CLINICAL PAPER

Computer assisted planning and custom-made surgical guide for malunited pronation deformity after first metatarsophalangeal joint arthrodesis in rheumatoid arthritis: A case report

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Abstract

Arthrodesis of the first metatarsophalangeal (MTP-1) joint is a widely used procedure for the treatment of hallux valgus in patients with MTP-1 degeneration, severe or recurrent deformity, or inflammatory arthritis. In this case, ten years earlier, the patient's MTP-1 joint had been fused in a severe pronation deformity position. Subsequently, a laterally shifted tibial sesamoid and osseous rising of the phalanx base caused painful callosities. To correct the pronated deformity accurately, a custom-made surgical guide based on a three-dimensional computer tomography (3D-CT) simulation system was used. After correction of the deformity, the MTP-1 joint was again fused. Adequate correction was achieved, and the patient no longer complains of pain and can perform full weight-bearing on the forefoot. The difficulty and importance of placing the MTP-1 joint in an adequate rotational position in MTP-1 joint arthrodesis surgery were confirmed, as was the utility of 3D evaluation and a custom-made surgical guide for rotational adjustment between the metatarsal and the proximal phalanx. We believe that this system should be one of the indicators for adjusting the rotation, especially in revision MTP-1 joint fusion surgery.

Keywords

Computer assisted planning, custom-made surgical guide, metatarsophalangeal joint arthrodesis, rheumatoid arthritis, rotational adjustment, three-dimensional evaluation

History

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Introduction

First metatarsophalangeal (MTP-1) joint arthrodesis is a widely accepted method for the surgical treatment of hallux (big toe) valgus deformity in patients with MTP-1 joint degeneration [1–5]. In addition, this procedure can be used for patients with more severe deformities or recurrent hallux valgus, or with a deformity secondary to inflammatory arthritis of the joint [6–10]. If the MTP-1 joint is fused in malposition, pain and functional problems occur. The recommended hallux valgus angle is between 20° and 30° [11, 12]. Although the hallux valgus angle has not been shown to correlate with the clinical results [13], it may be a determinant of the development of arthritis in the interphalangeal joint [11].

Various authors have proposed values of hallux dorsiflexion from 0 to 40° [12, 14–18]. These values can be somewhat misleading in that a plane of reference is not given. In determining dorsiflexion angles of the hallux in relationship to the horizontal surface of the ground, there may be difficulty in duplicating this angle in a non-weight-bearing foot on the operating room table. As mentioned above, many authors suggest varying degrees of valgus and toe dorsiflexion, while it has been reported that the proper reference point for the rotation angle is 0° [19].

Rotation of the hallux results in undue pressure along either nail border, keratosis along a prominent medial or lateral condyle, or increased weight-bearing stress through the interphalangeal (IP) joint. Surgeons are told that, intraoperatively, they should use the nail plate as a guide to the degree of rotation present at the hallux. However, in the present case, the MTP-1 joint was fused in a severely pronated, rotated position, though angulation of the nail plate was used as a guide for rotation adjustment, suggesting the difficulty of achieving accuracy with this method. Angulation of the nail plate is varied by the flexibility of the IP joint, suggesting this

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guide is not always correct. It was therefore thought important that guides without a striding IP joint should be developed and used to avoid errors in determining the position of the distal phalanx bone and/or nail plate.

The shape of the bone surface and the pronation deformity of the MTP-1 joint differs between cases. Therefore, use of a patient-specific cutting and rotational guide for the first metatarsal and first proximal phalangeal bone was considered appropriate. This system was originally developed as a simulation system consisting of a 3D computer program and a custom-made osteotomy template that allows the reproduction of a preoperative simulation during the actual surgery for correction of fracture malunion and deformity [20-24]. In the present case, this pronated deformity was evaluated three-dimensionally, and arthrodesis was performed in the re-aligned position after corrective osteotomy using a custom-made surgical guide.

