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REVIEW

Diagnosis and treatment of ankle syndesmosis injuries with associated interosseous membrane injury: a current concept review

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Abstract

Background Tibiofibular syndesmosis injury leads to ankle pain and dysfunction when ankle injuries are not treated properly. Despite several studies having been performed, many questions about diagnosis and treatment remain unanswered, especially in ankle syndesmosis injury with interosseous membrane injury. Therefore, the purpose of this study was to help guide best practice recommendations.

Methods This review explores the mechanism of injury, clinical features, diagnosis methods, and the treatment strategy for ankle syndesmosis injury with interosseous membrane injury to highlight the current evidence in terms of the controversies surrounding the management of these injuries.

Results Radiological and CT examination are an important basis for diagnosing ankle syndesmosis injury. Physical examination combined with MRI to determine the damage to the interosseous membrane is significant in guiding the treatment of ankle syndesmosis injury with interosseous membrane injury. In the past, inserting syndesmosis screws was the gold standard for treating ankle syndesmosis injury. However, there were increasingly more controversies regarding loss of reduction and broken nails, so elastic fixation has become more popular in recent years.

Conclusions Anatomical reduction and effective fixation are the main aspects to be considered in the treatment of ankle syndesmosis injury with interosseous membrane injury and are the key to reducing postsurgery complications.

Keywords Tibiofibular syndesmosis · Interosseous membrane · Injuries · Management

Introduction

Despite the common occurrence of ankle injuries, there are pitfalls associated with diagnosis and disagreement with treatment of ankle syndesmosis injury. In particular, orthopaedic surgeons need to understand the complex nature of ankle syndesmosis injury with interosseous membrane injury. Patients with ankle syndesmosis injury may present years after the initial injury with insidious, progressive pain, often with swelling after activity. These symptoms have a serious impact on the patients' quality of life [1]. Statistics show that patients with these symptoms account for 22–60% of patients with ankle syndesmosis injury, which has a relationship with the diagnosis and treatment of patients at their initial visit [2]. Therefore, it is very important to diagnose and treat ankle syndesmosis injuries with interosseous membrane injury more accurately.

External rotation stress is the most important mechanism for the separation of the distal tibiofibular syndesmosis. External rotation of the foot will cause external rotation and external displacement of the fibula, resulting in a gradual increase in the tension of the anterior inferior tibiofibular ligament and interosseous ligament until the ligament is broken. The injury will lead to interosseous membrane damage once the fibula is moved outward beyond the extent of the interosseous membrane [3, 4]. When the external rotation stress is large enough and continues to be transmitted to the proximal fibula, it may result in a stress concentration at a position of the fibula due to the limitation of the superior tibiofibular syndesmosis and if the fibula has not been shifted to the outside, i.e., fibula fracture will occur under excessive

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stress [5]. In addition, because the distance between the tibia and fibula is gradually widened from the distal to proximal ends and the interosseous membrane in the middle section is a curved surface, this external rotation stress means that the level of interosseous membrane damage is lower than for fibula fracture under the limitation of superior tibiofibular syndesmosis [6]. The tension of the interosseous membrane injury site is simultaneously increased because of swelling, which often leads to shortening of the lower part of fibula under undamaged interosseous membrane limitation. This will lead to ankle instability and induce traumatic arthritis when the injury is not treated properly (Fig. 1). Therefore, we briefly analyze the appropriate diagnosis and treatments based on our experience of the diagnosis and treatment of ankle syndesmosis injury with interosseous membrane injury.

Diagnosis of ankle syndesmosis injury

Patients with ankle syndesmosis injuries with interosseous membrane injury have a clear history of external rotation of the foot, and obvious swelling of the calf. When examining the body, obvious tenderness will be observed in the upper part of the fibula and when pressing down on the surface of the interosseous membrane. The ankle valgus test will also induce or aggravate ankle pain. In addition, the external rotation stress test, squeeze test, dorsiflexion compression test, crossed-leg test, hook test, intra-operative stress tests in external rotation, and Chertsey test are meaningful for the diagnosis of ankle syndesmosis injury [7–13] (Table 1).

