Eklem Hastalıkları ve Cerrahisi
*Joint Diseases and Related Surgery*

**Experimental Study** / ***Deneysel Çalışma***

***Eklem Hastalık Cerrahisi***
*2009;20(2):107-113*

# In-vitro comparison of the lengthening and biomechanical properties of three tendon lengthening techniques

## Üç tendon uzatma tekniğinin uzatma düzeyi ve biyomekanik özelliklerinin deneysel olarak karşılaştırması

Kaan Gideroğlu, M.D.,[1] Serdar Toksoy, M.D.,[2] Mithat Akan, M.D.,[2] Serkan Yıldırım, M.D.,[2]
Emin Sümbüloğlu, Eng.,[3] Tayfun Aköz, M.D.[2]

[1]Department of Plastic and Reconstructive Surgery, Medicine Faculty of Abant İzzet Baysal University, Bolu, Turkey
[2]Department of Plastic and Reconstructive Surgery, Dr. Lütfi Kırdar Kartal Training and Research Hospital, İstanbul, Turkey
[3]Department of Mechanical Engineering, İstanbul Technical University, İstanbul, Turkey

**Objectives:** Clinically, the Z-plasty lengthening is the only method used in the upper extremity, whereas several different techniques such as the Vulpius and Baker are used in the lower extremity. In this study, the usage of the modified Vulpius and Baker tendon lengthening techniques in the upper extremity was investigated.

**Materials and methods:** Vulpius and Baker techniques are modified by changing their application site in 90 sheep fore-limb deep flexor tendons using three randomly divided groups. Z-plasty, V-Y-plasty (Modified Vulpius) and U-T-plasty (Modified Baker) techniques were used in groups I to III, respectively. Their elongation and biomechanical properties were compared.

**Results:** The Z-plasty technique provided significantly greater lengthening than the other two techniques, followed by the U-T-plasty technique. Failure load of the U-T-plasty technique was 60.7% higher than the Z-plasty technique and 45.4% higher than the V-Y-plasty technique. Repairs with the U-T-plasty and V-Y-plasty techniques were significantly stiffer than the repairs with the Z-plasty technique.

**Conclusion:** The U-T-plasty technique may be a good alternative to the Z-plasty technique because of its easy application and better biomechanical properties, especially in cases that need moderate-sized elongation and early mobilization. But the restorative properties of this technique need to be observed on an in-vivo model.

*Key words:* Tendon lengthening; lengthening properties; biomechanical comparison.

**Amaç:** Klinikte üst ekstremitede tendon uzatma yöntemi olarak özellikle Z-plasti uygulanırken, alt ekstremitede bu amaçla Vulpius ve Baker gibi çok sayıda farklı yöntemler uygulanmaktadır. Bu çalışmada Vulpius ve Baker yöntemleri geliştirilerek üst ekstremitede denendi.

**Gereç ve yöntemler:** Vulpius ve Baker yöntemleri uygulama yerleri değiştirilmek suretiyle geliştirilerek 90 adet koyun ön ayak derin fleksor tendonunda çalışıldı. Tendonlar rastlantısal olarak üç eşit gruba ayrıldı. Birinci gruba Z-plasti, ikinci gruba V-Y-plasti (Modifiye Vulpius), üçüncü gruba U-T-plasti (Modifiye Baker) yöntemiyle uzatma uygulandı. Uzama miktarları ve biyomekanik dayanımları değerlendirildi.

**Bulgular:** Z-plasti yöntemi her iki yöntemden de anlamlı derecede daha fazla uzatma sağladı. U-T-plasti yöntemi bu yöntemi izledi. U-T-plasti yönteminin Z-plasti yönteminden %60.7 ve V-Y-plasti yönteminden %45.4 daha fazla yük taşıdığı bulundu. U-T-plasti ve V-Y-plasti teknikleri ile gerçekleştirilen onarımlar Z-plasti ile yapılan onarımlardan anlamlı derecede daha sertti.

**Sonuç:** Özellikle orta derecede uzatma ve erken mobilize olmayı gerektiren olgularda U-T-plasti yöntemi, kolay uygulanabilirliği ve daha üstün biyomekanik özellikleri nedeniyle Z-plasti yöntemine alternatif olabilir. Ancak bu yöntemin iyileşme özellikleri bir in-vivo modelde araştırılmalıdır.

