CLINICAL ARTICLE

A New Method of Nice Knot Elastic Fixation for Distal Tibiofibular Syndesmosis Injury

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Objective: The distal tibiofibular syndesmosis (DTS) is a fretting joint and it is still a hot issue how to satisfy strong internal fixation while allowing fretting. This study described and evaluated a new method for elastic fixation of DTS injury with Nice Knot.

Methods: The study was designed as a retrospective study. Between June 2020 and June 2021, 31 patients who were diagnosed with ankle fracture and DTS injury without additional orthopedic injuries were enrolled in this case series. The study included 22 males and nine females, with an average age of 34.71 ± 14.66 years. All patients were treated with Nice Knot binding for DTS. Surgical time, length of stay, time of DTS fixation, total weight-bearing time, complications, imaging parameters, and functional scores at follow-up were recorded. Paired sample *t*-tests or single factor analyses of variance were used at intra-group comparison.

Results: All patients completed surgery with normal syndesmotic parameters. The recovery of DTS injury was verified by Hook and lateral malleolus rotation tests. The average follow-up time was 15.97 ± 3.30 months. Only one case showed superficial infection after surgery, and the wound healed after symptomatic treatment. In terms of imaging, there were no significant differences in tibiofibular clear space (TFCS), tibiofibular overlap distance (TFOS), medial clear space (MCS), and superior clear space (SCS) immediately and at different follow-up points after surgery. All obtained excellent and good outcomes according to the AOFAS score at least follow-up after surgery.

Conclusions: Nice Knot elastic fixation of DTS injury is firm and stable while maintaining the physiological micromotion of the ankle joint.

Key words: Ankle joint; Elastic fixation; Physiological micromotion; Syndesmotic parameter

Introduction

The distal tibiofibular syndesmosis (DTS) is composed of multiple ligaments and bony structures, which is a common site of orthopedic disease clinically. Accounting for 1%–11% of the total number of patients with ankle joint injury have DTS injury.[1] About 5%–10% of ankle sprains and 23% of ankle fractures are associated with DTS injury.[2] The injury of DTS can cause disorders of ankle joint mechanics and changes in the contact area of the tibiotalar joint surface, resulting in instability of the ankle joint. Dattani *et al.* pointed out that if the talus is moved outward by 1 mm, the contact area of the tibialis talus joint is reduced by 42%, thus aggravating the articular cartilage wear.[3] Petruccelli *et al.* calculate pressure, loading, contact time and the force–time integral to build a mathematical model and dynamic pedography by dividing the foot into 10 parts such as heel, thumb and middle foot. It is pointed that even the nonarticular fractures caused by translation, rotation, and shortening of non-joint areas can lead to overall deformity of the leg, changes in foot loading, and even joint disease.[4] Injuries of DTS, whether or not combined with ankle fractures, should be accurately reduced and fixed to prevent the occurrence of long-term traumatic arthritis.

Tibiofibular screws were the most commonly used clinical method for the treatment of DTS injury in the past. They could provide a strong fixation effect, but some studies showed it required a second operation to remove the implant, and complications such as screw fracture,

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joint stiffness, osseous fusion, along with poor prognosis, existed.[1,5–7] The DTS is a fretting joint with an average of 0.86, 0.38, and 0.29 mm fretting at the coronal, axial, and sagittal positions, respectively, and the fibula rotates about 1° on average relative to the tibia.[8] However, the DTS with screw fixation has a range of only 0.5°–2.5°.[9] The tibiofibular notch is located on the posterolateral side of the distal tibia, with an angle of about 30°. There is little variation in depth and position.[10] Elgafy *et al.* found that about 67% of the tibiofibular notches are >4 mm and crescent-shaped, and 33% are ≤4 mm, rectangular, and 1.0–7.5 mm deep, with an average of 3.5 mm, which means that the DTS is prone to poor reduction.[10] If the screw placement deviates, the fibula will not match the original fibula notch. According to Gardner *et al.*, the proportion of poor reduction of DTS can reach 30%–50%.[11] Therefore, it is gradually replaced by elastic fixation which is more consistent with the physiological function of the ankle joint. Suture button elastic fixation has been proven efficient by not only achieving strong internal fixation but also by retaining joint micromotion and avoiding the secondary removal of internal fixation—though it also causes complications such as internal fixation device sink and osteolysis, as well as increasing the tibial borehole to a certain extent.[5,12–14]