Case report

A 64-year-old woman with a 31-year history of rheumatoid arthritis (RA) (functional class II, radiographic stage IV) had been treated with methotrexate (MTX, 4 mg/wk) and tocilizumab (8 mg/kg). Ten years earlier, at another hospital, MTP-1 joint arthrodesis and resection arthroplasty of the lesser toes had been performed for forefoot deformity with painful hallux valgus deformity and callosities. However, the hallux pain remained, and painful callosities formed. Four years later, at the same hospital, a partial resection of

the osseous rising of the medial base of the proximal phalanx was performed, and extensor hallucis longus (EHL) elongation was also done for hyperextension of the IP joint. However, the hallux pain did not disappear, and the painful callosities remained (Figures 1 and 2). Subsequently, the deformity of the fused MTI-1 joint was evaluated three-dimensionally at our hospital. It was found that there was a severely pronated position of the proximal phalanx against the metatarsal (approximately 70° pronated) (Figure 3), with subsequent lateral shifting of the tibial sesamoid and osseous rising of the proximal phalanx base that caused painful callosities (Figure 2). Given these findings, it was decided to operate to correct the pronated deformity. After correction of the deformity, the MTP-1 joint was again fused as mentioned below. The patient no longer complains of pain and can perform full weight-bearing to the forefoot. The gait speed has increased, and the callosities have become smaller.

Simulation technique

The affected limb (from the ankle to the forefoot) was scanned using a computed tomography scanner (LightSpeed Ultra 16, General Electric, Waukesha, WI), with scan time of 0.5 s, scan pitch of 0.562:1, tube current of 10 to 50 mA, and tube voltage of 120 kV. Digital data from 1-mm slices were sent to a workstation (Precision Workstation 650, Dell, Round Rock, TX). The skin and bones of the affected foot were segmented, and 3D surface models were constructed by

Figure 1. Preoperative X-ray of the affected foot. The MTP-1 joint is fused in malposition (yellow arrow). The X-ray shows the internal rotation of the proximal phalanx (white arrow), and the sesamoid bone is laterally shifted (blue arrow) (Hardy grade 4).

Figure 2. The affected foot. The laterally shifted tibial sesamoid and osseous rising of the proximal phalanx base have caused painful callosities (yellow arrows).

Figure 3. Three-dimensional evaluation of the affected foot. The severely pronated position of the proximal phalanx against the metatarsal (approximately 70° pronated) is evident.

applying 3D surface generation of the cortex of the bone and skin using an original computer program based on the Visualization Toolkit (Kitware, Clifton Park, NY).

Design and manufacture of the custom-made osteotomy guide

To reproduce the preoperative simulation during the actual surgery, an operative method using a custom-made osteotomy template was designed based on preoperative 3D computer simulation using commercially available software (Magics RP, Materialise, Leuven, Belgium). This was embodied as a plastic model through rapid prototyping technology (Eden 250, Objet Geometries, Rehovot, Israel, or Viper si2, 3D

Systems, Rock Hill, SC) using medical-grade resin. The custom-made osteotomy template had a shape that closely fitted the bone surface and an osteotomy surface and drill-holes that guided the insertion of the Kirschner wires (K-wires). These K-wires were perpendicular to the longitudinal axis and horizontal plane of the metatarsal and proximal phalanx (Figures 3 and 4), and served intraoperatively as a rotational guide by parallelizing each other. The simulation for setting of the metatarsal and proximal phalanx cutting template is shown in Figure 4. The projections given were programmed to guide the bone saw in cutting the metatarsal and proximal phalanx perpendicular to the longitudinal axis (Figure 4).

Figure 4. The simulation for setting the metatarsal and proximal phalanx cutting templates (red). The K-wires (green) are perpendicular to the longitudinal axis of the metatarsal and proximal phalanx. The projections given were programmed to guide the bone saw in cutting the metatarsal and phalanx perpendicular to the longitudinal axis (*).

Figure 5. Intraoperative photograph of the custom-made surgical guide fixed with K-wires. (A, B) The distal end of the metatarsal and the proximal end of the proximal phalanx are fixed with K-wires with the aid of the 3D-CT-based custom-made surgical guide designed preoperatively. (C) The rotational position between the two bones is adjusted using the fixed K-wires as a rotational guide.

