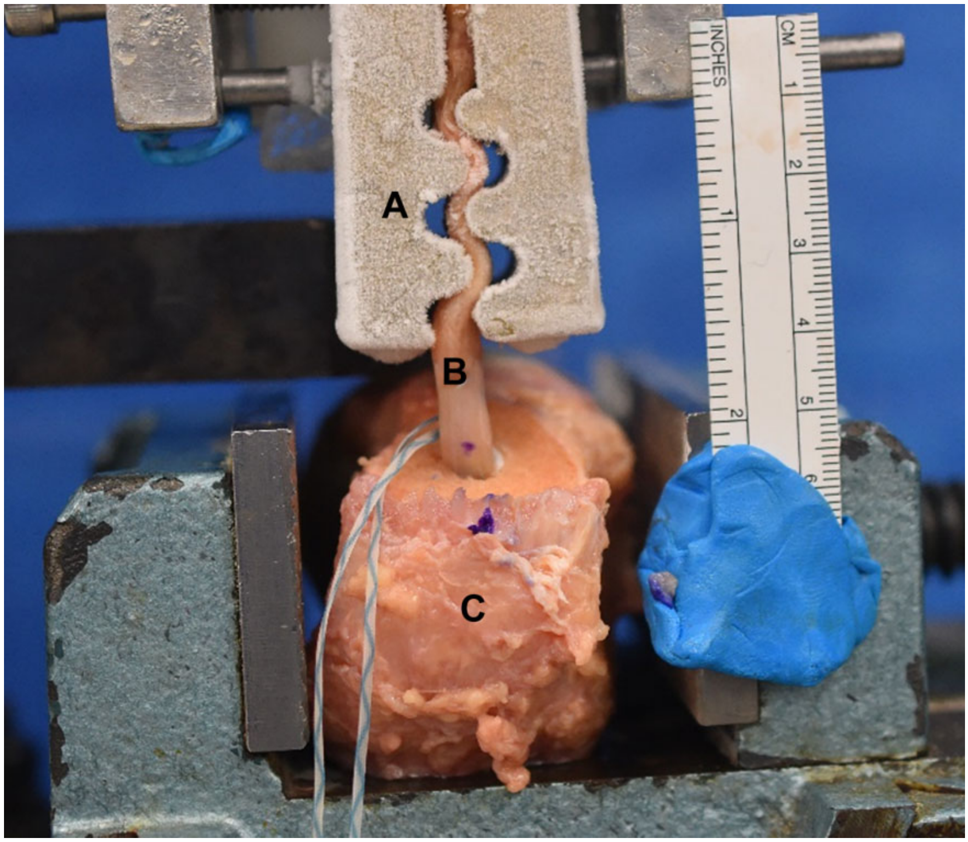

Figure 3. Biomechanical testing setup. Biomechanical testing was performed with an Instron 8871 servohydraulic materials testing system (Instron Corp, Canton, MA). The calcaneus construct (C) was fixated to the mechanical loading device (A) perpendicular to the long axis of the load cell in a neutral walking position. Flexor hallucis longus tendon (B) specimens underwent manual preloading to 5 N prior to loading. Cyclic loading was performed between 20 and 60 N at a rate of 1 Hz for 100 cycles. The specimens were pulled to failure at a rate of 1.25 mm/s after cycling was completed.

was drilled with a 6.5-mm reamer to a depth of 20 mm. The transferred tendons were fixed with a 6.25 × 15-mm “biotenodesis” soft tissue interference screw (Arthrex, Inc) with the foot in 20 degrees of plantarflexion.

A 2.6 × 12-mm cortical button (BicepsButton; Arthrex, Inc) was used for the interference screw with cortical button FHL transfer group (Figure 1). The cortical button was passed through the pilot hole and positioned on the underside of the plantar surface in the midline and adjusted perpendicular to the long axis of the calcaneus. The FHL was tensioned through the tunnel, and 8 consecutive half-hitch knots were tied. The tenodesis screw was introduced to the construct and inserted until flush.

Bone Density Analysis

All specimens underwent bone density analysis following interference screw or interference screw and cortical button placement in the method described by Geiger et al[7] (Figure 2). Specimens were placed on the scanning platform with the medial side facing upward and scanned with a 55-kV C-arm (Fluoroscan InSight FD; Hologic, Marlborough, MA). Scans were converted to TIFF files to maintain contrast region integrity and imported to ImageJ. Two 7 × 7-mm regions of interest were selected within 5 mm parallel to the pilot hole trajectory. The mean gray value was recorded using an 8-bit gray scale (0-255 scale). The quotient of the 2 values demonstrates a relative bone density value for the specimen.