*Anahtar sözcükler:* Tendon uzatma; uzama özellikleri; biyomekanik karşılaştırma.

- *Received: April 08, 2008 Accepted: October 21, 2008*

- Correspondence: Kaan Gideroğlu, M.D. Abant İzzet Baysal Üniversitesi Tıp Fakültesi Plastik ve Rekonstrüktif Cerrahi Anabilim Dalı, 14280 Gölköy, Bolu, Turkey. Tel: +90 374 - 253 46 56 / 3373 Fax: +90 374 - 253 46 15 e-mail: kaangideroglu@hotmail.com

Flexor tendon injuries are common and often result in disability.[1-3] In flexor tendon repair, there are two main clinical problems: *(i)* postoperative flexor tendon adhesions; and *(ii)* the need for additional tendon material for reconstruction.[4] Many drugs and biomaterials were investigated to solve the first problem, but none of them are being used routinely in the clinic.[5] Autologous tendon grafting, staged flexor reconstruction, and tendon lengthening techniques are used against the second problem.[4-6] The Z-plasty technique is the preferred technique when tendon lengthening is the treatment of choice in the upper extremity.[6] Several tendon lengthening techniques such as the Vulpius, Baker, Strayer, Z-plasty and the White are used in the lower extremity, but none of them, except for the Z-plasty is used in the upper extremity.[7]

We hypothesize that these lower extremity tendon lengthening techniques may be used also in the upper extremity with minor modifications. The purpose of this in vitro study was to investigate whether or not the recently modified Vulpius and Baker techniques could be used in upper extremity tendon reconstruction, and to compare their lengthening and biomechanical properties with the Z-plasty technique, which is the established method in upper extremity tendon lengthening.

## MATERIALS AND METHODS

### Specimen preparation

Forty-five adult sheep forelimbs were obtained from a local provider. Their deep flexor tendons were isolated (Figure 1a, b). Then the tendons were transected from their insertions (Figure 1c). Ninety tendon segments obtained from the arms of "Y" shaped sheep tendons were used for the experiment (Figure 1d). The ninety tendon segments were divided randomly into three main groups. The Z-plasty technique was applied in the first group, the modified Vulpius technique in the second group and the modified Baker technique in the third group. These groups were also divided into three subgroups: 1.0, 1.5 and 2.0 cm tendon lengthening was performed in the first, second and third subgroups, respectively.

### Surgical technique

A point was marked with a permanent marker at the 1.0 cm distal to the proximal end of the tendon (Figure 2a). Then a second point was marked according to the divided subgroups. The specifics of each lengthening technique were drawn between these points (Figure 2b-d). The only recent modification in the Vulpius and Baker techniques was in their application site. Although these techniques are clinically applied at the musculotendinous junction, in our study we applied them only on tendon segments.