Nice Knot is a double-stranded sliding knot described by Boileau *et al.*, which has the characteristics of firm fixation, good toughness, and fatigue resistance.[15] It has unique advantages in binding hard objects. Compared with the traditional planar non-sliding knot, it is not easy to slip and can achieve relatively high tension.[16,17] Nice Knot has been applied to patellar transverse fracture and mid-clavicle fracture and achieved good clinical results.[18,19] Peeters *et al.* pointed out in a review that Nice Knot has a significantly higher load to failure compared with metal ring binding, even prophylactic hip restraints and tibial tubercle osteotomy with absorbable suture fixation in revision total knee arthroplasty can bear greater stress.[20]

The purpose of this study was: (i) to assess the feasibility of the Nice Knot in treating DTS injury; (ii) to evaluate the safety of the surgery with Nice Knot fixation; and (iii) to evaluate the radiological and clinical outcomes in patients using the technique.

Materials and Methods

Inclusion and Exclusion Criteria

This study has been approved by the local ethics committee (YX2022-111), and all patients signed informed consent. The inclusion criteria were as follows: (i) preoperative X-ray showed a DTS injury or the intraoperative Hook test and external rotation stress test were positive,[21] (ii) age 15–65 years; (iii) all patients gave informed consent to the treatment regimen; (iv) the DTS was bound by Nice Knot during the operation: (v) the follow-up data were complete and lasted for >1 year. The exclusion criteria were: (i) open fracture; (ii) old fracture; and (iii) a dysfunctional ankle joint before injury.

Patient Demographics

From June, 2020 to June, 2021, a total of 31 patients with ankle fracture and DTS injury were enrolled in this study. The mean age was 34.71 ± 14.66 years old, the mean body mass index was 25.61 ± 4.67. There were 10 cases with a history of smoking. There were 22 male and nine female patients. Thirteen injuries occurred on the left side and 18 on the right. The causes of injury were fall from a height (eight cases), traffic accident (15 cases), sports sprain (five cases), and injury by direct violence (three cases). According to the Danis–Weber classification of ankle fracture, there are 10 cases of B, 14 cases of C1, and seven cases of C2 type. According to the Lauge–Hansen classification of ankle fracture, there were 12 cases of pronation-external rotation, 15 cases of pronation-abduction, and four cases of supination-external rotation. All patients were treated with Nice Knot elastic fixation for DTS injury.

Fig. 1 Schematic representation of wire crossover. It is used to pull back the suture through the bone marrow canal.

Operation Procedure

Anesthesia and Position

All surgeries were performed by the same group of physicians. All patients were given epidural or general anesthesia, and a tourniquet was used for routine disinfection towels. The lateral incision of the ankle joint and the standard incision of the medial malleolus were used, and the "4" font position and the posterior medial incision were adopted in the patients with posterior malleolus fracture.

Surgical Technique

After reduction and rigid internal fixation, the broken end of the fracture was reconfirmed by Hook and lateral malleolus rotation tests under C-arm X-ray by maintaining 5° dorsal extension of the ankle, restoring the inferior tibiofibular space with a point reduction forceps, and temporarily fixing it. At the 3 cm of the talus joint space, the direction of the coronal plane was 25°–30° and the horizontal plane was 10°–15°.[22] Close to the anterior edge of the fibula, a bone tunnel was made with a diameter of 2.5 mm Kirschner wire, and a double-strand polyester non-absorbable suture (ETHICON W4843/MB66/X519, Johnson, Hefei, Anhui, USA) was introduced from the outside to the inside (Fig. 1). The medial double strands were pulled back with vascular forceps close to the posterior edge of the tibia, and Nice Knot was used on the lateral side of the fibula. A thread was held by both hands and pulled hard. After obtaining satisfactory tension, the knot was tightened through three single-line knots, and the point reduction forceps was released. The detailed operation flow of the lower tibiofibular fixation is shown in Fig. 2, and the schematic diagram of the new elastic fixation method made by Nice Knot is shown in Fig. 3. The recovery of DTS injury was verified by Hook and lateral malleolus rotation tests under fluoroscopy, and the wound was sutured layer by layer.

Postoperative Care and Rehabilitation

As far as postoperative routine anti-inflammatory, swelling, and pain treatment is concerned, 24 h after operation, patients were encouraged to start ankle dorsal extension and metatarsal flexion. They gradually increased the exercise intensity and began to bear partial weight 8 weeks after surgery, until they were completely loaded.

