Cureus

Open Access Original
Article

DOI: 10.7759/cureus.12387

In Vivo Evaluation of the Mechanical Strength of a Slide Lengthening Technique With a Locking Mechanism Using a Rabbit Model

Dai Iwase [1] , Kentaro Uchida [1] , Yukie Metoki [1] , Hiroyuki Sekiguchi [2] , Jun Aikawa [1] , Takashi Matsuo [3] , Atsushi Matsuo [4] , Masashi Takaso [5]

1. Department of Orthopaedic Surgery, Kitasato University, School of Medicine, Sagamihara, JPN 2. Medical Sciences Research Institute, Shonan University, Chigasaki, JPN 3. Department of Orthopaedic Surgery, Minamitama Othopaedic Hospital, Kanagawa, JPN 4. Department of Orthopaedic Surgery, Saga Handicapped Children's Hospital, Kinryu, JPN 5. Department of Orthopedic Surgery, Kitasato University, School of Medicine, Sagamihara, JPN

Corresponding author: Kentaro Uchida, kuchida@med.kitasato-u.ac.jp

Abstract

Background

There are many reports of Achilles tendon lengthening procedures for equinus deformity of the ankle. We previously modified an Achilles tendon lengthening to prevent overextension with a locking mechanism suture before performing a sliding lengthening. The purpose of this study was to compare the biomechanical properties of the locking mechanism suture with sliding lengthening (L-SL) and Z-lengthening (ZL) using a rabbit model.

Methods

Thirty-six male Japanese white rabbits were assigned to two groups - half undergoing the L-SL technique and half undergoing the ZL technique on the flexor hallucis longus (FHL) tendon. Six rabbits in each group were sacrificed at one week, three weeks, and six weeks postoperatively and evaluated, while five rabbits underwent radiographical and biomechanical evaluation and one underwent histological evaluation.

Results

In extension length, L-SL was significantly lower than ZL one week postoperatively. In the L-SL group, elongation one week postoperatively was significantly lower than that three and six weeks postoperatively. In the ultimate failure load, L-SL was significantly higher than ZL one and three weeks after lengthening. In the L-SL group, the ultimate failure load one week postoperatively was significantly lower than that three and six weeks postoperatively. In the ZL group, there were significant differences at all time points.

Conclusion

L-SL had higher mechanical property in vivo.

Review began 12/08/2020
Review ended 12/24/2020
Published 12/30/2020

Categories: Orthopedics
Keywords: tendon, sliding lengthening, z-lengthening

Introduction

Equinus deformity of the ankle is one of the most common orthopedic problems in children with spastic cerebral palsy [1]. A previous study on the prevalence of certain gait patterns in children with cerebral palsy indicated that 64% of children with spastic hemiplegia have an equinus deformity [2]. Equinus disrupts the gait cycle by decreasing stability in the stance phase and causing inadequate clearance in the swing phase [3]. Optimal operative or nonoperative treatment is needed for the equinus of the ankle in patients with cerebral palsy.

Achilles tendon lengthening is one of the most commonly used orthopedic procedures to improve equinus deformity. Although many different lengthening procedures have been described [4, 5], two of the most common are the Z-lengthening technique (ZL) and sliding lengthening technique (SL). These methods are often used for fixed contractures [6, 7].

After an operation, the immobilization period varies from three to seven weeks to ensure healing before returning to full function or exercise [8]. Blaiser and White have recommended three weeks of immobilization after percutaneous sliding heel-cord lengthening [6], whereas Renshaw et al. have recommended six weeks in a short leg cast [9]. Some authors have suggested four weeks or more of short leg cast immobilization after ZL [10]. However, prolonged immobilization following operative treatment results

How to cite this article
Iwase D, Uchida K, Metoki Y, et al. (December 30, 2020) In Vivo Evaluation of the Mechanical Strength of a Slide Lengthening Technique With a Locking Mechanism Using a Rabbit Model. Cureus 12(12): e12387. DOI 10.7759/cureus.12387

in muscle weakness, joint contracture, slow recovery, and rehabilitation. Treatment of equinus deformity, therefore, requires lengthening techniques with a reduced immobilization period [5].

To achieve early mobilization, several lengthening methods having higher mechanical properties have been developed [5, 11]. Hashimoto et al. previously showed that the SL with mattress sutures technique has higher ultimate tensile strength than ZL for flexor pollicis longus tendons, flexor digitorum superficialis tendons, and flexor digitorum profundus tendons of fresh cadavers in vitro [12]. We previously modified White's SL [13] to allow extension by an exact amount and prevent overextension with a locking mechanism suture with sliding lengthening (L-SL) before performing extension [14-17]. However, the efficacy of L-SL in vivo remains to be determined.