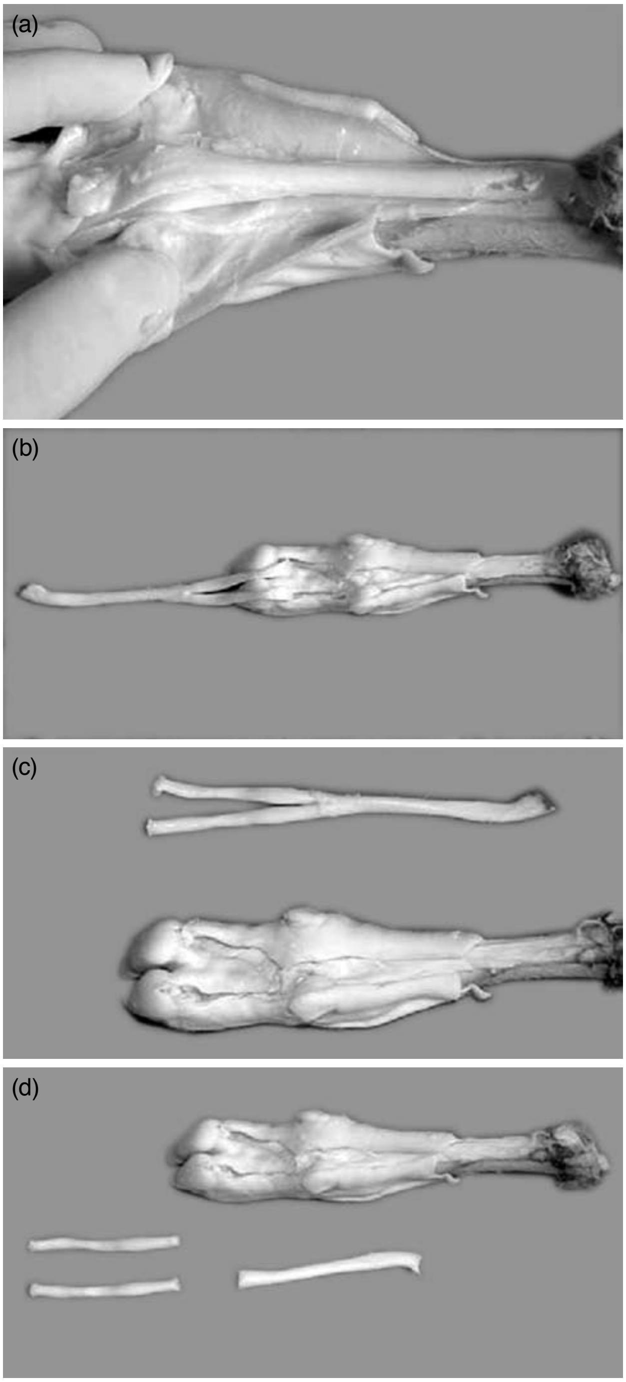

**Figure 1. (a-d)** Preparation of sheep tendons.

Following the planning of the lengthening under loupe magnification (x 4.5), all tendons were transected and repaired by the same surgeon with 4/0 polypropylene sutures using two core stitches (Figure 3a-f).

Approximately 5 mm of each tendon was sutured to each other in the suture site, compared to 7 mm in the second subgroup and 9 mm in the third. Before and after tendon lengthening, the lengths of all tendons were measured with millimetric paper and the differences were filed for statistical evaluation (Figure 4a, b). Biomechanical testing was performed immediately after completion of repairs in each group. All tendons were kept moist with a normal saline spray throughout preparation and testing.

**Biomechanical testing**

Only the tendons lengthened in 2 cm tendon segments were subjected to static testing, because we wanted to examine which method provided the lowest failure load under the most elongation. The tendons were placed in the clamps of the testing machine (Hydraulic Universal Test Machine, İstanbul Technical University, Mechanical Engineering Faculty, Strength Division, privately made), with a load cell of 400 N (Figure 5a). The clamps were tested by a 1 N preload to ensure against slipping and tearing at the clamp-tendon junction. Samples were tested for failure using a distraction rate of 20 mm/min (Figure 5b). Data were used to generate load displacement curves for every tendon (Figure 6). We assessed three variables for each repair: *(i)* The ultimate strength, *(ii)* stiffness and *(iii)* mechanism of failure (suture breakage or suture pullout).

The ultimate strength of the repair, or load to failure, was determined by the peak value on the curve and had a unit of reading in Newtons. The stiffness was determined by the tangent of the linear middle third of the load displacement of the curves and was reported in units of Newton per millimeter. The mechanism of failure was recorded as either suture pullout or suture breakage.

**Statistical methods**

Biomechanical and lengthening data were analyzed for statistical significance using the Kruskal-