Observation Assessment

The perioperative data were recorded, including operation time, hospital stay, DTS fixation time and complete weight-bearing time. The complications during the follow-up period were recorded, such as incision infection, loosening or failure

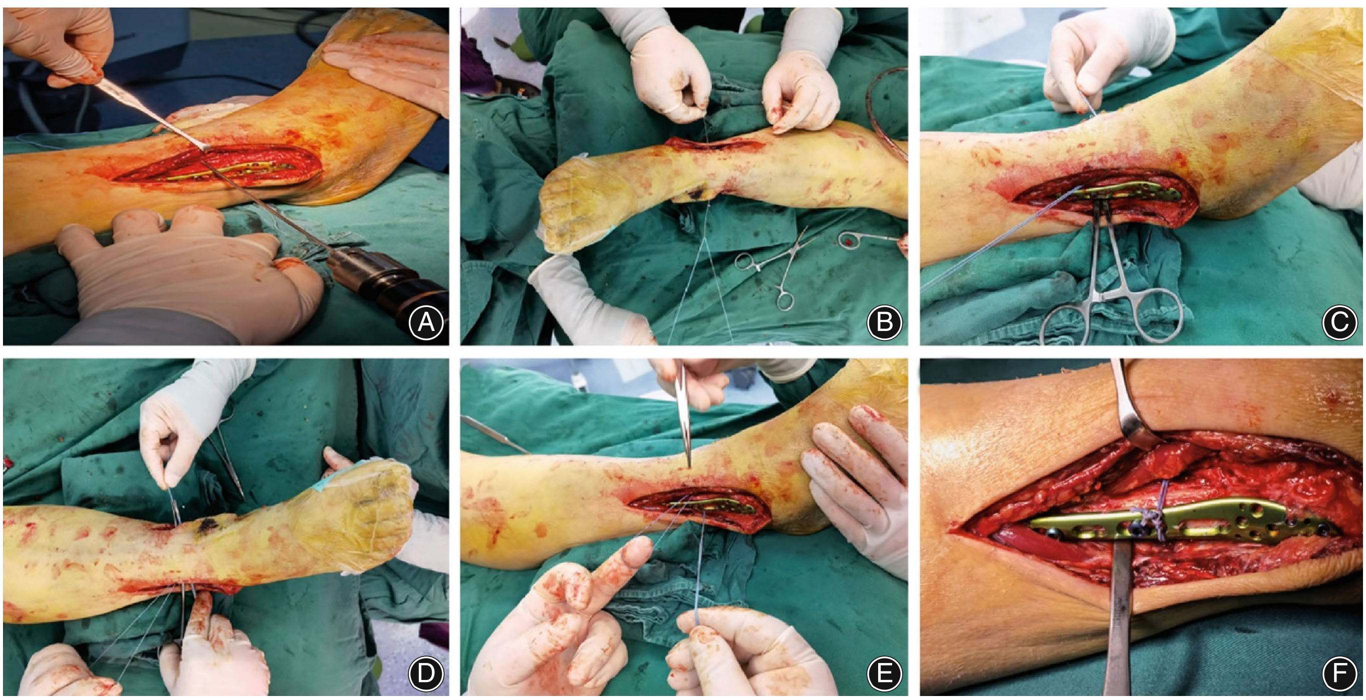

Fig. 2 Analysis of the operation of inferior tibiofibular fixation with Nice Knot. (A) 2.5 mm Kirschner wire clinging to the anterior edge of fibula to make a bone marrow canal. (B) Double strands were introduced laterally to medially through the bone marrow canal. (C) Vascular forceps close to the posterior edge of tibia and pierced medially. (D) Vascular forceps clamping the medial double strands and pulling back to the lateral side. (E) Holding of one thread in both hands, and Nice Knot being made on the lateral side of fibula. (F) After satisfactory tension, 3–4 single-strand knots being stabilized by Nice Knot

