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HANDSURGERY

Biomechanical comparison of the proximal interphalangeal joint arthrodesis using a compression wire

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Abstract

Introduction/aim Arthrodesis of the proximal interphalangeal joint of the finger is a common procedure for the treatment of osteoarthritis. The aim of this biomechanical study was to compare the primary stability of one, respectively, two compression wires to intraosseous wiring and tension band wiring for the arthrodesis.

Materials and methods The stability of the arthrodesis was tested by applying flexion ($n=11$) and extension ($n=10$) force with 10° bending. Arthrodesis was achieved by one, respectively, two crossed compression wires and intraosseous wiring. In a control group ($n=11$) tension band wiring was tested to 10° flexion and extension as well.

Results Mean values for flexion bending for intraosseous wiring were 10.94 N, for one compression wire 12.82 N, for tension band wiring 17.95 N, and for two crossed compression wires 20.42 N. Mean values for extension bending were 9.71 N for intraosseous wiring, 13.63 N for one compression wire, 21.43 N for tension band wiring and 22.56 N for two crossed compression wires.

Conclusion The primary stability of the compression wires was statistically significant superior to intraosseous wiring. In comparison to tension band wiring which showed an intermediate stability. The application of a compression wire could be considered for further clinical testing in the arthrodesis of interphalangeal joints.

Keywords Interphalangeal arthrodesis · Compression wire · Intraosseous wiring · Biomechanical study

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Introduction

In cases of severe osteoarthritis of the proximal interphalangeal joint (PIJ), which results from different pathological conditions, arthrodesis is a proven procedure in its treatment [1, 2]. Moberg defined the objectives of the arthrodesis as achieving a painless and stable union in a functional position, 15°–45° depending on the affected PIJ, in a timely manner [3, 4]. Nowadays, those criteria might have to be extended by adding active early motion stability, compression of the arthrodesis site, maximizing cancellous bony contact surface as well as implant stiffness [5–8].

An alternate option of treatment is the arthroplasty with different kinds of prostheses, all of which are burdened with some kind of complication but are continuously getting better clinical results [9, 10].

The compression wire (Koenigsee Implantate GmbH, Allendorf, Germany) was originally designed for percutaneous osteosynthesis of simple cross and short-angled fractures of phalangeal bones [11]. It features, similar to headless compression screws, two threads of a different pitch with a variable threadless section, which provide a secure and rigid cortical fixation, as well as compression of the arthrodesis (Fig. 1). The diameter varies from 1.0 mm at the tip to 1.8 mm at the second thread. The placement of the compression wire is achieved with the 50-mm positioning tip. The threads and main part of the compression wire follow the tip until compression is applied on the joint line. The end of the wire can be cut and buried under the skin, so it can be removed through minor incisions after confirmed bony fusion.

The aim of this study was to compare the biomechanical strength of a single oblique compression wire, respectively, two crossed compression wires, in contrast to intraosseous wiring by Lister and tension band wiring in an experimental feasibility study. Intraosseous wiring and tension band wiring are proven in numerous clinical and biomechanical trials and therefore were chosen as reference procedures [7, 8, 12–18]. The clinically relevant range of bending during active early motion mobilization should be no more than 5°–10°, therefore flexion and extension bending in this study were limited to this range [19].

The working hypothesis was that the stability of a single oblique compression wire, respectively, two crossed compression wires is superior in contrast to intraosseous wiring and tension band wiring when subjected to flexion and extension bending up to 10°.

Materials and methods

Based on preliminary tests, a power-analysis was performed, which suggested a sufficient sample size of five specimens per group.

A total of 21 formalin-fixed human cadaver specimens, all separated from the hand, were randomly assigned to two groups and subjected to flexion ($n = 11$) or extension ($n = 10$) bending up to 10°. In addition there was a control group ($n = 11$) in which tension band wiring was tested to flexion and extension bending to 10°. To eliminate intra- and interindividual differences in bone quality, each specimen was fused subsequently with each of the three different techniques for PIJ arthrodesis (intraosseous wiring, single oblique compression wire, and two crossed compression wires) and tested by undergoing flexion and extension motion. The tension band arthrodesis was tested in a similar fashion as a separate control group. Each arthrodesis was done with a standardized angle of 20°, to allow a more definitive comparison with the existing literature on PIJ arthrodesis. The angle was set using a finger goniometer.