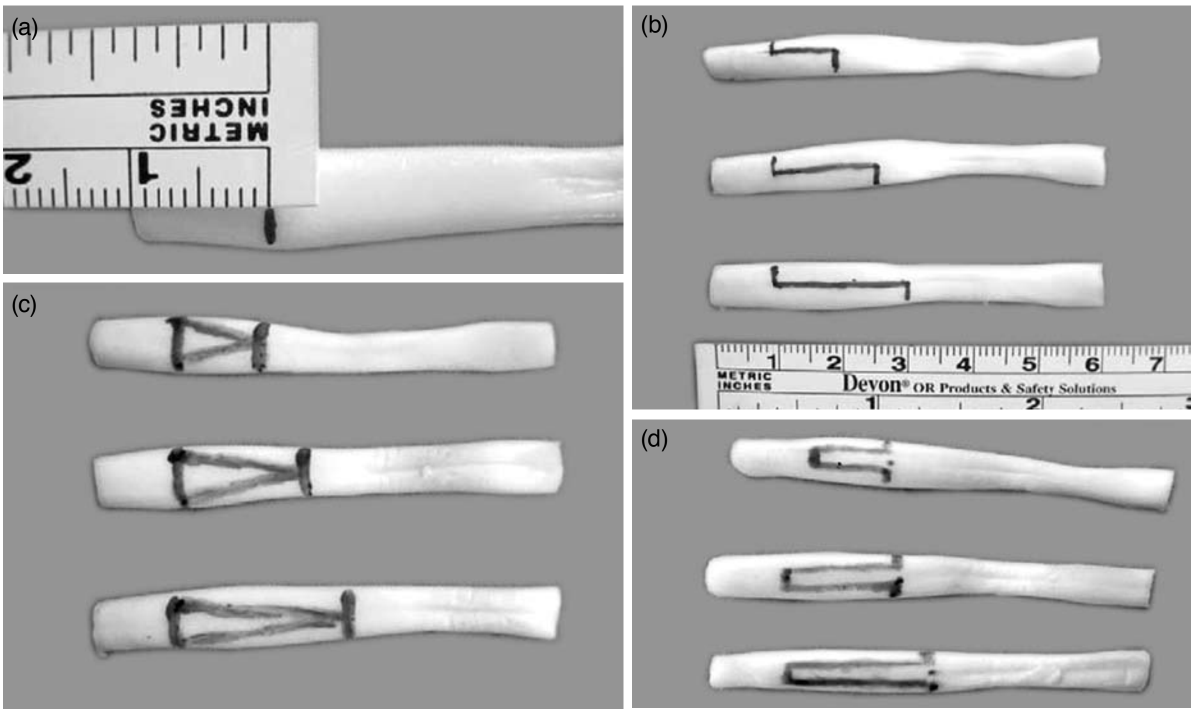


**Figure 2. (a)** Marking of the first point 1 cm distal from the proximal edge of the tendon. **(b)** Marking of the second point for Z-plasty 1 or 1.5 or 2 cm distal from the first point according to subgroups. **(c)** Marking of the second point for V-Y-plasty 1 or 1.5 or 2 cm distal from the first point according to subgroups. **(d)** Marking of the second point for U-T-plasty 1 or 1.5 or 2 cm distal from the first point according to subgroups.