Biomechanical Testing

Biomechanical testing was performed with an Instron 8871 servohydraulic materials testing system (Instron Corp, Canton, MA). The calcaneus construct was fixated to the mechanical loading device perpendicular to the long axis of the load cell in a neutral walking position (Figure 3). FHL tendon specimens underwent manual preloading to 5 N prior to loading. Cyclic loading was performed between 20 and 60 N at a rate of 1 Hz for 100 cycles. The specimens were pulled to failure at a rate of 1.25 mm/s after cycling was completed. FHL tendon transfer techniques were evaluated

Table 1. Cadaveric Specimen Demographics.[a]

Specimen	Age	Limb	Sex	Tendon Diameter (mm)	Normalized Tendon Diameter (mm)	Bone Density	Normalized Bone Density
Biotenodesis screw							
1L	58	L	M	6	0.91	0.92	1.15
2R	58	R	M	6	0.91	0.93	1.14
3L	53	L	M	5.5	0.99	0.94	1.12
4R	42	R	M	5.5	0.99	1.04	1.01
5R	60	R	M	5.5	0.99	1.06	1.00
6L	61	L	M	5.5	0.99	0.95	1.11
7L	60	L	F	5.00	1.09	1.28	0.83
8L	52	L	F	5.50	0.99	1.12	0.95
9L	70	L	F	5.50	0.99	1.07	0.99
10R	55	R	F	4.00	1.36	1.11	0.95
11R	60	R	F	5.50	0.99	1.01	1.05
12R	68	R	F	5.00	1.09	1.13	0.93
Mean	58.08			5.38	1.02	1.05	1.02
SD				0.51	0.11	0.10	0.09
Biotenodesis screw + cortical button							
1R	58	R	M	6.00	0.91	1.08	0.97
2L	58	L	M	5.50	0.99	0.97	1.09
3R	53	R	M	5.50	0.99	1.00	1.05
4L	42	L	M	5.50	0.99	0.98	1.08
5L	60	L	M	5.50	0.99	1.00	1.06
6R	61	R	M	5.50	0.99	1.07	0.99
7R	60	R	F	6	0.91	1.15	0.92
8R	52	R	F	5.5	0.99	1.12	0.94
9R	70	R	F	6	0.91	1.11	0.95
10L	55	L	F	4.5	1.21	1.15	0.91
11L	60	L	F	5.5	0.99	1.07	0.99
12L	68	L	F	5	1.09	1.09	0.97
Mean				5.50	0.99	1.07	0.99
SD				0.41	0.08	0.06	0.06
Total mean				5.44	1.01	1.06	1.01
Total SD				0.46	0.10	0.08	0.08

[a]Age, limb, sex, tendon diameter, and bone density are presented for all 24 calcaneus samples utilized.

for cyclic displacement (mm), structural stiffness (N/mm), and ultimate load (N). Cyclic displacement was recorded during cyclic loading and based on actuator displacement to achieve required loading. Structural stiffness was considered to be the slope of the load-displacement curve directly following the cyclic loading stage. Ultimate load was considered the peak load postcycling at or prior to failure.

Statistical Analysis

Normality of data was evaluated with a Shapiro-Wilk test. Paired *t* tests were performed to evaluate differences in FHL repair technique for cyclic displacement, structural stiffness, and ultimate load. Additionally, a linear regression analysis was performed to investigate interactions between bone density and strength of the FHL repair technique. The level of significance was set at $P < .05$.

Results

Cadaveric specimen demographics are presented in Table 1. Average tendon diameter of the 24 FHL samples was 5.44 ± 0.46 mm. Average bone density for all 24 calcaneus samples was determined to be 1.06 ± 0.08 g/cm^2.

Average and normalized data for cyclic displacement, structural stiffness, and ultimate load is presented in Table 2. Loading data were normalized with respect to bone density and tendon diameter to account for inherent anatomic differences between cadaveric specimens. Data for the 3 biomechanical variables were determined to be normally distributed. The addition of a cortical button for FHL transfer to the calcaneus did not significantly affect cyclic displacement (0.78 ± 0.52 mm vs 0.87 ± 0.80 mm, 95% CI –0.63, 0.81) or structural stiffness (162.11 ± 43.34 N/mm vs 167.57 ± 49.19 N/mm, 95% CI –22.97, 33.89). Addition of the cortical button to the FHL tendon transfer construct resulted in a significantly increased ultimate load (343.72 ± 68.93 N) compared to interference screw alone (255.62 ± 77.17 N) (95% CI –124.29, –51.92; $P = .0002$) (Figure 4). Linear regression analyses did not reveal any significant interactions between bone density and FHL tendon transfer technique.

