Distal Ulna Reconstruction using the Second Metatarsal: Anatomical Study

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Abstract

Background The ulnar head is a key stabilizer of the wrist and forearm. The authors investigated the possibility of using the second metatarsal bone to replace the distal ulna in an anatomical study.

Methods The morphology of the distal ulna and the head of the second metatarsal (MT2) were studied using three-dimensional computerized tomographic (CT) scans of the wrist and foot in 52 patients without pathology related to these two areas, and 11 cadaveric specimens. The radius and height of the best-fit cylinder for both epiphyses were measured in the CT scans and compared. In the cadaveric specimens an osteotomy of the metatarsal neck was performed to rotate 90 degrees the head of the MT2 to match the shape of the distal ulna.

Results The osseous morphology of the distal ulna and the head of the MT2 are roughly cylindrical, but differently oriented relative to the diaphyseal axes. In the osteotomized cadaveric MT2 specimens, the overall morphology was relatively similar that of the distal ulna. The mean length of the MT2 after the osteotomy was 65 mm.

Conclusion The head of the MT2 was found to have a similar cylindrical morphology to that of the ulnar head, with a different orientation. The radius of the cylinder was similar, although the height was bigger for the MT2. After a rotation osteotomy of the neck of the MT2 the overall shape and orientation of the epiphysis was more similar to the distal ulna. A vascularized transfer of an osteotomized MT2 would be an option for autologous reconstruction of the distal ulna in selected patients, but further study is needed in terms of the vascular supply, ligamentous reconstruction, and reconstruction of the sigmoid notch.

Level of Evidence Therapeutic, level IV.

Keywords

- ulnar head
- DRUJ
- second metatarsal

The ulnar head is a key stabilizer of the wrist and forearm. Apart from its role in forearm rotation as an integral part of the distal radioulnar joint (DRUJ), the ulnar head maintains transverse forearm stability upon elbow flexion, preventing radioulnar convergence.¹ Although important capsule-ligamentous structures contribute to the overall stability of the DRUJ, the anatomic integrity of the distal ulna is a prerequisite

for this stability, especially during transverse loading with elbow flexion and lifting weight.^{2,3}

The distal ulna deficit may be due to trauma, tumor resection, or secondary to surgical treatment of DRUJ degeneration. Although the results of these resections are acceptable in terms of pain relief,⁴ the impact on transverse forearm stability has been recognized, boosting the research for prosthetic

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replacement.⁵ Ulnar head prostheses, either simple or constrained total DRUJ implants, have been devised to restore or maintain forearm stability.⁶ Besides congruency between the sigmoid notch and the implant, ulnar head hemiarthroplasty implants rely on soft tissues for stability, whereas constrained DRUJ implants are self-stabilizing. In general, implant arthroplasty is better indicated in elderly, low-demand patients. In young, active individuals autologous reconstruction would be preferable, although there is no available donor area that matches the ulnar head anatomy. The authors investigated the possibility of using the second metatarsal bone (MT2) to replace the distal ulna in an anatomical study. To make the MT2 more similar to the distal ulna, an osteotomy was performed in the MT2 in cadaveric specimens. The potential use of this construct as a vascularized composite transfer for autologous reconstruction of the distal ulna is suggested.

Materials and Methods

After proper institutional review board approval, the morphology of the distal ulna and the head of MT2 were studied in patients without pathology related to these two areas, using three-dimensional (3D) computerized tomographic (CT) scans. A total of 52 files of patients to whom 3D CT scans of the wrist and the foot were performed at a tertiary hospital were retrospectively reviewed (male:female ratio, 1:1). The age ranged from 19 to 63 years (mean: 36 years). The osseous anatomy was digitized with a 64-slice Siemens SOMATOM Sensation CT system (0.6-mm contiguous axial slices; Siemens Medical Solutions, Malvern, PA). DICOM (Digital Imaging and Communications in Medicine) raw datasets were reconstructed by use of the 3D software program MIMICS (Materialise, Leuven, Belgium).

The ulnar and metatarsal heads were geometrically assimilated to the cylinders (best-fit cylinder) for measurement and comparison (► **Figs. 1–3**). The best-fit cylinder was overim-

Fig. 1 Semiaxial, distal-to-proximal, view of the MT2 (left) and the ipsilateral ulna (right). The overall shape is different, although both epiphyses can be assimilated to a cylinder. The ulnar cylinder is perpendicular to the diaphyseal axis, while the MT2 cylinder is sagittally coplanar to the diaphysis. MT2, second metatarsal.

Fig. 2 The MT2 has been rotated 90 degrees to show the gross similarity of the respective epiphyses. MT2, second metatarsal.

posed on the widest part of the ulnar head and the MT2 using MIMICS software. The height and the radius of curvature of both cylinders were measured in the 3D reconstructions. The ulnar styloid process was ignored for height measurements. The accuracy of this technique was limited by the resolution of the CT scans with 0.5 mm for all measured dimensions.

Fig. 3 The best-fitting cylinder was calculated for the epiphyses of the distal ulna and the MT2. The height (H) and the radius (R) were measured for comparison. After osteotomy of the neck of the M2 and a 90 degree rotation, the cylinder is oriented perpendicular to the diaphyseal axis, similar to the distal ulna.

Fig. 4 Semiaxial view of the right distal ulna and the modified MT2 of the same individual. The MT2 construct is fixed with 2.0 mm plate and screws. The overall morphology is similar. MT2, second metatarsal.