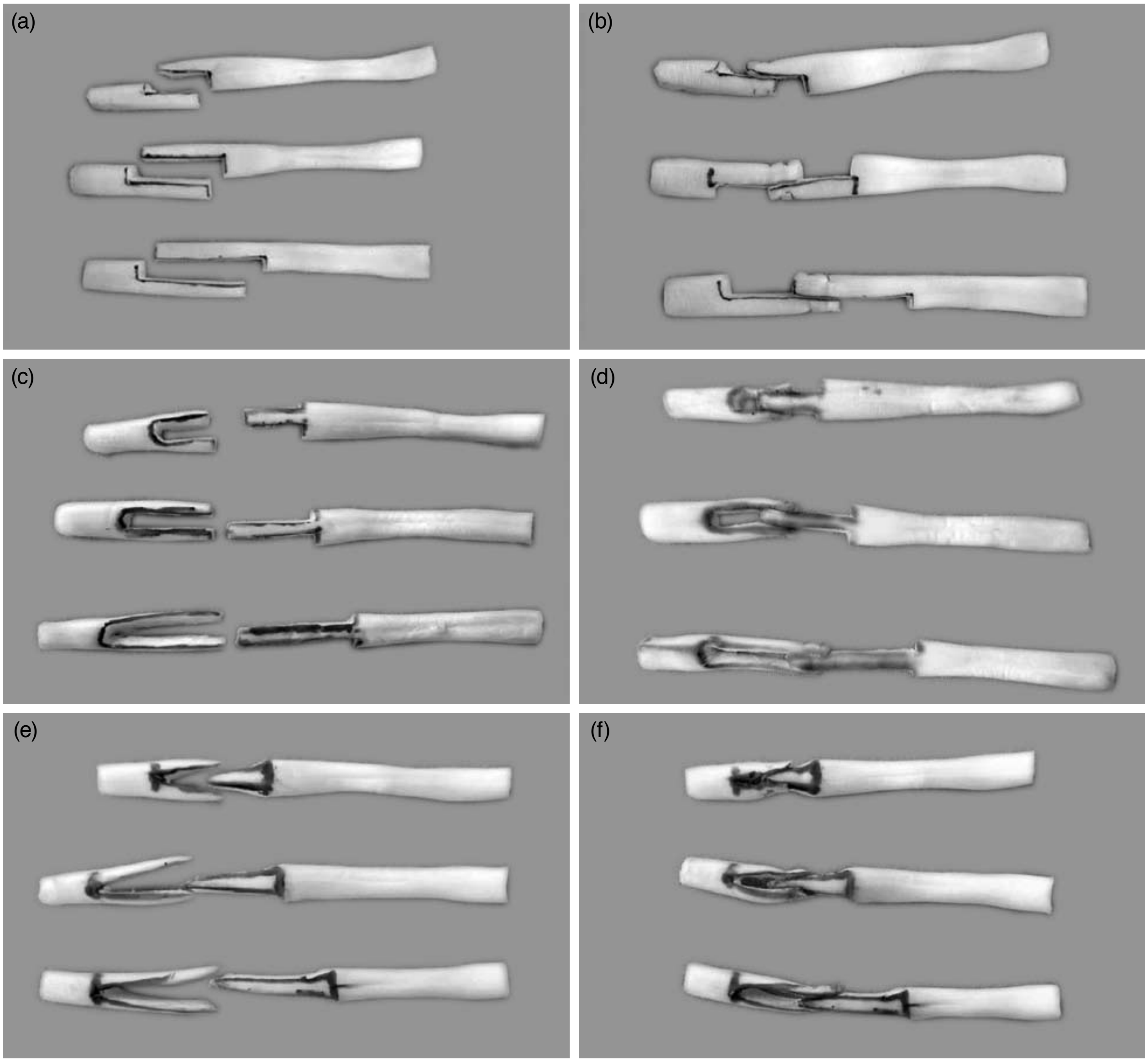


**Figure 3.** Views of the tendons after incisions were made according to the drawings and repairs finished. Left and right **(a, b)** above Z-plasty technique, **(c, d)** middle U-T-plasty technique, **(e, f)** V-Y-plasty technique.

Wallis test and Dunn's multiple comparison test. The GraphPad Prisma V.3 program was used for statistical analysis. A level of $p<0.05$ was considered to be statistically significant.

