Comparison of Treatment Results for Mallet Finger Fractures in Children Between Low-Intensity Pulsed Ultrasound Stimulation and Ishiguro's Method

HAND
2018, Vol. 13(1) 80–85
© The Author(s) 2017
Reprints and permissions:
sagepub.com/journalsPermissions.nav
DOI: 10.1177/1558944717692095
hand.sagepub.com

Tsuyoshi Ota¹, Soichiro Itoh², and Yoshihiko Matsuyama¹

Abstract

Background: We compared the treatment results for displaced mallet finger fractures in children between low-intensity pulsed ultrasound (LIPUS) stimulation and Ishiguro's method, which involves extension block and arthrodesis of the distal interphalangeal (DIP) joint with pinning. **Methods:** Eleven cases (5 females and 6 males; average age, 13.5 years) of mallet finger were operated with Ishiguro's method, and 8 cases (3 females and 5 males; average age, 13.0 years) were treated with LIPUS stimulation. Lateral radiographs were used to determine the distance of fragment displacement and the percentage of the articular surface involved in the fragments. Functional outcomes in flexion and extension and those estimated using Crawford's evaluation criteria at the final visits were assessed in each group. **Results:** The duration needed for fracture healing was longer, however, active extension and flexion of the DIP joint were significantly larger in the LIPUS group compared with those in the pinning group. Functional recovery was excellent in all cases in the LIPUS group; however, recovery was good in 3 cases and excellent in 8 cases in the pinning group. Extension of the DIP joint was significantly larger when pins were removed in 35 or lesser days postoperatively compared with cases in which pin fixation was continued for more than 35 days. **Conclusions:** LIPUS therapy may be recommended as an option to treat type I mallet finger in children for whom initiation of treatment was delayed up to 8 weeks. When Ishiguro's method is applied to the displaced mallet fracture in children, arthrodesis of the DIP joint for more than 5 weeks should be avoided to prevent flexion contracture.

Keywords: mallet finger, children, Ishiguro's method, low-intensity pulsed ultrasound (LIPUS)

Introduction

Epiphyses of the distal phalanges begin to ossify from 1 to 3 years of age and ends in 13 to 16 years of age.⁵ Prior to epiphyseal closure, Salter-Harris type I or II fractures occur through the growth plate or through the juxtaepiphyseal region 1 to 2 mm distal from the growth plate. Because terminal extensor tendons insert into the dorsal portion of the distal phalanx, the epiphysis, mallet finger deformity occurs as a result of Salter-Harris type II injury caused by an axial load to the tip of an extended finger, leading to forced flexion at the distal interphalangeal (DIP) joint. Proposed indication of the surgical treatment of mallet finger fractures is the involvement of greater than 30% of the intra-articular surface or association with volar subluxation of the distal phalanx.¹⁰ The Ishiguro method, which involves extension block and arthrodesis of the DIP joint with pinning in the reduced position,⁷ is an easier and less invasive procedure to treat mallet fractures when compared with other currently available operative methods—pull-out wiring,¹⁸

compression pin fixation,¹⁷ hook plate fixation,¹⁵ and microcrew fixation.⁹ The Ishiguro method facilitates closed reduction and permits indirect anatomical reduction of the fracture. Therefore, this method may be applied to cases of displaced mallet fracture in children. However, our extensive study of earlier research in this area indicates that the effectiveness and safety of this method have not been proven as yet for children. For all mallet fractures, although conservative therapy is preferable for treatment of patients prior to epiphyseal closure to prevent premature closure of the growth plate, in this case, continuous dorsal, volar, or stack splinting as long as 8 weeks is needed.¹³ Therefore, a

¹Saiseikai Kawaguchi General Hospital, Japan

²Tokyo Medical and Dental University, Japan

Corresponding Author:

Soichiro Itoh, Department of Inorganic Materials, Institute of Biomaterials and Bioengineering, Tokyo Medical and Dental University, 2-3-10 Kanda-Surugadai, Chiyoda, Tokyo 101-0062, Japan.
Email: itoso.gene@gmail.com

method alternative to splinting, which does not limit the active range of motion (ROM), is needed to improve the compliance difficulty of splints, to keep the splint in the appropriate position, in children, especially for whom initiation of treatment was delayed. There are many reports that suggest that low-intensity pulsed ultrasound (LIPUS) systems are an option for treating fracture nonunion. Prospective clinical trials demonstrated LIPUS was clinically effective in healing of delayed union,¹⁴ nonunion,^{3,12} and fresh fractures.^{4,11} The LIPUS system (EXOGEN1; Bioventus, LLC, Durham, North Carolina) has hence been approved by the US Food & Drug Administration as a class III noninvasive device. However, there are very few studies that deal with the use of LIPUS to treat finger and carpal fractures.^{2,6} In this study, we compared the treatment results between LIPUS stimulation and Ishiguro's method for displaced mallet finger fractures in children.