The purpose of this study was to compare the biomechanical properties of L-SL and ZL using a rabbit model in vivo to assess their utility in allowing earlier mobility.

Materials And Methods

The experimental protocol was approved by the Kitasato University School of Medicine Animal Care Committee (reference number: 2019-133). Thirty-six male Japanese white rabbits with an average weight of 3-3.5kg were purchased from Oriental Yeast Co., Ltd (Tokyo, Japan). We randomly divided them into two groups: L-SL and ZL groups (each n=18). We operated on the right flexor hallucis longus tendon (FHL) of each rabbit under anesthesia consisting of medetomidine hydrochloride (ZENOAQ, Fukushima, Japan), butorphanol tartrate (Meiji Seika Pharma, Tokyo, Japan), and midazolam (Sandoz, Tokyo, Japan) at a ratio of 3:1:1.

For L-SL, we first marked a length of 15 mm (Figure *1A*) with 4-0 polypropylene as in Figure *1B*-C. Each loop length was 10 mm, which was equivalent to the planned extension amount (Figure *1C*). Next, we made symmetrical transverse half incisions on the 15 mm mark (Figure *1D*) and carefully extended the tendon (Figure *1E*). Finally, a stainless steel soft wire was applied to both ends of the incision. For ZL, we first marked the tendon in a Z-shape and then performed a vertical incision (Figure *1F*). After that, suturing was done the same way as for L-SL (Figure *1G*-H). Next, we made symmetrical transverse half incisions on the markings (Figure *1I*) and extended the tendon (Figure *1J*).

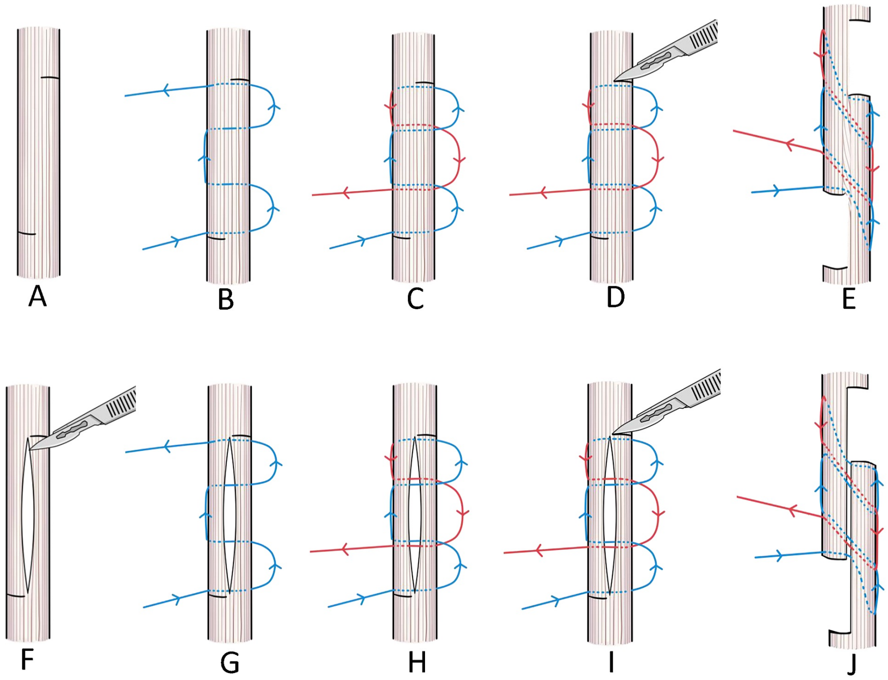

FIGURE 1: The L-SL (upper) and ZL (lower) methods of tendon lengthening

L-SL - locking mechanism suture with sliding lengthening; ZL - Z-lengthening

Finally, two stainless steel soft wires were positioned proximally and distally to allow elongation to be evaluated radiologically. No immobilization was applied, and the animals were kept in a cage. Six rabbits each were sacrificed at one, three, and six weeks postoperatively and evaluated (n=6 in each group for respective time points). Five rabbits were used for radiographical and biomechanical evaluation. The remaining rabbit was used for histological evaluation.

Radiographical evaluation

To measure the amount of extension after tendon lengthening, lateral radiographs of the leg were taken immediately after surgery and one, three, and six weeks postoperatively under anesthesia. Extension length was measured between the proximal and distal wires (Figure *2*).