Auxiliary examination is an important basis for the diagnosis of ankle syndesmosis injury, and X-ray examination is one of the most commonly used techniques. The tibiofibular overlap should normally be > 6 mm in the anteroposterior radiograph and > 1 mm in the mortise radiograph as measured 1 cm proximal to the tibial plafond. The tibiofibular clear space should be < 6 mm in both the anteroposterior and mortise radiographs as measured 1 cm proximal to the tibial plafond (Fig. 2). The medial clear space should be less than or equal to the clear space between the talar dome and the tibial plafond. Decreased tibiofibular overlap, increased tibiofibular clear space, and increased medial clear space on either weight-bearing or non-weight-bearing radiographs indicate syndesmotic disruption [14–16]. The mechanical axis is estimated either by the line perpendicular to the tibial plafond (talocrural angle) or the line parallel to the distal fibular shaft (bimalleolar angle), and the talocrural angle with a normal range of 72° to 86° (Fig. 2). Abnormal fibular shortening is reflected by an approximate linear relationship of a 1° angle difference to 1 mm of shortening [17]. In addition, equal joint space, intact Shenton's line of the ankle, and an unbroken curve between the lateral talus and the peroneal groove of

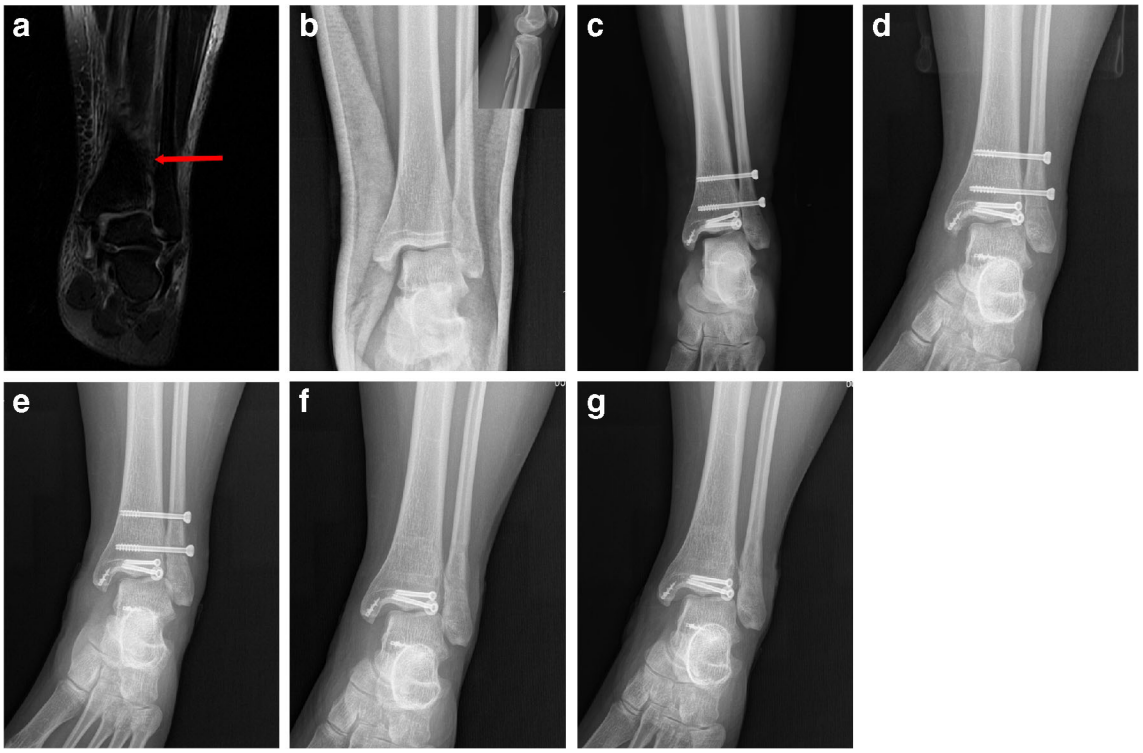

Fig. 1 **a** Arrows on MRI images show interosseous membrane injury. **b** Pre-operative X-ray. **c** Post-operative X-ray. **d** X-ray findings at 6 weeks after surgery. **e** X-ray findings at 12 weeks after surgery. **f** X-ray findings at 24 weeks after surgery. **g** X-ray findings at 48 weeks after surgery. Surgical treatment failure of ankle syndesmosis injury with interosseous membrane injury due to unrecoverable fibula shortening