The specimens were cleared of all soft tissues, except for the collateral ligaments and the articular cartilage. A technique of bone preparation, which preserves the geometrical shape of the bone ends and provides a large area of bone contact (cup-and-cone and pepper-pot method), was used for fusion.

Bone mineral density was measured by dual energy X-ray absorptiometry (Prodigy, GE Healthcare GmbH, Solingen, Germany) and correlated to the biomechanical stability.

For all tests that featured the compression wire, a threadless section of 10 mm length was used. The arthrodesis was achieved with three turns of the trailing thread inserted into the cortical bone to ensure a standardized compression. Crossing the joint with an angle of 45° in the radio-ulnar plane, the compression wire was inserted 8 mm proximal of the arthrodesis site (Fig. 2).

Intraosseous wiring and tension band wiring were done with a cerclage wire of 0.8 mm and a K-wire of 1.0 mm (Figs. 3, 4). All implants used comprised of medical stainless steel.

Using a universal testing machine (Zwick Z050®, Zwick GmbH & Co. KG, Ulm, Germany), tests were run in four-point bending. The extensions of the force conductor were positioned 3 mm proximally and distally from the arthrodesis site on the specimen. The ends of the proximal and the distal phalanx were embedded in cylinders of cold polymerised plastic. A cylindrical embedment was chosen to allow compensatory rotational movement and constant contact area on the specimen-holder during loading. After the joints were fused, the specimens were placed in a custom-made sample holder (Fig. 5). Force was applied continuously at a rate of 100 mm/min in steps of 0.5° until

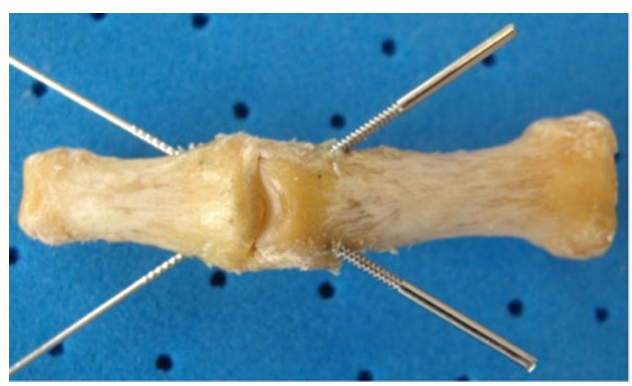

Fig. 2 Photograph of the arthrodesis of the proximal interphalangeal joint using compression wire

Fig. 1 Photograph of the different pitches and threadless section of the compression wire

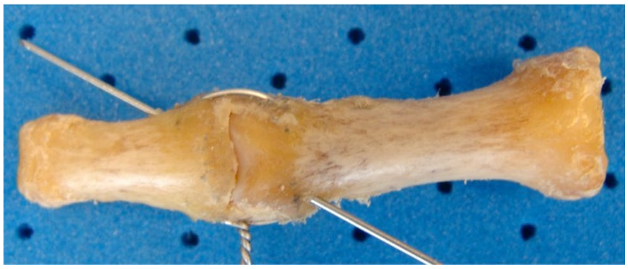

Fig. 3 Photograph of the arthrodesis of the proximal interphalangeal joint using intraosseous wiring

Fig. 4 Photograph of the arthrodesis of the proximal interphalangeal joint using tension band wiring

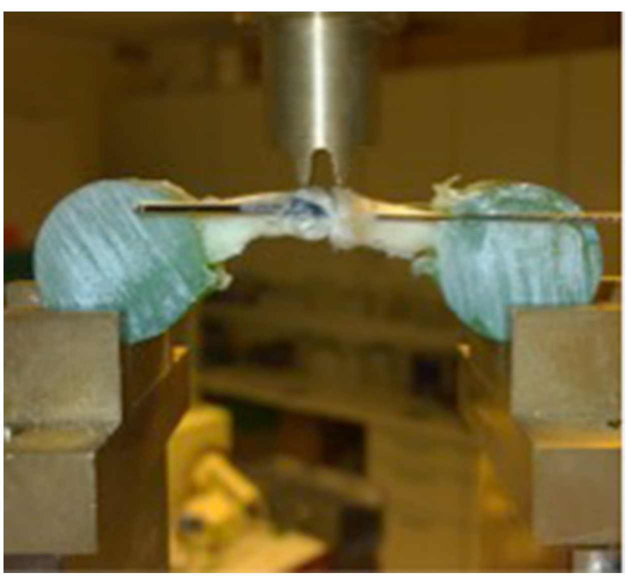

Fig. 5 Photograph of the testing jig setup during a test of the compression wire

a maximum of 10° flexion or extension was achieved and the required force recorded by a computer using testXpert II software (Zwick GmbH & Co. KG, Ulm, Germany).