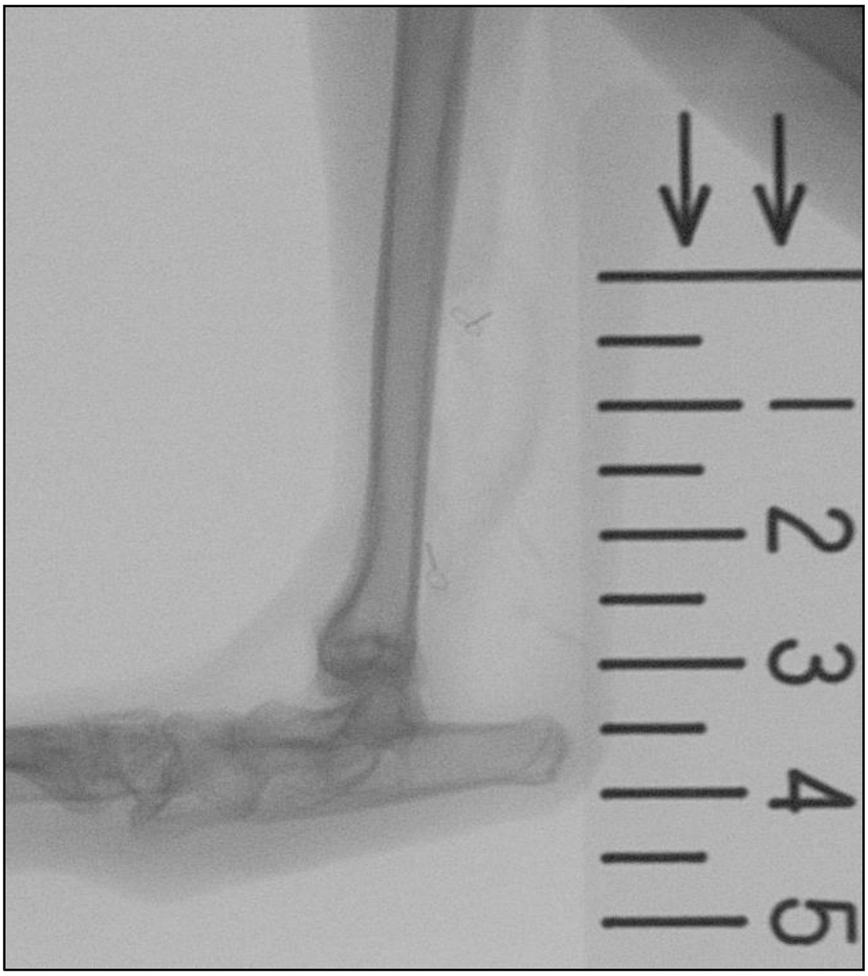

FIGURE 2: Radiograph of a treated ankle with radiopaque wires marking the ends of the incision

Biomechanical evaluation

A digital force gauge FGPX-20 (Nidec-Shimpo Corp., Kyoto, Japan) was used for this study. Following sacrifice, we conducted traction experiments at 20 mm/min until failure and then calculated the ultimate failure load from the load-displacement curve (Figure *3*).

