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Review Article

Fixation Methods for Calcaneus Fractures: A Systematic Review of Biomechanical Studies Using Cadaver Specimens

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ABSTRACT

Calcaneal fractures are notoriously difficult to treat and wound complications occur often. However, owing to the rare nature of these fractures, clinical trials on this subject are lacking. Thus, biomechanical studies form a viable source of information on this subject. With our systematic review of biomechanical studies, we aimed to provide an overview of all the techniques available and guide clinicians in their choice of method of fracture fixation. A literature search was conducted using 3 online databases to find biomechanical studies investigating methods of fixation for calcaneal fractures. A total of 14 studies investigating 237 specimens were identified. Large diversity was found in the tested fixation methods and in the test setups used. None of the studies found a significant difference in favor of any of the fixation methods. All tested methods provided a biomechanically stable fixation. All the investigated methods of fixation for calcaneal fractures seem to be biomechanically sufficient. No clear benefit was found for locking plates in the fixation of calcaneal fractures; however, a subtle mechanical superiority might exist compared with nonlocking plates in the case of fractures in osteoporotic bone. Several of the techniques tested would be suitable for a minimal invasive approach. These should be investigated further in clinical trials.

Calcaneal fractures are uncommon, and surgical treatment provides a challenge for surgeons owing to the high risk of wound complications and secondary posttraumatic osteoarthritis (1). Research has shown that patients with a displaced intraarticular calcaneal fracture (Sanders type $\geq$2) should preferably undergo surgery, not conservative treatment (2,3). Surgery is needed to restore the calcaneal anatomy and thus lower the rate of posttraumatic (talocalcaneal) osteoarthritis (2). The optimal calcaneal fracture fixation construct should provide rigid fixation of the main fracture fragments, have only minimal prominence of the implant (because of the thin soft tissue layer over a large area of the calcaneus), and should require as little soft tissue dissection as necessary for reconstruction (4).

Three widely accepted surgical options are available to achieve these goals: open reduction and internal fixation (ORIF) through an extended lateral approach, ORIF through a less invasive approach (i.e., sinus tarsi approach), and a fully percutaneous approach after closed reduction.

ORIF using the extended lateral approach allows for good fracture reduction; however, wound problems can be a major drawback. The rate of postoperative wound infections after ORIF of displaced fractures of the calcaneus is high, $\leq$25% (1). Therefore, less invasive approaches have gained interest (5,6). These less invasive techniques were developed to respect the soft tissue, minimizing the disturbance of the soft tissue envelope to decrease the risk of postoperative wound complications.

Possible internal fixation constructions include (or are a combination of) plates, screws, intramedullary devices, and Kirschner wires. Another option is to add bone substitute to enhance the strength of the screw fixation (7,8).

For osteosynthesis using ORIF, the procedures in the past few years have shown a tendency toward the application of locking plate and screw constructs, creating an angular stable construction. For noncalcaneal fractures, locking plate fixation was found to be beneficial by adding to the strength of the construction (9). This has been especially true in osteoporotic bone (10).

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Indirect, closed reduction comes with a greater risk of incomplete anatomic reduction of the joint surface, especially, if the fracture pattern is complex. When restoration of the anatomy is not possible, patients can develop posttraumatic osteoarthritis and arthrodesis might become necessary to relieve the pain (11).

Numerous clinical studies on the fixation of calcaneal fractures have been reported. However, because biomechanics are the basis for successful fixation of all fractures, we aimed to provide an overview of the biomechanically tested types of fixation of calcaneal fractures and identify which type of fixation has the best biomechanical properties. Identifying the fixation method with the best biomechanical properties could provide guidance for clinical trials regarding the different types of fixation for calcaneal fractures.

Materials and Methods

Search Strategy

The present systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (12). The online databases of PubMed, Embase, and Web of Science were searched using the following keywords: calcaneus, postmortem, biomechanical, fracture fixation, and their synonyms, each fitted for the specific databases. Full search threads are available in the Appendix.

Inclusion Criteria

Reports were included if they met the following criteria:

1. The study concerned displaced intraarticular calcaneal fractures (Sanders type $\geq$2)
2. The report concerned postmortem (cadaveric) human specimens
3. The study was a biomechanical study
4. Internal fixation had been performed

No date limits were imposed on the search. The reports were screened by 2 independent reviewers (S.A.D., F.W.S.), using an online tool (available at: www.covidence.org). Disagreements on inclusion were solved through discussion with a third person (T.S.).