All FHL transfer repair techniques, both interference and interference with cortical button, failed owing to the tendon

Table 2. Biomechanics Data.[a]

Specimen	Cyclic Displacement (mm)	Normalized Cyclic Displacement (mm)	Structural Stiffness (N/mm)	Normalized Structural Stiffness (N/mm)	Ultimate Load (N)	Normalized Ultimate Load (N)
Biotenodesis Screw						
1L	2.54	2.64	119.90	124.73	285.71	297.22
2R	0.26	0.27	169.72	174.59	214.78	220.94
3L	0.19	0.21	165.28	183.81	320.36	356.27
4R	0.10	0.10	229.92	230.52	293.57	294.34
5R	0.17	0.17	229.06	225.75	390.72	385.07
6L	1.06	1.17	137.27	150.93	270.00	296.87
7L	0.25	0.22	303.33	272.71	358.49	322.30
8L	0.19	0.18	153.87	143.79	233.90	218.58
9L	1.27	1.24	127.06	124.01	174.36	170.17
10R	0.69	0.89	86.80	112.10	137.00	176.93
11R	1.27	1.32	142.98	148.31	192.36	199.52
12R	2.01	2.03	118.18	119.60	127.67	129.20
Mean	0.83	0.87	165.28	167.57	249.91	255.62
SD	0.78	0.80	58.19	49.19	80.82	77.17
Biotenodesis Screw + Cortical Button						
1R	0.12	0.11	230.37	203.55	457.62	404.35
2L	1.82	1.95	95.80	102.82	357.00	383.17
3R	0.80	0.83	145.98	151.89	435.53	453.17
4L	0.20	0.21	227.63	243.60	351.99	376.68
5L	1.15	1.21	167.34	175.40	400.71	420.01
6R	0.82	0.80	137.28	134.47	324.13	317.50
7R	0.09	0.07	262.30	218.55	379.39	316.10
8R	1.21	1.13	170.91	159.64	366.90	342.70
9R	1.25	1.08	114.23	98.78	228.60	197.68
10L	0.48	0.53	142.67	157.69	257.21	284.28
11L	0.97	0.95	186.29	181.73	373.01	363.88
12L	0.47	0.49	111.62	117.21	252.47	265.13
Mean	0.78	0.78	166.04	162.11	348.71	343.72
SD	0.51	0.52	49.99	43.34	68.74	68.93

[a]Cyclic displacement, structural stiffness, and ultimate load is presented along with the normalized values. The 3 biomechanics variables were normalized to the specimen tendon diameter and BMD.

pulling through the construct. The interference screw and cortical buttons remained undisturbed throughout the experimental procedures (Figure 5).

Discussion

Interference screw augmented with cortical button tension slide is one technique for FHL tendon transfer in the setting of chronic Achilles pathology.[16] The cortical button tension slide technique may help with accurate FHL tendon placement; however, no biomechanical investigations have been performed to assess the impact of a cortical button in an interference screw FHL tendon transfer construct. Results from this cadaveric biomechanical study demonstrate an increase in FHL tendon transfer ultimate load to failure with the addition of a cortical button tension slide technique but no change in cyclic displacement or structural stiffness.

Anatomic considerations of the FHL tendon contribute to successful soft tissue integration for Achilles pathology repair. The FHL is adjacent to the Achilles tendon as it transverses the ankle joint and functions in the same phase as the gastrocnemius and soleus muscle complex.[8,15] The effect on weightbearing due to FHL tendon transfer is minimal in a single incision transfer technique, and the FHL is quickly able to restore strength required for gait as one of the strongest plantar flexors.[5,11] Some investigators have postulated that Achilles tendon healing may be accelerated as a result of increased vascularity provided by the low-lying muscle belly of the FHL.[8,15]

The interference screw and cortical button construct has been proven effective for soft tissue reattachment and reconstruction in several joints. A principal contribution of cortical buttons for soft tissue fixation is an increased ultimate failure load.[9,13,17,18] These findings are consistent in the present study, in which an average 34% increase in ultimate load was observed when the cortical button was introduced into the interference FHL transfer construct. In the knee, an additional advantage for adding cortical button to