Table 1 Clinical and intra-operative stress test names, descriptions, and positive indicators for syndesmotic injuries

Test	Description	Positive result
External rotation stress test	Applying an external rotation stress to the involved foot and ankle with the knee held at 90° of flexion and the ankle in a neutral position	Pain over the anterior or posterior tibiofibular ligaments and over the interosseous membrane
Squeeze test	Compressing the fibula to the tibia above the midpoint of the calf	Pain in the area of the interosseous ligament or its supporting structures
Dorsiflexion compression test	Patient standing and actively dorsiflexing to simulate the normal loading of the syndesmosis ligaments, and the patient dorsiflexed once unassisted and once with the therapist applying a manual compressive support around the malleoli.	A significant increase in the ankle range of motion with added compression or (and) a decrease in the end of range pain with added compression
Crossed-leg test	With the patient sitting and both knees in 90° of flexion and feet on the ground, the injured leg is lifted and the ankle is placed on the superior aspect of the uninjured knee, and then applies a gentle force with hand on the medial side of the knee.	Pain in the area of the interosseous ligament
Hook test	The force is applied to the lateral malleolus with a bone hook, and the syndesmosis is assessed under fluoroscopy in both the lateral and anteroposterior radiographs.	Lateral movement of the fibula or widening of the mortise on intraoperative radiographs
Intra-operative stress tests in external rotation	The F-tool was applied to the medial aspect of the forefoot and lateral aspect of the hind foot. The proximal tibia was stabilized, and a consistent external rotational force of 7.2 Nm is applied to the ankle mortise by using a linear strain gauge.	Increased medial clear space at the ankle mortise
Intra-operative Chertsey test	A 20-gauge needle was inserted into the lateral aspect of the ankle joint and 2 to 4 mL radio-opaque contrast injected. Anteroposterior (AP) and lateral radiographs were obtained by the image intensifier.	The contrast dye was seen tracking up to the syndesmotic space.

the fibula are three criteria for normal distal fibula length in the mortise view [18, 19] (Fig. 3). Moreover, fibular shortening can be identified by the X-ray contrast on the other side of the ankle when ankle syndesmosis injury is suspected.

Although standard radiographic views are effective in assessing moderate-to-severe ankle syndesmosis injury, subtle syndesmotic widening is notoriously difficult to measure. However, computed tomography (CT) can directly and clearly show the positional relationship of the distal tibiofibular syndesmosis, which can be used to directly measure the gap of distal tibiofibular syndesmosis and compare it with the contralateral side. Therefore, it has higher diagnostic value for ankle syndesmosis injury when the radiographic markers are equivocal [20]. The CT scan of the distal tibiofibular syndesmosis is usually measured and analyzed by scanning the most prominent level of the anterior tibial tuberosity, and it is generally believed that an ankle syndesmosis injury is present when the gap is > 6 mm or wider than 2 mm compared with the other side. In addition, ankle syndesmosis injury with a separation of 2–3 mm can be confirmed by the coronal plane in CT images [21, 22]. Magnetic resonance imaging (MRI) is commonly used to diagnose ankle syndesmosis injury but also used to assess the extent of interosseous membrane damage; thus, it is best to have a > 25° angle in the coronal plane to observe the interosseous membrane more clearly [23, 24]. In addition, ultrasound and ankle arthroscopy are also commonly used to diagnose ankle syndesmosis injury [25–27].