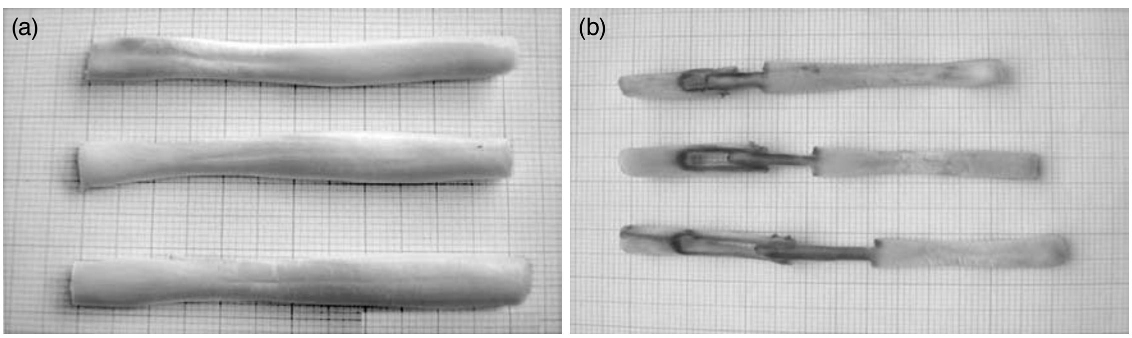


**Figure 4.** Measurement of tendon length with millimetric paper **(a)** before **(b)** and after repair.

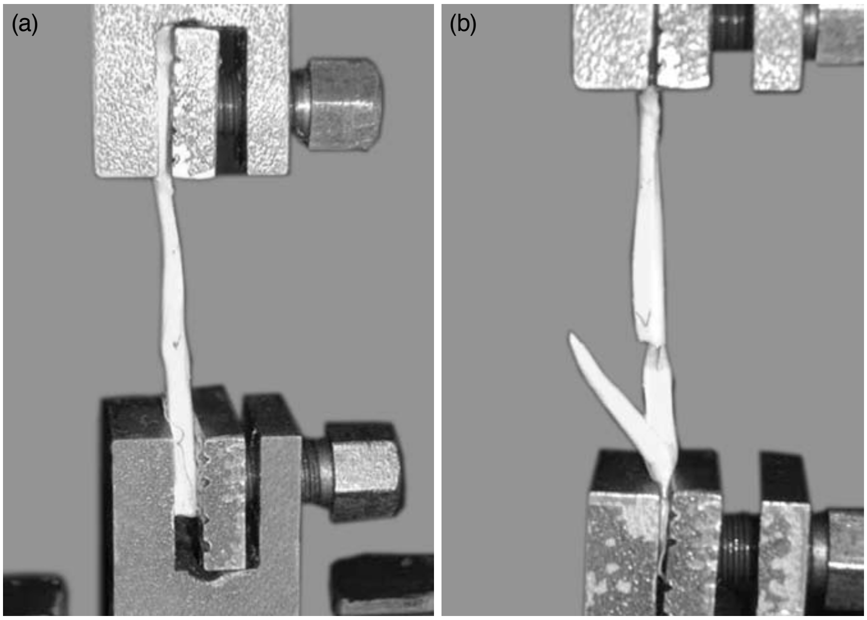


**Figure 5. (a)** View of tendon placed in testing machine. **(b)** Failure of moment of a repaired tendon.

## RESULTS

### Surgical method and lengthening properties

Surgically Z-plasty technique was the easiest technique and U-T-plasty technique was as easy as this technique. On the other hand application of V-Y-plasty technique was not easy when compared with the other two techniques. The Z-plasty technique provided significantly greater ($p<0.05$) lengthening than the other techniques for all subgroups (Table I). The U-T-plasty technique followed this technique. The difference between all subgroups was significant ($p<0.05$), except for the subgroups in which tendon lengthening was applied by V-Y and U-T-plasty in 1 cm tendon segments ($p>0.05$; Table I).

### Failure load and stiffness

*Failure load:* Statistically, the failure load of the U-T-plasty technique was 60.7% higher than the Z-plasty technique and 45.4% higher than the V-Y-plasty technique ($p<0.05$; Table II; Figure 7). There was no significant difference between the failure loads of the V-Y-plasty and Z-plasty techniques.

*Stiffness:* Repairs with the U-T-plasty and V-Y-plasty techniques were significantly stiffer than repairs with the Z-plasty technique ($p<0.05$). There was no significant difference between the stiffness of the U-T-plasty and V-Y-plasty repairs.

### Mechanism of failure

Failure of the repairs occurred either due to suture pullout or suture breakage. Failure occurred due to suture breakage in five of the Z-plasty lengthenings, three of the U-T-plasty lengthenings, and two of the V-Y-plasty lengthenings.

## DISCUSSION

Tendon repair techniques are one of the basic surgical procedures.[8] Clinically, there are two main problems in flexor tendon repairs: *(i)* Postoperative tendon adhesions and *(ii)* the need for additional tendon material for reconstruction.[4] The first problem occurs with all tendon injuries and ongo-

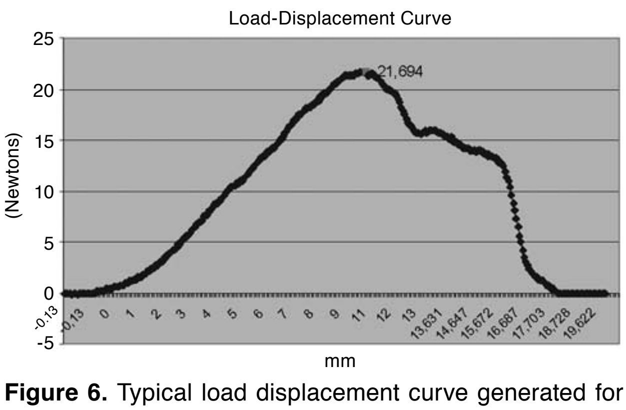


**Figure 6.** Typical load displacement curve generated for each test. The peak represents the load to failure and the slope of the linear region of the curve represents the stiffness.