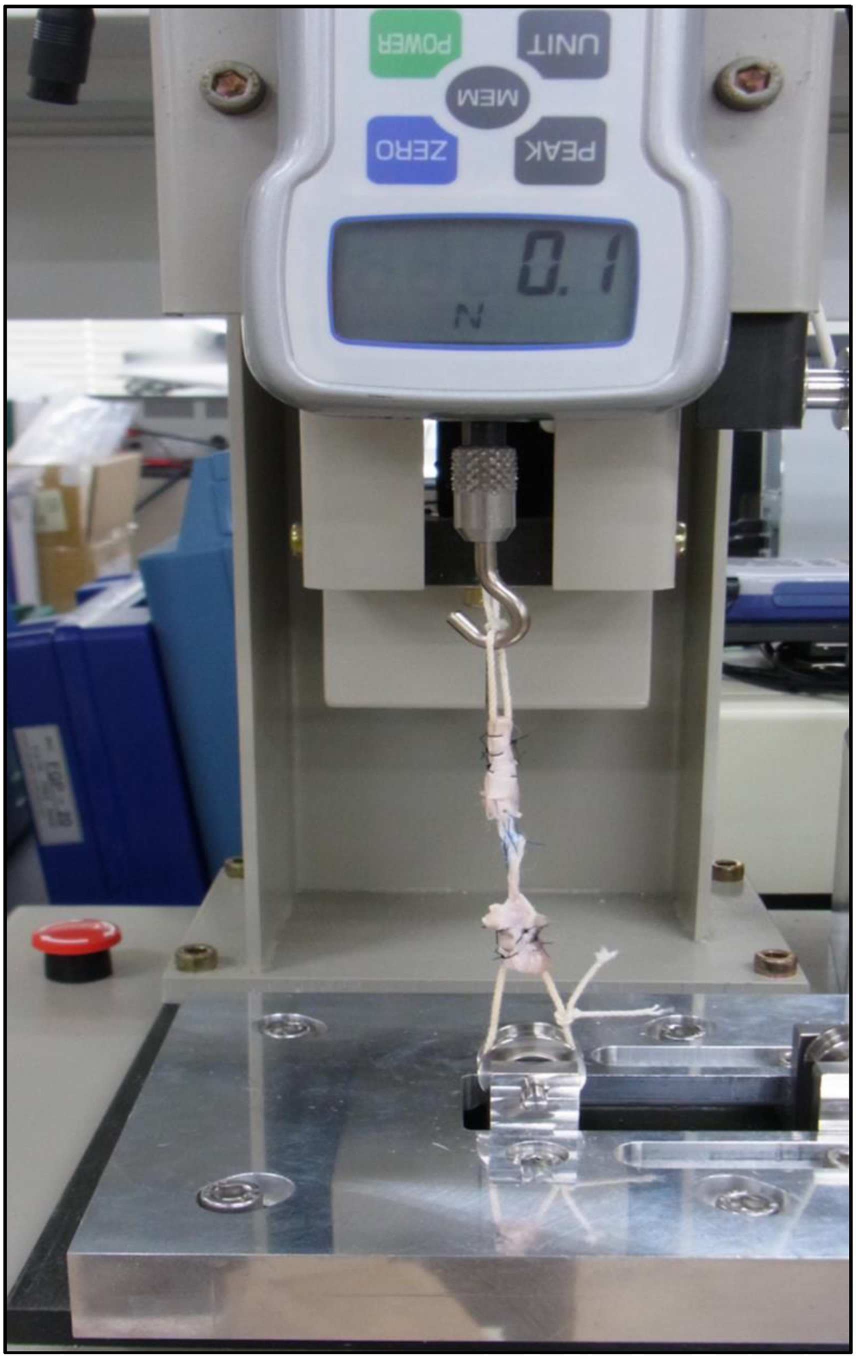

FIGURE 3: Use of a digital force gauge to conduct traction experiments at 20 mm/min until failure

Histology

The tendon specimens were fixed in 4% paraformaldehyde solution for 48 hours at 4°C. They were then immersed in 5% carboxymethyl cellulose (CMC) gel for 10 min, transferred to hexane, and completely frozen using solid carbon dioxide. The tendon specimens were then cut into 6-µm-thick sections with a tungsten carbide blade. The sections were dried at -25°C and stained with hematoxylin and eosin (Kureha Special Laboratory Co., Ltd., Tokyo, Japan).

Statistical analysis

We used Student’s t-tests to compare differences between SL and ZL at each postoperative interval after sacrifice. The Kolmogorov-Smirnov test was used to determine whether or not the data were normally distributed. The Tukey-Kramer method was used to compare differences in the postoperative period after the sacrifice in each group. All statistical analyses were performed with SPSS software (Version 25.0; IBM Inc., Armonk, USA). A p-value of < 0.05 was considered statistically significant.

Results

Radiographical evaluation

The distance between the proximal and distal wires of the L-SL group was significantly lower than that of the ZL group one week postoperatively (p=0.048, Table *1*). In the L-SL group, elongation at one week postoperatively was significantly lower than that at three and six weeks (p=0.047 and p=0.043, respectively). On the other hand, there was no significant difference in the ZL group among all periods (p=0.050).

	One week	Three weeks	Six weeks
L-SL	25.8±8.5	84.0±22.9[b]	85.2±10.2[b]
ZL	60.0±11.9[a]	100.2±14.6	98.6±6.8

TABLE 1: Extension length following tendon lengthening

[a] p<0.05, L-SL versus ZL by student T-test.

[b] p<0.05, one week versus three and six weeks by Tukey-Kramer method.