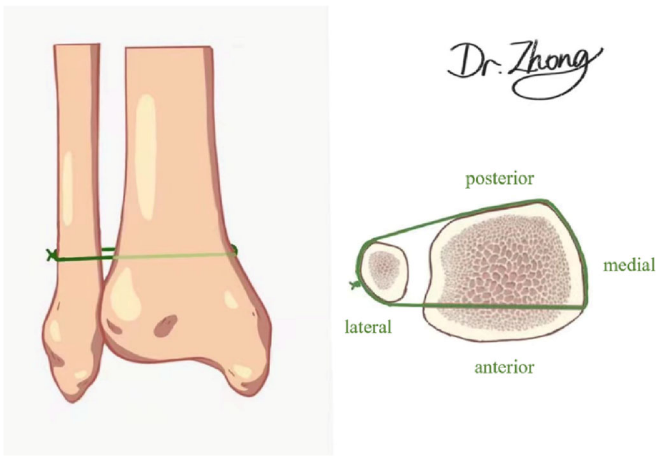

Fig. 3 Schematic diagram of tibiofibular syndesmosis injury under Nice Knot elastic fixation

of the internal fixation device, or deep venous thrombosis. Clinical and radiological evaluations were performed immediately, 1, 3, 6 months, and 1 year after surgery. The tibiofibular clear space (TFCS), tibiofibular overlap distance (TFOS), medial clear space (MCS), and superior clear space (SCS) were measured on positive X-ray films to evaluate the reduction. The clinical effect was evaluated according to the American Orthopedic Foot and Ankle Society Score (AOFAS). The AOFAS was excellent (90–100 points), good (75–89 points), fair (50–74 points) and poor (<50 points). Patients' demographics, mechanism of injury, and fracture patterns are summarized in Table 1.

Statistical Analysis

Statistical analysis was performed using SPSS Statistics (version 26.0; IBM, Chicago, IL, USA). The measurement data were expressed as $\overline{x} \pm s$, and paired sample t-tests or single factor analyses of variance were performed to compare TFCS, TFOS, MCS, SCS and American Orthopedic Foot and Ankle Society Score (AOFAS) at different time points. p-values of less than 0.05 indicated statistical significance.

Results

General Results

All patients were included in the study. The average follow-up time was 15.97 ± 3.30 months, the average hospital stay was 15.03 ± 3.93 days, the average time of surgery was

TABLE 1 Patients' demographics, mechanism of injury, and fracture patterns

Patient ID	Age (years)	Gender	Side	Causes of injury	Danis–Weber type	Lauge–Hansen type
1	32	M	R	Fall from height	C2	Pronation-external rotation
2	29	M	L	Fall from height	B	Supination-external rotation
3	18	M	R	Sprain	C1	Pronation-external rotation
4	25	F	R	Car accident	C2	Pronation-external rotation
5	58	F	R	Car accident	C2	Pronation-abduction
6	63	M	R	Car accident	C1	Pronation-external rotation
7	51	M	L	Car accident	C1	Pronation-abduction
8	21	M	L	Fall from height	B	Supination-external rotation
9	36	F	L	Car accident	C1	Pronation-abduction
10	40	M	R	Car accident	C2	Pronation-external rotation
11	22	M	L	Sprain	C2	Pronation-external rotation
12	58	F	R	Fall from height	C1	Pronation-abduction
13	34	F	L	Car accident	C1	Pronation-abduction
14	17	F	R	Car accident	B	Pronation-abduction
15	29	F	R	Hit by heavy object	B	Supination-external rotation
16	30	M	L	Car accident	C1	Pronation-external rotation
17	15	M	R	Car accident	B	Pronation-external rotation
18	33	M	R	Fall from height	C1	Supination-external rotation
19	19	M	R	Car accident	C2	Pronation-abduction
20	59	F	L	Hit by heavy object	C1	Pronation-abduction
21	27	M	R	Car accident	C1	Pronation-abduction
22	35	M	R	Hit by heavy object	C1	Pronation-external rotation
23	22	M	L	Fall from height	B	Pronation-abduction
24	54	M	R	Car accident	B	Pronation-external rotation
25	38	M	L	Car accident	C1	Pronation-abduction
26	19	M	R	Sprain	C2	Pronation-abduction
27	20	M	R	Sprain	B	Pronation-external rotation
28	47	M	L	Fall from height	C1	Pronation-external rotation
29	23	M	L	Car accident	C1	Pronation-abduction
30	20	F	L	Sprain	B	Pronation-abduction
31	38	M	R	Fall from height	B	Pronation-abduction

Abbreviations: F, female; L, left; M, male; R, right.