Exclusion Criteria

Studies were excluded based on the full-text. They were excluded if they met the following criteria:

1. Used nonhuman calcanei (e.g., saw bone)
2. Not in English.
3. Study topic of arthrodesis
4. Conference abstract
5. Review

The references of the included reports were checked for additional relevant studies.

Data Extraction

Data extraction included the type of fixation technique used; fracture type; number of specimens; bone mineral density and/or age of the specimens; test setup; outcome measures; and major findings and/or conclusions. We did not perform a meta-analysis (due to the heterogeneity of the data) and as a result of this no statistical tests were applied. When addressing statistical significance we cited the authors of the included studies.

Results

The search was performed on September 1, 2016. The search yielded a total of 413 hits, including: 168 (40.68%) Pubmed hits, 168 (40.68%) Embase via Ovid hits, and 77 (18.65%) Web of Science hits.

After identifying the studies in the different databases, duplicates were removed (n = 188 [45.52%]). This left 225 (54.48%) reports to screen by title and abstract. Of those, 206 (49.88%) did not meet inclusion criteria and were excluded. A total of 19 (4.6%) studies were selected for full text screening, of which 5 (1.21%) studies were excluded. The reasons for exclusion were non-English language (n = 2) (13,14), the report was a conference abstract for an included study (n = 2) (15,16), or the study was a review (n = 1) (17). The cross-reference check of the included studies did not result in additional relevant reports. A flowchart of the search can be found in the Fig.

In total, 237 calcanei were investigated. The fractures were inflicted by osteotomy, impact loading, or the use of stress-risers (i.e., load to failure testing). The investigated calcaneal fracture fixation techniques included conventional plates, locking plates, unicortical screws, bicortical screws, small fragment plates, intramedullary devices, augmented screw osteosynthesis, compression bolts, and longitudinal screws added to lateral plates. The results of the included studies are listed in the Table (3,8,10,18–28). The authors concluded that all tested fixation methods seemed to be biomechanically adequate and did not differ significantly from each other. The use of locking devices did not seem to strengthen the construction compared with the conventional devices (10,20–22).

Discussion

The aim of the present systematic review was to provide an overview of the biomechanically tested fixation methods for fixation of the calcaneus fractures and to determine which fixation method has the best biomechanical properties. We systematically retrieved reports on biomechanically tested fixation methods for calcaneal fractures. A wide variety of fixation methods, test setups, and outcome measures was found. Owing to the heterogeneity of the studies, definitive conclusions could not be drawn; however, all tested techniques appeared to be biomechanically adequate. Furthermore, we found a tendency toward the use of minimally invasive and intramedullary fixation methods in recent last years (18,19,29). Locking plates did not seem to provide a biomechanically stronger fixation of calcaneal fractures than nonlocking plates (10,20,21).

An anatomic plate with compression bolts provides biomechanical stability as good or better than that provided by the conventional anatomic plate and cancellous screws. The construction with compression bolts significantly improved the lower displacement during cyclic loading and the axial load to failure (30). It is not surprising that compression bolts can enhance the stability; however, the possible disruption of the soft tissue caused by compression bolts might have consequences in clinical practice. Additional disadvantages include that a bilateral approach is needed, requiring more extensive dissection, and the construction is bulky under the skin.

Locking plate fixation was biomechanically superior to conventional plating in noncalcaneal fractures (9,31). This was typically in the case of osteoporotic bone, a condition that causes weakness of the bone and thus more easily leads to loosening of the fixation and subsequent failure to maintain reduction of the fracture (2). Richter et al (32) found more rigidity in specimens treated with a locked plate compared with a conventional plate, although no significant difference was found in the load to failure. Furthermore, they found that polyaxially locked plates provided increased stability compared with uniaxially locked plates (33). However, they used saw bone specimens instead of human calcanei. It is well known that artificial bones have different biomechanical characteristics than human bone (34), mandating careful interpretation of their results. Four studies biomechanically investigated locking plates (10,20–22). Three studies failed to show a significant beneficial effect of locking plates compared with nonlocking plates in the fixation of calcaneal fractures, questioning the benefit of using locking plates in these patients (10,20,21). The study by Stoffel et al (22) was the only one to find locking plates to be beneficial in the case of displaced intraarticular calcaneal fractures in osteoporotic bone. However, the difference between ultimate displacement and work to failure was not significant in their study (22). They suggested that the irreversible deformation of a construction with