Patients and Methods

From January 2002 to April 2008, 11 cases (5 females and 6 males; average age, 13.5 years; range, 11-15 years) of mallet finger fractures were operated on with Ishiguro's method. The indication for surgery was the presence of a displaced fracture involving more than 30% of the articular surface and an arising gap or step-off regardless of the size. Between May 2008 and March 2014, 8 cases (3 females and 5 males; average age, 13.0 years; range, 11-15 years) of the fractures were treated using a LIPUS system (SAFHS 4000J; Teijin, Tokyo, Japan). All these children suffered mallet fractures during sports activities. Informed written consents were obtained from parents of all children who were treated with either Ishiguro's method or LIPUS stimulation. All procedures in this study were in accordance with the ethical standards of the committee responsible for approving human experimentation at the authors' institution and with the Helsinki Declaration of 1975 as revised in 2008.

Surgical Procedure of Ishiguro's Method

Surgery was performed under digital nerve block anesthesia and an image intensifier control. With traction of the distal fragment of the distal phalanx, the DIP joint was maintained in maximum flexion passively, and the first 1.0-mm Kirschner wire (K-wire) was passed directly above the dorsal side of bone fragment and inserted into the condyle of the middle phalanx for extension block. The second 1.0-mm K-wire was inserted into the condyle of the middle phalanx from the tip of the distal phalanx to fix the DIP joint following closed reduction by extending the DIP joint. The fixation angle of the joint was less than 20° to keep reduction without gap of the articular surface. After immobilization of the DIP joint with a splint for 4 to 5 weeks, 2 pins were removed, and active DIP joint exercises were encouraged.

Treatment With a LIPUS Device

LIPUS stimulation was started once per day for 20 minutes under the following parameter configuration until bone union: average intensity I, 30 mW/cm²; ultrasound frequency F, 1.5 MHz; signal impulse duration, 200 μs; repetition rate, 1 kHz; effective radiating area, 3.88 cm²; and temporal average power, 117 mW. Splints were not used during LIPUS therapy because the patients hoped an early return to play. They were recommended to perform ROM exercises and allowed to play carefully without jamming their finger. All patients treated with LIPUS stimulation did not have any period of immobilization nor prior treatment of any kind at the time of their injury before undergoing LIPUS therapy.

Preoperative lateral radiographs were used to determine the distance of fragment displacement from the initial position (gap) and the percentage of the articular surface involved in the fragments. The cases in each group were classified according to Wehbe and Schneider's classification.¹⁶ No patient had any medical history of bone diseases that could have influenced treatment results. Radiographs were obtained every week until bone union was verified and then every 2 weeks until the finger's functional improvements plateaued. By evaluating loss-of-fracture margins or development of a bone-to-bone callus bridge, bone union was defined when bridging of more than 3/4 of involved cortices was completed with a lateral view.⁸ Functional outcomes in flexion and extension and those estimated using Crawford's evaluation criteria¹ at the final visits were assessed in each group.

Baseline data included the age, duration from injury, and gap and the percentage of the articular surface involved in the fragments, which were calculated using the lateral radiographs in both the LIPUS application group (LIPUS group) and the Ishiguro's method applied group (pinning group). These data were compared using the Mann-Whitney test. Then, treatment results, including duration needed for fracture healing, mean follow-up duration (treatment period), active extension (Ext) and flexion (Flex) of the DIP joint, and step-off of the articular surface at the final follow-up in the groups, were compared using the Mann-Whitney test. The population variance among these investigation items in each group, as well as duration until pin removal in the pinning group, was compared using the Bartlett test. The existence of a difference in the population mean was determined using 1-way analysis of variance (ANOVA). Thereafter, the statistical significance between these values in the groups was detected using the Pearson product-moment correlation coefficient. Furthermore, active Ext and Flex of the DIP joint in the 2 groups, in which pin fixation was continued for more than 35 days and pins were removed in 35 or lesser days after the operation, were compared using the Mann-Whitney test. A *P* value of <.05 was considered to be statistically significant.

Table 1. Basic Information of Patients in the LIPUS Application Group and the Ishiguro Method Applied Group.