L-SL - locking mechanism suture with sliding lengthening; ZL - Z-lengthening

Biomechanical evaluation

Although the ultimate failure load of the L-SL group was significantly higher than that of the ZL one and three weeks after lengthening (p=0.001 and p=0.028, respectively, Table *2*), that of both groups increased with time. In the L-SL group, the ultimate failure load at one week postoperatively was significantly lower than that at three and six weeks (p<0.001 and p=0.028, respectively). In the ZL group, there were significant differences at all time points (p<0.001).

	One week	Three weeks	Six weeks
L-SL	7.8±1.2	42.4±2.0[b]	60.1±8.1[b]
ZL	1.0±0.0[a]	35.6±1.5[a,b]	56.4±3.0[b,c]

TABLE 2: Ultimate failure load

[a] p<0.05, L-SL versus ZL by student T-test.

[b] p<0.05, one versus three and six weeks by Tukey-Kramer method.

[c] p<0.05, three versus six weeks by Tukey-Kramer method.

L-SL - locking mechanism suture with sliding lengthening; ZL - Z-lengthening

Histology

In the ZL group, fiber continuity was not confirmed at one week but was confirmed in the L-SL group (Figure *4*). Continuity was confirmed in both the SL and ZL groups at three and six weeks postoperatively.

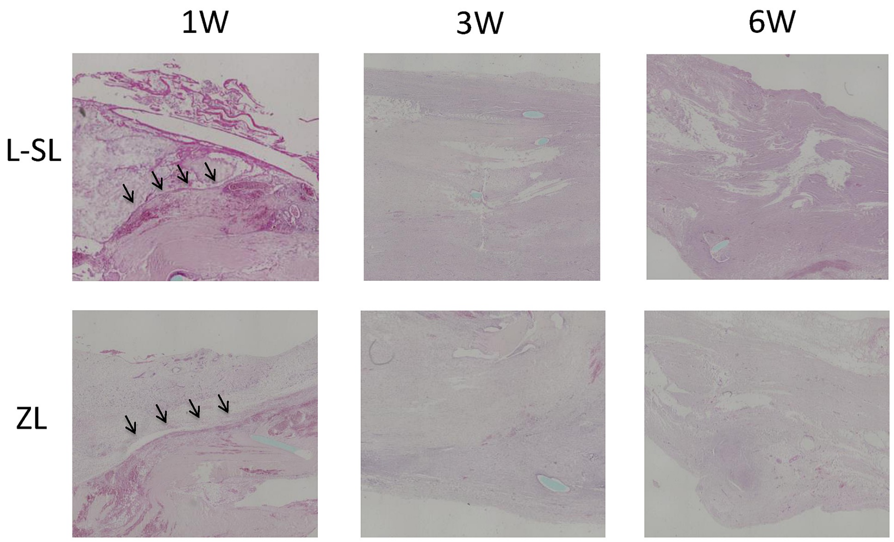

FIGURE 4: Histological sections at one, three, and six weeks showing early one-week fiber continuity with L-SL (arrows, first row)

L-SL - locking mechanism suture with sliding lengthening; ZL - Z-lengthening; W - week

Discussion

Previous studies have suggested that earlier mobilization after tendon lengthening can prevent adhesions and contracture, as a result, lead to quicker recovery [5, 17]. However, earlier mobilization may also cause calcaneal gait with overlengthening [18]. To improve these issues we have investigated L-SL. In this study, L-SL had higher mechanical properties than ZL one week and three weeks postoperatively in vivo rabbit model. In addition, continuity of tendon tissues was observed in L-SL one week after the operation. These results suggest that L-SL may have higher mechanical properties due to the maintenance of continuity in the early postoperative period. L-SL may allow earlier mobilization than ZL in the clinical setting.

Overlengthening frequently occurs after Achilles tendon lengthening [19, 20]. Overlengthening of the Achilles tendon causes crouched or calcaneus gait. In our study, we evaluated whether L-SL prevented overlengthening. L-SL resulted in significantly less elongation than ZL one week after the operation. L-SL may help to sustain the tendon length after lengthening, albeit its effect was examined over only a short period.

Several limitations of this study warrant mention. First, the results obtained from small animal models are not always relevant for human applications. Additional studies using large animal models are therefore important, and essential to confirm our present findings. Second, regarding the animals' lack of immobilization after tendon lengthening, overlengthening could occur via animal ambulation. Further investigation using an animal model with fixation to immobilize the leg is needed.

Conclusions

In conclusion, L-SL had higher mechanical property in vivo. This property may allow early active exercise in clinical settings.