TABLE 2 Comparison of follow-up data immediately after operation and at each time point after operation

Radiological Parameters	Immediately after surgery	1 month after surgery	3 months after surgery	6 months after surgery	1 year after surgery	*P*-value
TFCS	3.87 ± 0.56	3.80 ± 0.65	3.97 ± 0.79	4.07 ± 0.82	3.95 ± 0.77	0.695
TFOS	7.96 ± 1.21	8.30 ± 1.00	8.45 ± 1.12	8.26 ± 1.45	8.22 ± 1.22	0.480
MCS	2.97 ± 0.43	3.25 ± 0.42	3.03 ± 0.49	3.23 ± 0.40	3.16 ± 0.55	0.063
SCS	2.99 ± 0.37	3.23 ± 0.46	3.25 ± 0.43	3.15 ± 0.33	3.18 ± 0.44	0.103
AOFAS	41.13 ± 8.30	63.87 ± 9.21	78.06 ± 9.41	88.03 ± 7.02	95.32 ± 5.86	<0.001

Abbreviations: AOFAS, American Foot Surgery Association ankle-hindfoot score; MCS, medial clear space; SCS, superior clear space; TFCS, tibiofibular space; TFOS, tibiofibular overlap distance.

2.38 ± 0.75 h, the average time of DTS fixation was 12.58 ± 2.08 min, and the average time of complete weight-bearing was 10.01 ± 1.87 w. In this study, the injuries of all patients were successfully fixed after reduction of DTS.

Radiological Improvement

There was no significant difference in the average values of TFCS, TFOS, MCS, and SCS immediately after the operation or at different follow-up time points (Table 2). The internal fixation was stable and there was no obvious loosening. Fig. 4 shows a representative case of DTS fixed with Nice Knot in this study. The X-ray at 1 year and 3 months after the fracture operation showed that the fracture healed well, and the internal fixation was in place. The Nice Knot was found to be stable during the operation of removing fixation device.

Clinical Improvement

At the last follow-up, the AOFAS score was 27 excellent, four good, 0 fair, or 0 poor. The AOFAS increased significantly from 41.13 ± 8.30 preoperatively to 95.32 ± 5.86 at the 1 year after surgery ($P < 0.001$).

Complications

During the follow-up period, there was only one patient (direct violent injury, local skin abrasion around the incision) developed a superficial infection lasting 2 weeks after operation. The wound healed after dressing change, 7 days of antibiotic treatment, and local lamp physiotherapy, whereas in the other patients healing occurred in one stage. There were no internal fixation failure and loosening, DVT, or deep infection among all patients.