**TABLE I**

Results for mean provided lengthening

| Technique | Provided lengthening (mm) (in 1 cm tendon segment) Mean±SD | Provided lengthening (mm) (in 1.5 cm tendon segment) Mean±SD | Provided lengthening (mm) (in 2 cm tendon segment) Mean±SD |
|---|---|---|---|
| Z-plasty | 4.70±0.48* | 9.90±0.57** | 13.60±0.52*** |
| V-Y-plasty | 3.40±0.52 | 6.40±0.52 | 8.90±0.57 |
| U-T-plasty | 3.80±0.42 | 8.20±0.42† | 11.60±0.52†† |

*: p<0.05 compared with V-Y-plasty and U-T-plasty techniques; **: p<0.05 compared with V-Y-plasty and U-T-plasty techniques; †: p<0.05 compared with V-Y-plasty technique; ***: p<0.05 compared with V-Y-plasty and U-T-plasty techniques; ††: p<0.05 compared with V-Y-plasty technique.

ing refinements include aggressive postoperative rehabilitation protocols and improved repair techniques.[4] The second problem occurs with injuries involving substantial tendon material loss and during the correction of contractures.[4-6,9] Autologous tendon grafting and tendon lengthening are the techniques that can be used to solve this second problem. The Z-plasty is the only alternative that can be used if tendon lengthening is chosen as a repair method in the upper extremity, although several alternatives such as the Vulpius and Baker techniques can be used in the lower extremity.[6-9]

In our study, we investigated the two techniques used in lower extremity (the Baker and the Vulpius) and whether or not they can be used in upper extremity with a recent minor modification compared with the Z-plasty. We found that the technically modified Baker (U-T-plasty) and modified Vulpius (V-Y-plasty) can be used on upper extremity tendons and the application of U-T-plasty was as easy as the Z-plasty technique. On the other hand, application of the V-Y-plasty was not as easy as the other two techniques and when this technique was used for longer elongation, the tendon slits in the arms of "V" were becoming thinner. We could not obtain a tendon elongation as good as the other two techniques in the same tendon length by this technique. We also found that, in order to obtain the same amount of elongation with the Z-plasty, the V-Y-plasty technique should be applied aproximately in 1.5x longer tendon segments. As a result of this finding, we think that the V-Y-plasty can be used successfully only in larger tendons such as wrist flexor tendons which need elongation no more than 1 cm. When we compared the U-T-plasty technique with the Z-plasty technique, we found that it was as easy as Z-plasty technique, that it provided a reasonable tendon elongation and that it can be used in upper extremity tendon defects. In a clinical study, the Vulpius and Baker techniques were compared in the Achilles tendon lengthening and it was found that the Z-lengthening might be more appropriate when large amounts of correction were needed.[10] These results correlate with our findings. The Z-plasty provides a reasonably higher amount of elongation but it carries a risk of over-lengthening,[11] so that we think that the U-T-plasty may be a good alternative to Z-plasty to avoid the risk of over-correction.

An ideal postoperative management of a flexor tendon repair involves active mobilization. This rehabilitation protocol demands strong repair techniques.[12] Load to failure testing showed that

**TABLE II**

Results for failure load and stiffness

| Technique | Failure load (N) Mean±SD | Stiffness (N/mm) Mean±SD |
|---|---|---|
| Z-plasty | 15.91±5.58 | 2.67±0.82† |
| V-Y-plasty | 17.59±4.52 | 4.96±1.50 |
| U-T-plasty | 25.57±4.73* | 5.54±0.95 |

*: p<0.05 compared with Z-plasty and V-Y-plasty techniques; †: p<0.05 compared with U-T-plasty and V-Y-plasty techniques.

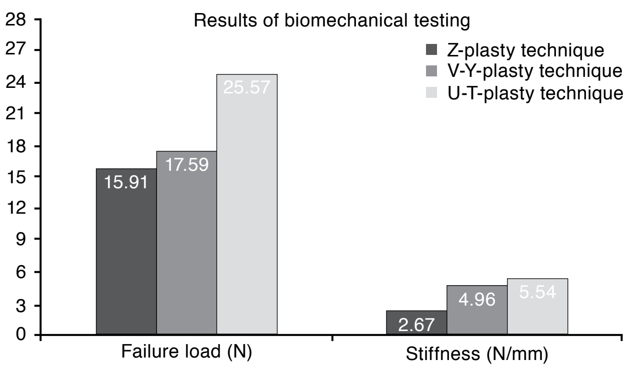


**Figure 7.** Results of failure load and stiffness of each repair. N: Newton; N/mm: Newton per millimeter.

the mean ultimate strength of the U-T-plasty technique was significantly higher than the other techniques. There was no significant difference between the ultimate strength of the V-Y-plasty Z-plasty technique although the V-Y-plasty has a nearly 45% higher mean failure load. Both modified techniques had significantly stiffer repair capacities than the Z-plasty technique. According to these findings, in cases of postoperative active mobilization rehabilitation protocol requirements, both modified techniques, especially the U-T-plasty, provide a great advantage through higher failure loads and stiffer repairs, compared to the Z-plasty. Several factors which were addressed, such as suture material and caliber, the repair technique and the number of strands crossing the repair site, affect the strength of a tendon repair.[13,14] In this study, the same surgeon repaired tendons by using two core sutures with the same suture material in the same caliber. The only the difference in the repairs was the technique applied. As a result, we think that the differences in repair strengths were a direct result of the repair method used. The effect of suture materials and techniques should be investigated in further studies.