The effect of interosseous membrane injury on the treatment of fibula fracture

The interosseous membrane is a membranous structure with a thickness of about 1 mm connecting the tibiofibular, which is mainly composed of fibrous connective tissue. The anterior fibres of the interosseous membrane and the intercondylar tibia are slanted at an angle of 15°–20° and obliquely downward to stop at the tibia. The posterior fibres of the interosseous membrane are almost distributed vertically between the tibia and fibula, which is important for controlling the lateral displacement of the fibula [5, 6]. Therefore, excessive lateral movement of the fibula caused by external rotation stress will lead to injury of the interosseous membrane and distal tibiofibular syndesmosis separation will occur. Furthermore, fibula fracture will occur when the external rotation stress exceeds the range of the fibula; therefore, fibula fracture with interosseous membrane injury is unstable and it is especially important to restore the original anatomical relationship and stable fixation of the fibula.

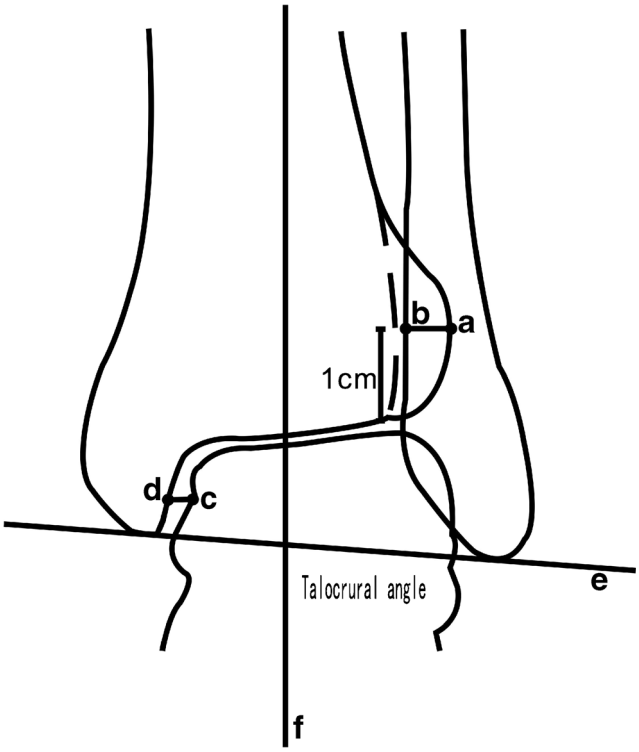

Fig. 2 Common radiographic measurements for diagnosing syndesmotic injuries, including tibiofibular overlap (**a**, **b**), medial clear space (**c**, **d**), and talocrural angle(**e**, **f**). Tibiofibular overlap is measured 1 cm proximal to the plafond. Talocrural angle is formed by the intersection of two lines, one drawn the line perpendicular to the tibial plafond as the vertical line (**f**), a second drawn between the tips of the two malleoli on the mortise radiograph (**e**), and normal values range from 72° to 86°

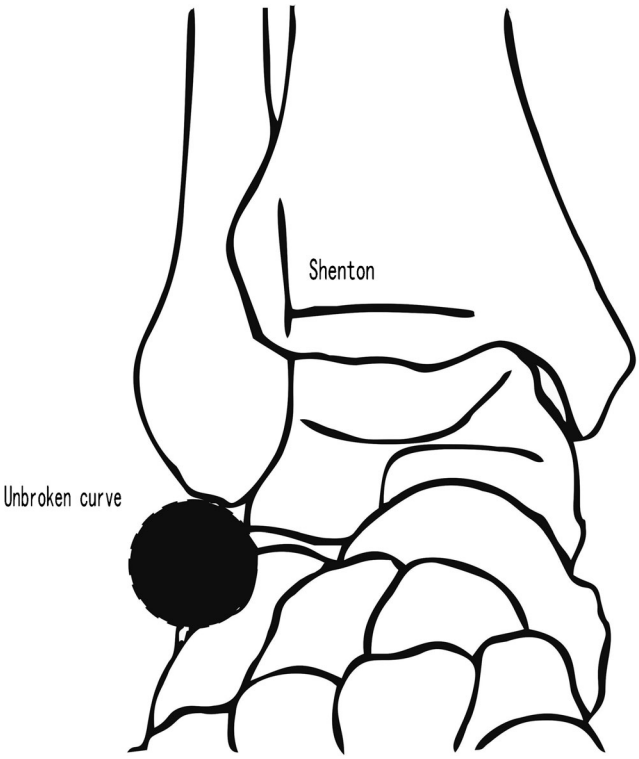

Fig. 3 Intact Shenton line of the ankle: the contour of the dense subchondral bone of the tibia can be followed over the syndesmotic space to the fibula, where a small spike is seen, and this spike points directly to the level of the tibial subchondral bone. Unbroken curve: between the lateral talus and the peroneal groove of the fibula.