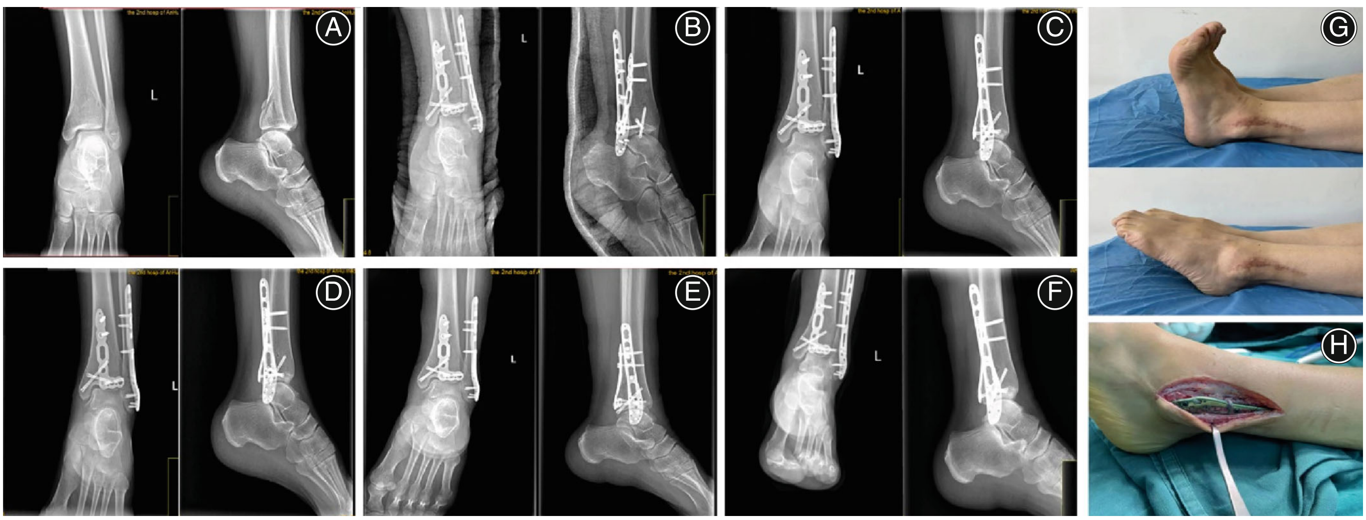

Fig. 4 Imaging data of a typical case. (A) Preoperative X-ray positive film showing right ankle fracture with inferior tibiofibular syndesmosis injury. (B) Immediate postoperative X-ray showing good reduction of the fracture with the inferior tibiofibular syndesmosis having returned to normal. (C–F) X-rays 1 (C), 3 (D), 6 (E), and 12 (F) months after surgery showing internal fixation and stable position of inferior tibiofibular syndesmosis. (G) Good ankle joint movement at the last follow-up. (H) Nice Knot was stable when internal fixation was removed.

Discussion

Our Current Findings

In our series, we found that binding DTS by Nice Knot was safe and effective. None of the 31 patients experienced internal fixation failure during the study period. This method is not only firmly fixed, but also can satisfy the joint fretting, encourage patients to perform early postoperative functional exercise, which is conducive to the functional rehabilitation of the ankle joint, reduce patients' pain, and obtain the optimal AOFAS score with high patient satisfaction.

Comparison with Traditional Rigid Fixation

In the past, the gold standard for the treatment of DTS injury was the use of cortical bone screws, which could provide an absolutely stable environment for the healing and fiber remodeling of the inferior tibiofibular ligament. There is no consensus on screw type, quantity, diameter, placement direction, location, number of penetrating cortices, need to remove screw, screw removal time, and other parameters.[1,5,6,23–25] If the screw is not removed before the load-bearing movement, the bearing force of the screw will change repeatedly with the fretting of the DTS, which will eventually lead to the fatigue effect of the metal and screw fracture. Therefore, most scholars suggest that the screws should be removed 8–12 weeks after an operation, and patients should begin weight-bearing exercises step by step, thus inevitably adding an internal fixation extraction operation. This technology successfully avoids the above problems. Andersen *et al.* pointed out that wound infection occurred in 9.2% of cases with DTS injury fixed with cortical screws; 6.6% of cases relapsed and separated after screw removal, and 5% of cases developed wound infection after screw removal.[26] For incisional complications, a multifactorial approach should be adopted, including age, diabetes and other influencing factors, in order to have a fair and predictable risk factor. In this study, only one patient developed superficial infection, which was closely related to skin abrasions around the incision.[27] The thread knot was specially fixed on the posterolateral side of the fibula, which could effectively avoid the local skin uplift of the lateral fibula caused by the thread knot and reduce the ankle joint volume of the lateral fibula. In addition, in order to achieve a firm fixation effect during the operation, the screws need to be tightened, resulting in the tibiofibular space becoming smaller because of the compression force on the screws.[28] When the reduction is poor, the hard screws do not allow the fibula to match the physiological fibula notch. Due to the above series of complications, it is gradually replaced by elastic fixation which is more in line with the fretting of DTS.

Comparison with Classical Elastic Fixation

In recent years, clinicians have favored the elastic fixation represented by suture button devices, which can meet a certain fixation strength and are more in line with the fretting of the ankle joint. This allows patients to take early functional exercise and have their ankle function restored in a short time. It also reduces the internal fixation fracture, loosening, and other complications, while avoiding losing reduction after screw removal, reducing the rate of poor reduction and avoiding a second operation. Finally, the pain and economic burden of patients are also ameliorated.[12,13,29–31] A prospective study found that the rate of poor reduction of the lower tibiofibula immediately after removal of the suture button device was similar to that of the inferior tibiofibular screw, but the rate of poor reduction of the screw increased significantly during the 2-year follow-up, while the suture button remained stable.[29] Teramoto *et al.* confirmed that there was no significant difference in the fixation effect between a suture button device and an inferior tibiofibular screw under the same anatomic reduction.[32] Nevertheless, some authors have pointed out the shortcomings of using sewing button devices through research. DeGroot *et al.* reported complications such as osteolysis, enlargement of tibial drilling and device subsidence.[12] Naqvi *et al.* pointed out the complications of suture button devices, such as body discomfort, soft tissue stimulation and wound infection, but these are not unique to the device.[13] In addition, the final fixation mode of the device is wire knot fixation, and the initial tension and the final firmness of the fixation will vary with different operators. Compared with other elastic fixations, especially suture-button, seamless metal implants at the bone tunnel can avoid osteolysis and device subsidence caused by wear between the metal and the bone tunnel to a certain extent. In addition, this technique has a wider indication, even if the fracture of the distal medial malleolus is not accompanied by the fracture of the medial malleolus. When making the bone tunnel, the elastic fixation can be completed immediately through the medial skin without medial incision. It is also easier to remove the fixation by simply cutting the suture.