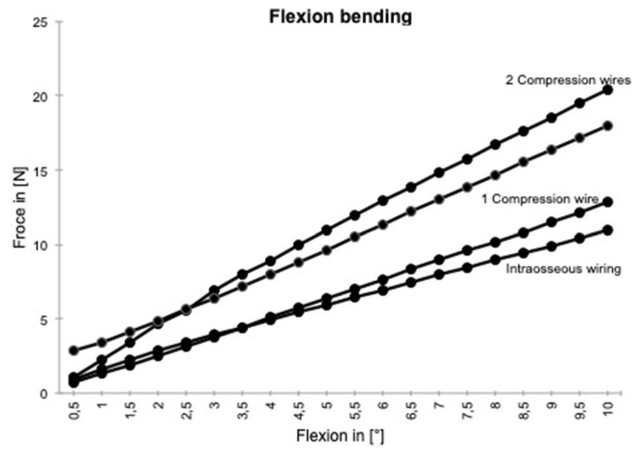

Fig. 6 Diagram depicting the average flexion bending stability to 10° for intraosseous wiring, one single compression wire and two crossed compression wires

Main outcome was the force necessary to achieve a bending of 10°. Statistical evaluation of the arithmetic mean was carried out using a two-way ANOVA with flexion/extension as between-subjects factor, and wiring technique as within-subjects factor, and a two-way ANCOVA with the additional inclusion of the bone mineral density as the covariate. Since the tension band arthrodesis was carried out as a separate control group no statistical comparison to the other techniques was feasible.

Results

Flexion bending showed a necessary mean value of force to achieve bending of 10° for intraosseous wiring of 10.94 N (SD 3.86 N), for one compression wire of 12.82 N (SD 5.56 N), 17.95 N (SD 4.18 N) for tension band wiring and for two crossed compression wires of 20.42 N (SD 6.57 N) (Fig. 6). Similar results could be shown for the extension bending with mean values of 9.71 N (SD 3.27 N) for intraosseous wiring, 13.63 N (SD 3.91 N) for one compression wire, 21.43 (SD 3.44 N) for tension band wiring and 22.56 N (SD 3.43 N) for two crossed compression wires (Fig. 7). There was a highly significant superiority of the crossed compression wires in comparison to the other two techniques ($p < 0.0001$) and a significant superiority of the single compression wire compared to intraosseous wiring ($p < 0.05$) for flexion as well as extension bending. Tension band wiring showed an intermediate stability with respect to the other techniques.

The average bone mineral density in the flexion group was 0.31 g/cm^2 and 0.29 g/cm^2 in the extension group but there was no statistically significant correlation between biomechanical stability and bone mineral density within each

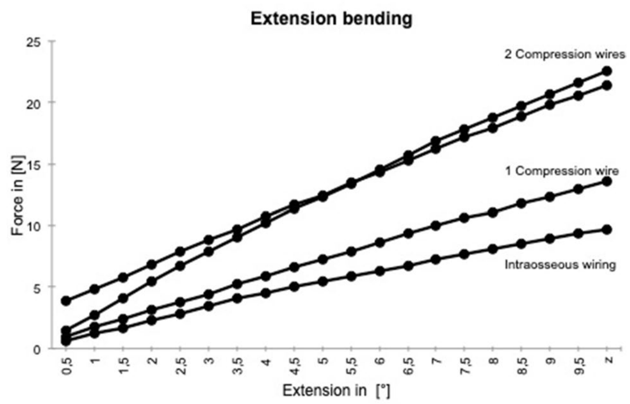

Fig. 7 Diagram depicting the average extension bending stability to 10° for intraosseous wiring, one single compression wire and two crossed compression wires

group ($p > 0.05$). The tension band wiring group showed an average bone mineral density of 0.28 g/cm^2.