	LIPUS	Pinning
Age, y	13.0 ± 1.8	13.5 ± 1.4
Duration from injury, wk	7.2 ± 3.4**	2.3 ± 1.5**
Gap, mm	1.3 ± 0.6**	0.6 ± 0.3**
Articular surface, %	50.8 ± 7.5	43.5 ± 11.8

Note. The values are average ± standard deviation. LIPUS = low-intensity pulsed ultrasound.

** $P < .01$.

Table 2. Number of Patients in the Groups Classified According to Wehbe and Schneider's Classification.

Classification	LIPUS	Pinning
Type I (no joint subluxation)		
Subtype A	0	1
Subtype B	8	10
Subtype C	0	0
Type II (subluxation of DIP joint)		
Subtype A	0	0
Subtype B	0	0
Subtype C	0	0
Type III (physis of the distal phalanx involved)		
Subtype A	0	0
Subtype B	0	0
Subtype C	0	0

Note. Subtype A: <1/3 of the articular surface. Subtype B: 1/3 to 2/3 of the articular surface. Subtype C: >2/3 of the articular surface. LIPUS = low-intensity pulsed ultrasound; DIP = distal interphalangeal.

Results

Basic information regarding the patients is summarized in Table 1. The duration until treatment from injury was significantly longer, and the preoperative gap between fragments was longer in the LIPUS group compared with those in the pinning group (each $P < .01$). There was no significant difference in the age and the percentage of the involved articular surface in the groups. According to Wehbe and Schneider's classification, there were 8 type IB fractures (no DIP joint subluxation with a fragment including 1/3-2/3 of the articular surface) in the LIPUS group, and 1 type IA (no DIP joint subluxation with a fragment including less than 1/3 of the articular surface) and 10 type IB fractures in the pinning group (Table 2). Treatment results are summarized in Table 3. In all cases, complete bone union was obtained in each group. The duration needed for fracture healing ($P < .01$) and mean treatment period ($P < .05$) were significantly longer in the LIPUS group compared with those in the pinning group. The active Ext and Flex of the

Table 3. Treatment Results of LIPUS Stimulation and Ishiguro's Method.

	LIPUS	Pinning
Fracture healing, wk	11.0 ± 4.0**	5.8 ± 0.4**
Treatment period, wk	13.0 ± 4.1*	9.5 ± 2.2*
Duration of pinning, d	—	36.6 ± 4.1
Ext at the last visit, degree	-0.4 ± 8.2**	-9.1 ± 6.2**
Flex at the last visit, degree	83.3 ± 7.5**	68.2 ± 7.5**
Step-off, mm	0.3 ± 0.2	0.4 ± 0.3
Complications	None	None

Note. The values are average ± standard deviation. LIPUS = low-intensity pulsed ultrasound; Ext = extension; Flex = flexion.

* $P < .05$. ** $P < .01$.

Table 4. Active Ext and Flex of the Distal Interphalangeal Joint in the 2 Groups, in Which Pin Fixation Was Continued for More Than 35 Days and Pins Were Removed in 35 or Lesser Days After the Operation.

	>35 d	≤35 d
Ext at the last visit, degree	-13.3 ± 4.1*	-4.0 ± 3.8*
Flex at the last visit, degree	66.7 ± 8.2	70.0 ± 7.1

Note. The values are average ± standard deviation. Ext = extension; Flex = flexion.

* $P < .05$.

DIP joint at the final follow-up, however, were significantly larger in the LIPUS group compared with those in the pinning group (each $P < .01$). There was no significant difference in the step-off of the articular surface in the groups. There was no correlation between examined items in the LIPUS group. However, duration until pin removal correlated positively with duration needed for fracture healing ($P < .05$) and negatively with the active Ext of the DIP joint ($P < .01$) in the pinning group. These results suggest that the period of pinning is prolonged when union of fractures delays and Ext limitation of the DIP joint follows as a result. Furthermore, the active Ext of the DIP joint was significantly larger in the group in which pins were removed in 35 or lesser days after the operation than in the group in which pin fixation was continued for more than 35 days ($P < .05$; Table 4). Functional recovery determined using Crawford's evaluation was excellent (full DIP joint Ext and Flex, without pain) in all 8 cases in the LIPUS group; however, functional recovery was good in 3 (Ext deficit of less than 10° and full Flex of DIP joint, without pain) and excellent in 8 cases in the pinning group (Table 5). No complications, including growth disturbance, deformity of bone, skin necrosis, and nail deformity, were observed in the groups.

We present radiographs of a representative case in each group.

Table 5. Number of Patients Evaluated by Crawford's Evaluation Criteria.

Classification	LIPUS	Pinning
Excellent (full distal joint extension, full flexion, no pain)	8	8
Good (0°-10° of extension deficit with full flexion, no pain)	0	3
Fair (10°-25° of extension deficit, any flexion, loss, no pain)	0	0
Poor (>25° of extension deficit, persistent pain)	0	0

Note. LIPUS = low-intensity pulsed ultrasound.