Surgical technique

The tourniquet was inflated to 250 mm Hg and surgery was carried out through a previous skin incision. After the incision, subcutaneous soft tissue was retracted, and the periosteum

was split, exposing the bone surface. Preparation of the osseous surfaces commenced with a flat resection of the distal end of the metatarsal and the proximal end of the proximal phalanx, which was carried out with the aid of the 3D-CT-based custom-made surgical guides designed preoperatively

Figure 6. Postoperative X-ray of the affected foot. The MTP-1 joint is re-fused in the proper rotational position. Improvements in the pronated deformity and the sesamoid position are seen (Hardy grade 2).

(Figure 5A and B) and fixed with the K-wires. Next, the guide was broken and removed while leaving the K-wires in place. The rotational position between the two bones was then adjusted using the fixed K-wires, which served as a rotational guide by parallelizing each other (Figure 5C). After confirmation of sufficient and adequate correction, the MTP-1 joint was re-fixed with two 3-mm cannulated screws and an AcuTwist® screw. The duration of non-weight-bearing was 4 weeks, after which the patient was allowed to do full weight-bearing with an insole.

Discussion

Though it is very important to fix the MTP-1 joint in an appropriate position, with the appropriate hallux valgus angle, dorsiflexion angle, and rotation angle between the metatarsal and proximal phalanx bone, this is not always easy. In fact, the present case showed a proper hallux valgus angle and appropriate hallux dorsiflexion, but the rotation angle was not acceptable, suggesting the limitation and difficulty of achieving accuracy with this method using the nail plate as a guide for rotational adjustment. An alignment gauge has been designed specifically for use in metatarsophalangeal fusion surgery, indicating the importance of having a guide available to provide an accurate index of rotation and alignment. Furthermore, surgeons are told that, intraoperatively, they should use the nail plate as a guide to the degree of rotation present at the hallux. However, angulation of the

nail plate is varied by the flexibility of the IP joint, suggesting that this guide is not always correct. It was therefore thought to be important that guides without a striding IP joint should be developed and used to avoid errors in determining the distal phalanx bone and/or nail plate position (rotation).

In the current case, a custom-made surgical guide without a striding IP joint was used (Figures 4 and 5). In the process of making the guide, 3D evaluation of the deformity can be performed, because this guide is based on a 3D-CT simulation system. As shown in the simulation picture, one can clearly recognize the severely pronated deformity of the fused MTP-1 joint and the laterally shifted tibial sesamoid which causes the painful callosity preoperatively (Figures 2 and 3). One can also see that the rotational deformity was corrected, and that the subsequent repositioning of the sesamoid was appropriate postoperatively (Figures 6 and 7). In such surgery, it is difficult to identify an adequate starting position and the direction of bone cutting because the MTP-1 joint is already fused, so landmark information is poor. In such cases, a pre-made custom guide is very useful (Figures 4 and 5). We found it easier to perform the procedure using the guide, because there was no confusion about the bone cutting. When using this guide for surgery, however, removal of soft tissue from the surface of the bone is very important, because remaining soft tissue causes an insufficient fit between the guide and the bone surface, so that bone cutting becomes rough and

Figure 7. Images created from the 3D-CT data of the affected foot postoperatively. The rotational deformity is corrected, and the sesamoid is properly repositioned postoperatively.

inaccurate. After the osteotomy, the K-wires used for fixation of the guide are very useful, because they can serve as an indicator for rotational adjustment by parallelizing each other (Figure 5B and C).

It is thought that revision surgeries of MTP-1 joint fusion will increase in the future. A custom-made surgical guide is not always necessary in MTP joint fusion surgery, but it provides surgeons with an accurate indicator in revision surgery. In the future, we plan to increase the number of cases, and re-evaluate the approach. Furthermore, we want to make such a custom-made guide more commercially available. To realize this concept, a fully controlled and tested system, manufacture's support, and the augmentation of education for technical assistance will be important.

Conclusion

In the present case, the difficulty and importance of adequate rotational positioning in MTP-1 joint fusion were reconfirmed. Furthermore, it is very important and useful to perform three-dimensional evaluation preoperatively, and then to use a custom-made surgical guide for rotational adjustment. We believe that this system should be one of the indicators for adjusting the rotation, especially in revision MTP-1 joint fusion surgery.

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Declaration of interest

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