The connection between the tibia and fibula is based on the superior tibiofibular syndesmosis, distal tibiofibular syndesmosis, and interosseous membrane. The load transfer of the fibula will be reduced by 30% when the interosseous membrane is injured; therefore, the injury will easily lead to irregular load and dynamic changes in the ankle when the continuity of the fibula is not restored [28]. Long-term changes in ankle load will cause articular cartilage damage and eventually cause arthritis [29]. The fibula fracture above the 7 cm of the lateral malleolus was previously considered to not affect the rotation stability of the ankle joint; thus, there was no need to specially treat the fibula fracture [30]. For example, a good result can be achieved without internal fixation of the fibula fracture in Maisonneuve injury [31, 32]. However, the middle fibula fracture with interosseous membrane injury often has a short deformity of the fibula [33]. If the fibula fracture is not fixed, it is difficult to restore the ankle joint at an anatomical location and the fixation of distal tibiofibular syndesmosis easily fails due to shear stress. However, it is difficult to quantitatively assess the degree of interosseous membrane injury; thus, the relationship between internal fixation of middle fibula fracture and interosseous membrane injury is still lacking.

Treatment of ankle syndesmosis injury

Distal tibiofibular syndesmosis and the interosseous membrane are important factors in maintaining the stability of the ankle joint. It is easy to cause lateral displacement of the talus during the movement of the ankle joint when injured. Moreover, studies have found that a lateral displacement of the talus at 1 mm will reduce the tibia contact surface by 40% and the displacement of the talus at > 1.5 mm will result in concentrating stress in the ankle such that articular surface degeneration will occur in the ankle during long-term activity [33–35]. However, the location of the fibula fracture is considered by some researchers as an important basis for the evaluation of interosseous membrane and distal tibiofibular syndesmosis injuries. Distal tibiofibular syndesmosis does not need to be fixed when the fibula fracture line is located within 5 cm of the ankle joint [36]. In addition, Chissell [35] believed that if the medial malleolar fracture is strongly fixed, it is necessary to fix the distal tibiofibular syndesmosis only when the fibula fracture line is > 15 cm from the ankle. However, a long-term follow-up showed that distal tibiofibular syndesmosis injury without fixating would seriously affect the ankle function and also advocated that the distal tibiofibular syndesmosis requires anatomic reduction or even incision to ensure the quality of the reduction [37].

In our opinion, the interosseous membrane is damaged only when the external rotation stress is strong; therefore, the ankle joint is often unstable when ankle syndesmosis injury occurred in addition to interosseous membrane injury. Thus, effective internal fixation is necessary (Fig. 4).

Syndesmosis screw fixation remain the most common fixation method for ankle syndesmosis injury. When inserting the screw, it should be about 30° forward from the posterolateral fibula and perpendicular to the distal tibiofibular; otherwise, it may shift the fibula backward. The screw should simultaneously be parallel to the ankle surface; otherwise, the fibula length may change [38]. In addition, the anatomic reduction of the fibula after fracture must be determined before inserting the screw. The ankle can be placed in a dorsiflexion position to prevent the decrease of the post-operative dorsiflexion angle when the posterior part of the talar block is used as a template to restore the acupoint width [39]. In addition, it should be noted that the syndesmosis screw is not a lag screw. Excessive pressure may lead to narrowing of the axillary point and limited dorsiflexion of the ankle joint; therefore, a reamer should be applied to the tibia and fibula before driving the screw [40, 41]. At the same time, if a reduction forceps is used, the best position is at one-third posterior to the fibula and anterior to the tibia. Excessive compression that would cause the tibia shift to backwards or rotate should be avoided [40, 42]. Finally, during syndesmotic reduction and fixation in the supine position, supporting the foot under the heel should be avoided because it will cause significant anterior subluxation of the fibula [43].