Figure 1. The demonstrable radiographs in the LIPUS group. (a) At the first visit, the dorsal fragment, including 59.5% of the articular surface, displaces 2.39 mm. (b) After 9 weeks of LIPUS stimulation, prominent new bone has been formed into the gap, and this case is diagnosed as a bone union.

Note. LIPUS = low-intensity pulsed ultrasound.

Case 1 in the LIPUS Group

A 12-year-old male who was injured playing baseball visited our outpatient clinic 10 weeks after injury with complaint of long-finger swelling and pain of the nondominant hand. The dorsal fragment, including 59.5% of the articular surface, displaced 2.4 mm on the radiograph taken at the first visit; however, prominent new bone formation progressed with LIPUS stimulation until bone union was obtained as early as 9 weeks (Figure 1). The functional result in this case was evaluated as excellent.

Case 2 in the Pinning Group

A 11-year-old female who was injured playing dodgeball visited our outpatient clinic the day after injury with a complaint of index-finger swelling and pain of the dominant hand. The dorsal fragment, including 40.9% of the articular

Figure 2. The demonstrable radiographs in the pinning group. (a) The dorsal fragment including 40.9% of the articular surface displaces 0.4 mm on the radiograph taken at the first visit. (b) Reduction and fixation with Ishiguro's method is performed; the distal interphalangeal joint is fixed with 12° flexion. (c) Complete bone union is obtained without gap after 6 weeks.

surface, displaced 0.4 mm on the radiograph taken at the first visit (Figure 2). She was treated with Ishiguro's method; the DIP joint was fixed with 12° flexion. After immobilization of the joint with a splint for 4 weeks, 2 pins were removed. Complete bone union was obtained after 6 weeks, and the functional result was excellent.

Discussion

For displaced mallet fractures involving more than 30% of the articular surface or fractures with palmar subluxation, surgical treatment is indicated. However, considering that 41% of surgically treated mallet fractures developed post-operative complications such as marginal skin necrosis on the dorsal aspect of the distal phalanx, recurrent extension lag, permanent nail deformities, transient infections along the K-wires and pull-out steel wires, and osteomyelitis,⁸ currently available methods including pull-out wiring, compression pin fixation, hook plate fixation, and microscrew fixation may affect children's return to play after operation. In contrast to this, Ishiguro's method is easier and less invasive when compared with these procedures, and it facilitates closed reduction and permits indirect anatomical reduction of the fracture in adults. Considering that no complications, including disturbance of growth, deformity of bone, skin necrosis, and nail deformity, were observed in the pinning group in this study, this method may be applied to cases of displaced mallet fracture in children as a safe and reliable procedure.

On the other hand, LIPUS is a painless therapy performed daily for 20 minutes at home by patients

themselves without surgical procedure. In addition, LIPUS may be a favorable tool for athletes, especially those who are children. However, very few reports of LIPUS treatment for finger fractures can be found. To the best of our knowledge, the report of Huber et al⁶ is the only one dealing with the use of LIPUS to treat nonunion of the finger. They reported a case successfully treated with LIPUS, a 19-year-old man with a nonunion of his ring finger after first treatment with K-wire fixation, and they concluded that LIPUS may be considered as an option to treat nonunion in fractures of the hand, especially because it is a soft tissue conserving method with a good functional result. In our study, application of LIPUS treatment was delayed significantly, and accordingly, the duration needed for fracture healing and treatment period were longer in the LIPUS-applied cases compared with cases treated with Ishiguro's method. However, bone union was obtained in all cases with minimal displacement, and the treatment results, including functional outcomes in the LIPUS group, were superior to those in the pinning group. This result may arise from treatment without splinting that can allow active motion during therapy. Considering that we could successfully treat these patients without a splint during LIPUS stimulation, it is suggested that osteoid, the unmineralized organic portion of the bone matrix, was already formed in the gap during the waiting period and its maturation to the bone tissue could be enhanced by LIPUS stimulation. In contrast, Ishiguro's method may be recommended as a safe and reliable procedure. However, ROM limitation occurred in some cases. Ext of the DIP joint decreased significantly in the group in which pin fixation was continued for more than 35 days. Considering that average fracture healing time was 5.8 weeks, fixation of the DIP joint for more than 5 weeks should be avoided to a maximum extent when Ishiguro's method is applied to the displaced mallet fracture even in children.