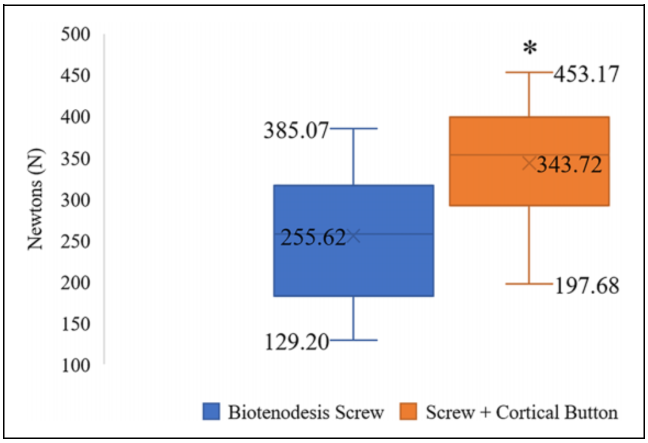

Figure 4. Normalized ultimate load box plot. Addition of the cortical button to the flexor hallucis longus tendon transfer construct resulted in a significantly increased ultimate load (343.72 ± 68.93 N) compared with interference screw alone (255.62 ± 77.17 N) (95% CI –124.29, –51.92; $P = .0002$).

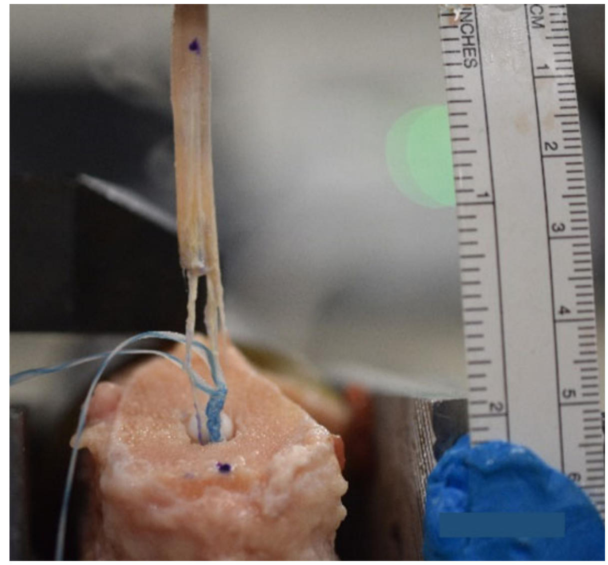

Figure 5. All flexor hallucis longus tendon transfer repairs failed by the tendon being pulled through the construct. The interference screw placement was not affected in any trials.

interference screw use has been decreased displacement at the bone-tendon interface,[20] although we did not find that in the current study for FHL transfer.

The clinical advantage of cortical button augmentation could be faster recovery and repair construct confidence, as opposed to failure mitigation. The cortical button augment should decrease risk associated with osteoporotic bone. Presence of osteoporosis or osteopenia will interfere with the interference screw fixation, which may be mediated with cortical button fixation to strong cortical bone.[2,10] Although no FHL transfer failures have been reported in the literature, the cortical button augmentation hold potential to enhance postoperative success.[16]

Bone mineral density has been reported with mixed results to affect tendon transfer in the foot and ankle. A study evaluating FHL tendon transfer using tendon-to-tendon suture or screw fixation reported a positive correlation between BMD and ultimate load in the interference screw group.[3] Conversely, Sabonghy et al[14] reported no significant interaction between BMD and pull-out strength in tendon transfer using the flexor digitorum longus tendon. In the current study, numerous comparisons were performed to evaluate whether BMD affected FHL transfer fixation. The BMD of the cadaveric samples did not differ between tested groups; however, the BMD of the female cohort were significantly larger (1.12 vs 0.99 g/cm^2, $P = .00005$). Considering the age difference between genders (female = 61 years; male = 55 years), these findings are contrary to clinical observations and additional analysis was not performed.

This cadaveric study of FHL transfer biomechanics has clear limitations. FHL tendons were harvested during dissection, and the tendon length was not recorded. All FHL tendons were of sufficient length for transfer insertion, and the distance to the testing machine clamp was standardized. Interference screw size was not altered to accommodate different tendon or specimen size in order to standardize the technique. BMD of female cadaveric specimens was measured to be significantly larger than the male cohort used. This finding is contrary to what is clinically observed. The bone was of adequate quality and density for all specimens tested. The other clear major limitation of the study, like all cadaver-based tests, is that the effects of healing with tendon or bone integration cannot be modeled by our study design.

Conclusion

Enhanced strength can be achieved with FHL tendon transfer to the calcaneus by using an interference screw augmented with cortical button fixation vs interference screw alone. Comparative clinical trials are needed to determine if the additional mechanical strength has clinical impact.

Ethical Approval

Ethical approval was not sought for the present study because biomechanical studies utilizing de-identified cadaveric specimens does not require ethical approval by our institution.

Declaration of Conflicting Interests

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