Currently, despite extensive biomechanical and clinical research, there is still no consensus on the size of the screws, the number of screws, the number of cortical screws involved, and the location of the fixation. Some biomechanical studies have shown that a 4.5-mm screw will provide stronger shear stress than a 3.5-mm screw, and multiple syndesmosis screws will ensure greater torsional stiffness [44–46]. However, it has also been pointed out that the distal tibiofibular syndesmosis will be stably fixed with a single 3.5-mm screw through the three-layer cortex if the distal tibiofibular injury was initially reduced anatomically [47]. A recent questionnaire-based study about the preferred size for the syndesmosis screw found that just over 50% of surgeons used 3.5-mm cortical screws, and others either used 4.5-mm cortical screws or a suture fixation device [48]. However, it is recommended that two screws be used in high fibular fractures (Maisonneuve fracture) [49]. Despite numerous studies, the evidence remains split between the use of either 3.5- or 4.5-mm cortical screws, and it appears to depend on surgeons' experience and preference. In addition, studies have shown that the closer to the surface of ankle, the higher stability of the screw, and 2.0 cm above the ankle is the best position for screw fixation [50]. Based on our previous clinical experience and the literature, we consider that the ankle syndesmosis injury with interosseous membrane injury will be stabilized by fixing two 3.5-mm syndesmosis screws at a position from 2 to 4 cm above the ankle. Thus, we usually fix three cortex layers to allow for small changes in the distal tibiofibular width during activity [49, 51].

The screw breaks easily because of the long time of retention, so many doctors choose to remove the screws prematurely. However, there is no consensus on whether to allow weight bearing prior to removal of the screw, or on the duration that the screws should remain inserted. The danger with weight bearing while the screws are in situ is the increased risk of loosening, breakage, and pain. Therefore, some authors advocate removal of the screws prior to weight bearing. However, the time for nail removal is debated. Some people consider that the screws can be removed if the distal tibiofibular syndesmosis has been stable for six to eight weeks after surgery, while others state that reinjury is easy at this time and

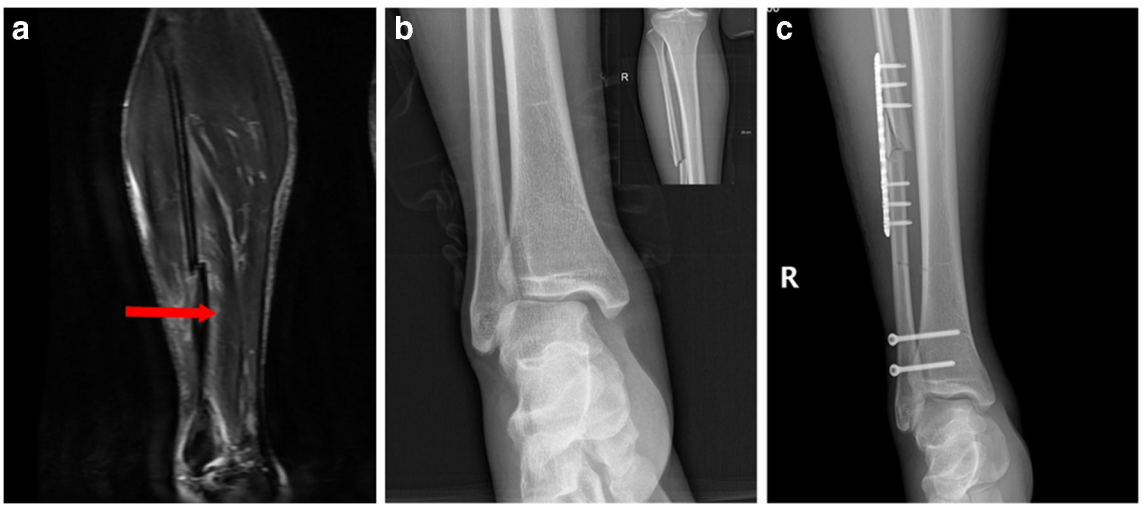

Fig. 4 **a** Arrows on MRI images show interosseous membrane injury. **b** Pre-operative X-ray. **c** Postoperative X-ray. Surgical treatment of ankle syndesmosis injury with interosseous membrane injury