The major limitations of our study are small sample numbers in the groups and lack of a control group. The number of cases of displaced mallet finger fracture indicated for operation in children is few, and our extensive study of the existing research indicates that comprehensive reports of postoperative results of Ishiguro's method in children are not available. For such cases, conservative therapy including splinting could not be chosen as a control. Instead, we compared our results with those of cases treated with LIPUS stimulation, for whom initiation of treatment was delayed. Although it is hard to compare the results with a control group without LIPUS application, considering that we could successfully treat the patients without a splint using LIPUS stimulation, this may be a good therapeutic option for mallet finger fracture in children in delayed diagnosis. Meanwhile, we did not experience major complications in either the pinning or LIPUS group in this study. This may be due to small

sample numbers in the groups. Therefore, we would like to continue to collect data of therapeutic results to clarify these issues.

Conclusion

LIPUS therapy may be recommended as an option to treat type I mallet finger fracture in children for whom initiation of treatment was delayed up to 8 weeks. When Ishiguro's method is applied to the displaced mallet fracture in children, arthrodesis of the DIP joint for more than 5 weeks should be avoided to prevent flexion contracture.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

All procedures in this study were in accordance with the ethical standards of the committee responsible for approving human experimentation at the authors' institution and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent

Informed written consents were obtained from the parents of all children who were treated with either Ishiguro's method or low-intensity pulsed ultrasound (LIPUS) stimulation.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. Crawford GP. The molded polythene splint for mallet finger deformities. *J Hand Surg Am.* 1984;9:231-237.
2. Farkash U, Bain O, Gam A, et al. Low-intensity pulsed ultrasound for treating delayed union scaphoid fractures: case series. *J Orthop Surg Res.* 2015;10:72. doi:10.1186/s13018-015-0221-9.
3. Gebauer D, Mayr E, Orthner E, et al. Low-intensity pulsed ultrasound: effects on nonunions. *Ultrasound Med Biol.* 2005;31:1391-1402.
4. Heckman JD, Ryaby JP, McCabe J, et al. Acceleration of tibial fracture-healing by non-invasive, low-intensity pulsed ultrasound. *J Bone Joint Surg Am.* 1994;76:26-34.
5. Hensinger RN. *Standards in Pediatric Orthopedics.* New York, NY: Raven Press; 1986.
6. Huber M, Prantl L, Gehmert S. Successful treatment of nonunion in severe finger injury with low-intensity pulsed

- ultrasound (LIPUS): a case report. *J Med Case Rep*. 2012;6:209. doi:10.1186/1752-1947-6-209.
7. Ishiguro T, Itoh Y, Yabe Y. Extension block with Kirschner wire for fracture dislocation of the distal interphalangeal joint. *Tech Hand Up Extrem Surg*. 1997;1:95-102.
 8. Kang HJ, Shin SJ, Kang ES. Complications of operative treatment for mallet fractures of the distal phalanx. *J Hand Surg Br*. 2001;26:28-31.
 9. Kronlage SC, Faust D. Open reduction and screw fixation of mallet fractures. *J Hand Surg Br*. 2004;29B:135-138.
 10. Lubahn JD, Hood JM. Fractures of the distal interphalangeal joint. *Clin Orthop Relat Res*. 1996;327:12-20.
 11. Mayr E, Frankel VH, Ruter A. Ultrasound—an alternative healing method for nonunions? *Arch Orthop Trauma Surg*. 2000;120:1-8.
 12. Nolte PA, van der Krans A, Patka P, et al. Low-intensity pulsed ultrasound in the treatment of nonunions. *J Trauma*. 2001;51:693-703.
 13. Rettig AC. Closed tendon injuries of the hand and wrist in the athlete. *Clin Sports Med*. 1992;11:77-99.
 14. Schofer MD, Block JE, Aigner J, et al. Improved healing response in delayed unions of the tibia with low-intensity pulsed ultrasound: results of a randomized sham-controlled trial. *BMC Musculoskelet Dis*. 2010;11:229. doi:10.1186/1471-2474-11-229.
 15. Teoh LC, Lee JYL. Mallet fractures: a novel approach to internal fixation using hook plate. *J Hand Surg Am*. 2007;32:24-30.
 16. Wehbe MA, Schneider LH. Mallet fractures. *J Bone Joint Surg Am*. 1984;66:658-669.
 17. Yamanaka K, Sasaki T. Treatment of mallet fractures using compression fixation pins. *J Hand Surg Am*. 1999;24:358-360.
 18. Zhang X, Meng H, Shao X. Pull-out wire fixation for acute mallet finger fractures with K-wire stabilization of the distal interphalangeal joint. *J Hand Surg Am*. 2010;35:1864-1869.