Comparison with Other New Fixation Methods

In addition, some scholars have independently developed some fixation methods of DTS. The biomimetic elastic internal fixation devices independently developed by Xu *et al.* take the fibula side as the line buckle design and the tibia side as the nut on the main nail, which avoids the error of common knot fixation, but the notch of tibial lateral internal fixation is higher.[33] Zhao *et al.* proposed to use a curved nickel-titanium memory connector to repair the injury of DTS by screwing into the tibia and fibula with one claw and allowing a slight movement between joints through monocortical fixation. However, the learning time is long, and the device cannot easily be popularized.[34] Binding the DTS by the Nice Knot has a wider range of indications and is easier to perform than these metal implants.

Feasibility and Safety

It is the first time that Nice Knot is being proposed for binding the DTS. In our opinion, Nice Knot is a good method for elastic fixation, which not only retains the advantages of a suture button device but avoids joint stiffness, reduces bony fusion, and allows exercise without internal fixation materials, and also reduces possible shortcomings such as osteolysis and device sinking to a considerable extent. Our clinical research results also show that this method is well established, reliable, and has good clinical effects. In the 1-year follow-up, there was no loosening or failure of Nice Knot fixation, and the AOFAS score was as high as 95.32 ± 5.86, similar to the 91.06 score of a previous suture button device.[4] This method aligns with the biomechanical characteristics of DTS and allows joint fretting. When inferior tibiofibular reduction is poor during operation and ankle joint moves, inferior tibiofibula can be automatically matched and restored gradually, and functional exercise can be carried out early after operation. This is helpful for the recovery of the joint function and the reduction of long-term complications such as traumatic arthritis.

Advantages of Nice Knot Elastic Fixation for DTS Injury

This procedure has these advantages: (i) this method has the advantages of rigid fixation and other elastic fixation, not only fixed firmly, but also retained the joint fretting; (ii) the procedure is simple and easy to learn. it does not need special equipment and is easy to be popularized and applied in grass-roots hospitals; (iii) the technique only uses a single bone tunnel and only needs to pull the tail end of Nice Knot for compression, which is easy to operate and saves the time of lower tibiofibular fixation during operation; and (iv) the selection of the bone marrow tract is close to the anterior edge of the fibula, which is not easy to slide and has a large operating space. In addition, in the case of DTS injury with fibula fracture, A lot of internal fixation methods do not have appropriate placement points because of the lateral fibula plate blocking it. However, the proposed method successfully avoids this.

Strengths and Limitations

This study demonstrated a novel surgical technique of Nice Knot elastic fixation for DTS injury with excellent clinical results. The method has the advantages of simple operation, short learning curve, and ease of popularization. There are still some shortcomings in this study, and the lack of case–control studies further confirmed that the clinical effect of Nice Knot binding of inferior tibiofibula is better. In addition, the number of cases is small, and the follow-up time is short, which is not enough to evaluate the long-term effect. Therefore, we need long-term prospective randomized controlled trials to prove the efficacy of the proposed methods in the future.

Conclusions

Taken together, the use of Nice Knot to bind the DTS not only meets the fixation strength required for rigid fixation, but also retains the advantages of elastic fixation. It is simple to operate, easy to learn, and worth popularizing. This is a good fixation method for the treatment of DTS injury, and also points out how future research may overcome present challenges.

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Author Contributions

All authors had full access to the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design, JZ; Writing-Original Draft: QZ; Writing-Review & Editing, NZ, HY, RF; Supervision YY. Qigang Zhong, Junfeng Zhan and Hu Yang contributed equally to this work.

Ethical Statement

The Second Hospital of Anhui Medical University, Ethics Committee.

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