recommend removing screws at eight to 12 weeks [52–54]. In addition, some people use bioscrews instead of ordinary screws to avoid the trouble of removing screws, but the results show that the incidence of foreign body reactions will increase [55]. However, we consider that the statistical differences in nail removal times are due to the type of damage and that it is necessary to remove screws according to the specific damage. For example, interosseous membrane injury requires > three months to repair [56]; thus, we believe that the ankle syndesmosis injury with interosseous membrane injury needs to be fixed for 12 weeks while daily activity needs to be limited within these 12 weeks. In addition, some studies suggest that there is no significant difference in outcome between retaining and removing the screws [57]. In addition, some doctors found that patients with broken screws had an optimum clinical outcome whereas those with intact or removed syndesmotis screws did not achieve optimum results. Thus, these doctors advocated leaving the syndesmotis screws in situ indefinitely [58]. Therefore, there remains some debate around the timing for the fixing of distal tibiofibular syndesmosis injuries.

The distal tibiofibular syndesmosis injury fixed by syndesmosis screws is a rigid fixation, which has a certain limitation on slight movements of the ankle joint; therefore, it is not conducive to adjusting the accurate movement of the talus in the acupoint. Stress caused by excessive activity will cause problems such as screw breakage [59, 60]; therefore, it is recommended that elastic fixation that conforms to the biomechanical characteristics of distal tibiofibular syndesmosis be used in combination with micromotion. A suture button consists of a strong suture loop that is tensioned and secured between two metallic buttons that abut the outer cortices of the tibia and fibula or the fibular plate to provide stabilization of the ankle mortise. Thus, suture buttons appear to be a relatively new tool for surgical implants [61, 62] (Fig. 5). In addition, they offer more physiologic motion between the distal tibia and fibula, and it is not necessary to remove the device [63, 64]. However, suture buttons have been reported to have local complications, such as local irritation of soft tissue, infection, sinking of internal fixation devices, osteolysis, and bone tunnel widening [65–67]. We believe that the suture button is a better method for the treatment of ankle syndesmosis injury with interosseous membrane injury, but it is necessary to pay attention to patients with osteoporosis, foreign body rejection, and soft tissue conditions, and more clinical reports are needed in the future.

Common complications of ankle syndesmosis injury

Although distal tibiofibular syndesmosis with internal fixation is a common method for the treatment of ankle syndesmosis injury, complications are also common after treatment, such as