Additional Information

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** The study protocol was approved by our institutional Animal Care Committee. Issued protocol number 2019-129. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. Shore BJ, White N, Kerr Graham H: Surgical correction of equinus deformity in children with cerebral palsy: a systematic review. J Child Orthop. 2010, 4:277-290. 10.1007/s11832-010-0268-4
2. Wren TA, Rethlefsen S, Kay RM: Prevalence of specific gait abnormalities in children with cerebral palsy: influence of cerebral palsy subtype, age, and previous surgery. J Pediatr Orthop. 2005, 25:79-83.
3. Dietz FR, Albright JC, Dolan L: Medium-term follow-up of Achilles tendon lengthening in the treatment of ankle equinus in cerebral palsy. Iowa Orthop J. 2006, 26:27-32.
4. DeHeer PA: Equinus and lengthening techniques. Clin Podiatr Med Surg. 2017, 34:207-227. 10.1016/j.cpm.2016.10.008
5. Lin CL, Lin CJ, Huang MT, Su WR, Wu TT: Mesh Achilles tendon lengthening--a new method to treat equinus deformity in patients with spastic cerebral palsy: surgical technique and early results. J Pediatr Orthop B. 2013, 22:14-19. 10.1097/BPB.0b013e32835717b0
6. Blasier RD, White R: Duration of immobilization after percutaneous sliding heel-cord lengthening. J Pediatr Orthop. 1998, 18:299-303.
7. Yngve DA, Chambers C: Vulpius and Z-lengthening. J Pediatr Orthop. 1996, 16:759-764.
8. Li Z, Zhang N, Wang Y, Cao S, Huang Z, Hu Y: Stair-shaped Achilles tendon lengthening in continuity - A new method to treat equinus deformity in patients with spastic cerebral palsy. Foot Ankle Surg. 2019, 25:165-168. 10.1016/j.fas.2017.10.012
9. Renshaw TS, Green NE, Griffin PP, Root L: Cerebral palsy: orthopaedic management. Instr Course Lect. 1996, 45:475-490.
10. Rattey TE, Leahey L, Hyndman J, Brown DC, Gross M: Recurrence after Achilles tendon lengthening in cerebral palsy. J Pediatr Orthop. 1993, 13:184-187.
11. Kim HT, Oh JS, Lee JS, Lee TH: Z-lengthening of the Achilles tendon with transverse skin incision. Clin Orthop Surg. 2014, 6:208-215. 10.4055/cios.2014.6.2.208
12. Hashimoto K, Kuniyoshi K, Suzuki T, Hiwatari R, Matsuura Y, Takahashi K: Biomechanical study of the digital flexor tendon sliding lengthening technique. J Hand Surg Am. 2015, 40:1981-1985. 10.1016/j.jhsa.2015.06.120
13. White J: Torsion of the Achilles tendon: its surgical significance. Arch Surg. 1943, 46:784-787. 10.1001/archsurg.1943.01220110200033
14. Matsuo R, Yamamoto T, Ikehara A, Nakamura O: Effect of salivation on neural taste responses in freely moving rats: analyses of salivary secretion and taste responses of the chorda tympani nerve. Brain Res. 1994, 649:136-146. 10.1016/0006-8993(94)91057-X
15. Matsuo T, Hara H, Tada S: Selective lengthening of the psoas and rectus femoris and preservation of the iliacus for flexion deformity of the hip in cerebral palsy patients. J Pediatr Orthop. 1987, 7:690-698.
16. Matsuo T, Lai T, Tayama N: Combined flexor and extensor release for activation of voluntary movement of the fingers in patients with cerebral palsy. Clin Orthop Relat Res. 1990, 250:185-193.
17. Schuind F, Garcia-Elias M, Cooney WP, 3rd, An KN: Flexor tendon forces: in vivo measurements. J Hand Surg Am. 1992, 17:291-298. 10.1016/0363-5023(92)90408-H
18. Garbarino JL, Clancy M: A geometric method of calculating tendo Achillis lengthening. J Pediatr Orthop. 1985, 5:573-576. 10.1097/01241398-198509000-00013
19. Etnyre B, Chambers CS, Scarborough NH, Cain TE: Preoperative and postoperative assessment of surgical intervention for equinus gait in children with cerebral palsy. J Pediatr Orthop. 1993, 13:24-31.
20. Gaines RW, Ford TB: A systematic approach to the amount of Achilles tendon lengthening in cerebral palsy. J Pediatr Orthop. 1984, 4:448-451. 10.1097/01241398-198408000-00011