The mechanism of failure was mostly suture pullout in the U-T-plasty and V-Y-plasty techniques. We think the thinner tendon segments in the arms of V and U result in a repair that slides out of the tendon more easily.

The U-T-plasty technique has been shown to have biomechanical advantages over both the Z-plasty and V-Y-plasty techniques. Its biomechanical properties and technical simplicity make it a method that should be considered primarily for use in any tendon repair that needs moderate-size tendon elongation. We are aware that the result of our study is contrary to the established practice of using the Z-plasty technique in upper extremity tendon elongations. However, this result should be treated with caution, as our experimental model suffers from some weakness: Firstly, although there are experimental studies with sheep tendons in the literature,[12] still, the sheep tendons may have some differences from human tendons. Secondly, the mechanism of failure in a soft, healing, live tendon in vivo may be very different from our experimental model, so these properties should also be investigated in an in vivo experimental model.

## REFERENCES


1. Jansen CW, Watson MG. Measurement of range of motion of the finger after flexor tendon repair in zone II of the hand. J Hand Surg [Am] 1993;18:411-7.
2. Lane JM, Black J, Bora FW Jr. Gliding function following flexor-tendon injury. A biomechanical study of rat tendon function. J Bone Joint Surg [Am] 1976; 58:985-90.
3. Tanaka T, Amadio PC, Zhao C, Zobitz ME, Yang C, An KN. Gliding characteristics and gap formation for locking and grasping tendon repairs: a biomechanical study in a human cadaver model. J Hand Surg [Am] 2004;29:6-14.
4. Zhang AY, Chang J. Tissue engineering of flexor tendons. Clin Plast Surg 2003;30:565-72.
5. Beredjiklian PK. Biologic aspects of flexor tendon laceration and repair. J Bone Joint Surg [Am] 2003;85-A(3):539-50.
6. Stahl S, Goldberg JA, Lerner A. Flexor tendon lengthening in zone II injuries. Ann Plast Surg 1999;43:265-7.
7. Saraph V, Zwick EB, Uitz C, Linhart W, Steinwender G. The Baumann procedure for fixed contracture of the gastrosoleus in cerebral palsy. Evaluation of function of the ankle after multilevel surgery. J Bone Joint Surg [Br] 2000;82:535-40.
8. Carls J, Wirth CJ. Tendon suture: surgical techniques. Orthopade 2000;29:188-95.
9. Gerwin M. Cerebral palsy. In: DP Green, RN Hotchkiss, WC Pederson, editors. Green's operative hand surgery. Vol. 1, 3rd ed. New York: Churchill Livingsteone; 1999. p. 259-86.
10. Yngve DA, Chambers C. Vulpius and Z-lengthening. J Pediatr Orthop 1996;16:759-64.
11. Aktas S, Ercan S, Candan L, Moralar U, Akata E. Early mobilization after sliding and Z lengthening of heel cord. A preliminary experimental study in rabbits. Arch Orthop Trauma Surg 2001;121:87-9.
12. Dona E, Turner AW, Gianoutsos MP, Walsh WR. Biomechanical properties of four circumferential flexor tendon suture techniques. J Hand Surg [Am] 2003;28:824-31.
13. Dinopoulos HT, Boyer MI, Burns ME, Gelberman RH, Silva MJ. The resistance of a four- and eight-strand suture technique to gap formation during tensile testing: an experimental study of repaired canine flexor tendons after 10 days of in vivo healing. J Hand Surg [Am] 2000;25:489-98.
14. Winters SC, Gelberman RH, Woo SL, Chan SS, Grewal R, Seiler JG 3rd. The effects of multiple-strand suture methods on the strength and excursion of repaired intrasynovial flexor tendons: a biomechanical study in dogs. J Hand Surg [Am] 1998;23:97-104.