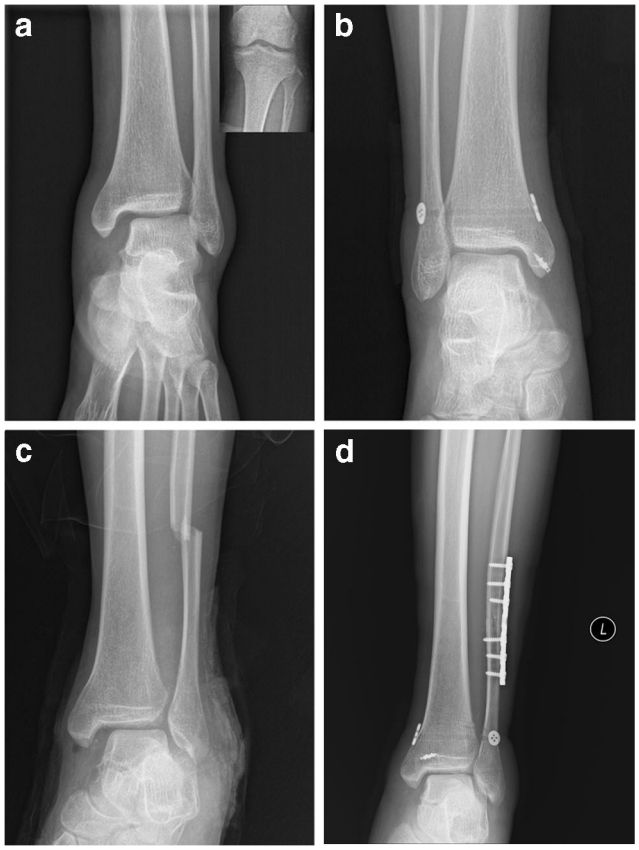

Fig. 5 **a** Pre-operative X-ray. **b** Post-operative X-ray. **c** Pre-operative X-ray. **d** Post-operative X-ray. The treatment ankle syndesmosis injury by suture buttons

heterotopic ossification, implant failure, malreduction of distal tibiofibular, and ankle arthritis. Among these complications, heterotopic ossification is a common radiographic finding following ankle syndesmosis injuries, but often, no special treatment is needed due to rare symptoms [68]. Fixation failure prior to complete healing can result in reduction loss and the need for revision. However, studies have found that patients with retained broken or loosened screws had better functional outcome scores than patients with retained intact screws when the screws broke or loosened after the ankle syndesmosis injury had healed [58, 69]. The loss of tibiofibular overlap or medial clear space widening is a common cause of malreduction of the distal tibiofibular and the main cause of osteoarthritis, where the incidence of malreduction and osteoarthritis will be 11–20.9% [70, 71]. However, osteoarthritis often includes pain and ankle movement abnormalities; therefore, it is often necessary to perform resurgery [72].

In recent years, various surgical techniques have been based on osteoarthritis causes. Among these techniques, extending the length of the fibula by fibula osteotomy is a common method for treating early pain in osteoarthritis caused by fibula shortening. However, there are different methods for fibula osteotomy, bone grafting, and deltoid ligament treatment [73, 74]. Distal tibiofibular arthrodesis

has been reported as an option for consideration in the treatment of young and active patients with arthritic changes in their ankle joint with concomitant chronic instability of syndesmosis [75]. In conclusion, these methods will effectively improve ankle function and relieve pain as a remedy for the first erroneous operation. Thus, anatomical reduction is the key to surgical treatment [76].

Conclusion

While ankle syndesmosis injury is one of the common diseases in orthopedic foot and ankle surgery, many unanswered questions about its diagnosis and treatment remain, especially in ankle syndesmosis injury with interosseous membrane injury. Radiation and CT examination are an important basis for diagnosing ankle syndesmosis injury. Physical examination combined with MRI to determine the damage of interosseous membrane is very significant in guiding the treatment of ankle syndesmosis injury with interosseous membrane injury. Syndesmosis screws were previously the gold standard for the treatment of ankle syndesmosis injury; however, controversies were increasing in the case of loss of reduction and broken nails. Accordingly, elastic fixation has become increasingly popular in recent years. Regardless of the fixation method used, anatomical reduction is the key to treatment. In addition, there is some controversy on the fixed time for using syndesmosis screws. We believe that the stability of distal tibiofibular syndesmosis is reduced with the interosseous membrane injury, and the time for syndesmosis screw fixation needs to be sufficient to avoid reseparation after removal. In conclusion, anatomical reduction and effective fixation are the main aspects to be considered in the treatment of ankle syndesmosis injury with interosseous membrane injury and are the key to reducing post-operative complications.

Authors' contributions Guang-Shu Yu participated in the design of the study and performed the statistical analysis. Yan-Bin Lin conceived the study and participated in its design and coordination and helped to draft the manuscript. All the authors read and approved the final manuscript. Guo-Sheng Xiong participated in literature search and data integration. Hong-Bin Xu and You-Ying Liu participated in statistical analysis of data.

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Compliance with ethical standards

Availability of data and material We state that all data generated during the present study are included in this article.

Competing interests The authors declare that they have no competing interests.

Abbreviations CT, computed tomography; MRI, magnetic resonance imaging

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