Discussion

The aim of this study was to investigate if a single oblique or two crossed compression wires would have a superior primary strength with regard to bending forces in comparison to intraosseous wiring and tension band wiring, since it has been stated that initial stiffness of the arthrodesis with a certain technique can be considered as one of the basic determinants for achieving solid bony union [5, 7].

Although there are numerous comparative biomechanical investigations on osteosynthesis of fractures of the phalangeal bones, there are only a few on PIJ arthrodeses. Due to a variety of experimental setups, differing loading directions and that most studies tested to failure, there is only a limited comparability between this study and others [7, 13, 14, 20–22]. Lately Alluri et al. tested 90/90 intraosseous wiring to 90/90 intraosseous wiring augmented with two headless cannulated screws and found the augmented version to be significantly superior when subjected to sagittal and coronal bending to 10°, but found no significant differences when loading to catastrophic failure. Capo et al. compared the Apex IP Fusion device (Extremity Medical, Parsippany, New Jersey, USA) with intraosseous wiring, tension band wiring, 90/90 intraosseous wiring and dorsal plate arthrodesis and tested sagittal and coronal bending to 10 N/mm as well as ultimate extension. In flexion bending, the apex IP fusion device was superior to all techniques but the dorsal plate, whereas it was superior to all of the other techniques in extension bending. In ultimate extension bending the intramedullary linked screw was significantly superior to all other techniques but intraosseous wiring. Mittelmeier et al. compared the biomechanical stability of intraosseous wiring, tension band wiring with absorbable PDS thread and cerclage wire under consideration of different angles of arthrodesis, insertion angles of the K-wires and preparation techniques of the bone surfaces using an acrylic bone model. Comparing the results at an angle of arthrodesis of 20°, a single compression wire and two crossed compression wires showed a nearly similar stability as tension band wiring with the absorbable PDS cord, but are inferior to tension band wiring with a cerclage wire, although there are major differences in the experimental setups which limit the comparability of results [14].

Kovach et al. compared the ultimate strength of two different types of intraosseous wiring, two crossed K-wires and tension band wiring in flexion bending. Although not statistically significant, tension band wiring tended to have the greatest strength, followed by intraosseous wiring [13].

This study has certain limitations. The use of cadaver bones in general for biomechanical testing along with the effect of their storage and conservation testing has been a controversial issue for some time. Though some authors point out the benefits of synthetic bone models as an alternative, cadaver bones are still considered to be the most realistic simulacrum for in vivo mechanical properties. At the same time, many studies have shown a modifying effect of alcohol fixation on certain mechanical properties, which may limit their use in biomechanical testing [23–25].

Especially with regard to biomechanical testing of proximal interphalangeal joint arthrodesis, it is noteworthy that Ayres et al. compared the Herbert screw in comparison to the tension band on fresh-frozen as well as formalin-fixed but did not get statistically significant results in either group [20].

Further biomechanical studies should be undertaken to evaluate the performance of compression wires compared to other established techniques such as screws or plates, which have performed favourably in other biomechanical trials [7, 20]. A third control group using a single K-wire was not considered, because the goal was to compare different in vivo usable techniques for proximal interphalangeal joint fusion. A single K-wire is not normally used in the fusion of phalangeal joints. In addition, consideration should be given to evaluating additional planes of motion, such as radial and ulnar flexion, rotational stability as well as using pressure measurement foils to monitor compression over the arthrodesis site [14, 19].

In summary, the statistical analysis shows that the primary stability of the PIJ arthrodesis by the compression wire is higher than with intraosseous wiring. The control group with tension band wiring showed an intermediate stability. Considering the results, the higher stability of the compression wire might imply higher early motions stability, which is key for achieving rapid solid bony union and decreasing failures. The compression wire should be further evaluated in biomechanical and clinical trials.

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Compliance with ethical standards

Conflict of interest Alexander Zach: workshop instructor and lecture for Königsee Implantate GmbH (Am Sand 4/OT Aschau, 07426, Allendorf, Germany). On behalf of all other authors, the corresponding author states that all other named authors hereby declare that they have no conflicts of interest to disclose.

Ethical approval This study was approved (Reference number: BB 130/13) by an institutional review board.

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