In an attempt at overcoming the difference in orientation of the ulnar and MT2 heads, a technical modification was performed on 11 cadaveric specimens. An osteotomy was performed at the neck of the MT2 and the head was rotated 90 degrees to place it perpendicular to the shaft (**→Figs. 4 and 5**), and fixed with a 2-mm plate (Compact Hand Synthes, Paoli, PA). The length of the epiphyseal segment osteotomized corresponded to the diameter of the ulnar head of the same cadaver. The congruency of the osteotomized MT2 and the ipsilateral sigmoid notch was evaluated by gross visual inspection in pronation, neutral, and supination in the axial plane. This modified distal MT2 was constructed in 10 specimens (randomly selected, ipsilateral dry MT2, radius, and ulna) and in one fresh cadaver to simulate a clinical composite osteochondral flap with a skin island for monitoring (**→Fig. 6**). The plate and screws were placed on the lateral (fibular), nonpedicle, side of the bone to

Fig. 6 Fresh cadaver specimen of the composite flap, right side. The flap includes the osteotomized MT2, the first dorsal metatarsal artery, saphenous vein, and a skin monitor. The distal ulna of the same individual is shown for comparison. MT2, second metatarsal.

Fig. 5 Palmar view of the right hybrid DRUJ between the radius and the modified MT2. The overall shape resembles a native DRUJ. DRUJ, the distal radioulnar joint; MT2, second metatarsal.

minimize the potential damage to the osseous blood supply. No anatomical studies on the vascularity of the MT2 after the osteotomy were done. The maximal length of the metatarsal construct after the osteotomy, excluding the subchondral bone at the base of the MT2, was measured in the dry specimens. The ipsilateral donor metatarsal was used.

Continuous data are presented as the mean, median, range, and standard deviation, expressed in millimeters, and compared using a Student *t*-test for independent groups. A *p* value ≤ 0.05 was considered statistically significant. Analysis of the data was conducted using the SPSS software package (version 17.0; SPSS Inc., Chicago, IL).

Results

The shape of the ulnar head can be assimilated to a cylinder axially oriented. The mean height of the best-fit cylinder of the distal ulna was 6.32 mm (standard deviation [SD], 0.87 mm). The mean radius of curvature of the distal ulna cylinder was 6.67 mm (SD, 0.98 mm). The shape of the head of the MT2 can be assimilated to a sagittally oriented cylinder. The height of this cylinder was 11.1 mm (SD, 1.27 mm), and its radius was 6.74 (SD, 0.46 mm) (**→Table 1**).

There was a significant statistical difference between the distal ulna and MT2 head for height ($p < 0.001$). There was no significant statistical difference between the radii of curvature of the cylinders for the distal ulna and the MT2 ($p = 0.92$). The total length of the modified MT2 was 65 mm (SD, 8.4 mm), and corresponds to the theoretical maximum length of the distal ulna that could be reconstructed with this technique. After the osteotomy the overall morphology of the modified MT2 was relatively similar to the distal ulna (**→Figs. 4–6**), with acceptable congruency of the hybrid DRUJ in pronation and supination (**→Figs. 7A–C**). Although the vascular anatomy of the MT2 after osteotomy was not investigated, limited periosteal elevation was necessary for bone cutting and fixation, adding little manipulation (and thus devascularization) compared with a standard metatarsophalangeal joint transfer.

Table 1 Comparison between height and radius of ulna and second metatarsal, without and with osteotomy

	Mean	Standard deviation	Range	p Value ^a
Height (mm)				
Ulna	6.32	0.87	4.91–8.51	
Second metatarsal	11.1	1.27	7.36–13.10	< 0.001 ^b
Radius (mm)				
Ulna	6.67	0.98	5.08–9.66	
Second metatarsal (II)	6.74	0.46	5.85–7.78	0.92

^ap Values based on Student *t*-analysis for comparison and measures.

^bSignificant difference.

Discussion

The relationship between the ulna and the radius is complex and affects the wrist and elbow dynamics. Of the three components of the radioulnar complex, the proximal radio-ulnar joint, the interosseous membrane, and the DRUJ, the latter is the most commonly injured. Intact skeletal anatomy is a prerequisite for DRUJ stability, especially regarding transversal forearm stability, and avoidance of radioulnar convergence upon elbow flexion.^{2–5} Restoration of this bony anatomy is essential for a stable radioulnar complex. Various prosthetic designs have been developed, including distal ulna hemiarthroplasty, constrained total joint replacement, and partial ulnar head replacement.⁶ The overall short-term results of prosthetic replacements are good, although mid- and long-term complications in active, young individuals are frequent.^{7,8} Autologous reconstruction would thus be desirable in this subset of patients.

The DRUJ is a relatively incongruent trochoid joint, the radius of curvature of the ulnar head being smaller than that of the sigmoid notch.⁹ This incongruity is functionally important, since the movement of the DRUJ is not simply a rotation of the distal radius around the ulnar head. There is a translational movement of the distal ulna relative to the radius, important for the amplitude of pronation–supination.¹⁰

Nonvascularized osteochondral grafts have limitations in size and are indicated only in smaller partial joint defects.¹¹ Vascularized osteochondral transfers have the definite advantage of excellent healing potential and longevity, although technical complexity and limitations in shape-matched donor areas preclude their widespread utilization.¹² Most frequently used in the reconstruction of small joints of the fingers as vascularized toe joint transfers, there have been anecdotal reports of vascularized joint reconstruction in other anatomical areas. There have been isolated attempts at vascularized reconstruction of the DRUJ. del Piñal et al described a creative vascularized osteochondral transfer from the base of the MT2 for reconstruction of the sigmoid notch and lunate facet of the radius with good short- and mid-term results.¹² The same author reported on a case of reconstruction of the articular portion of the ulnar head with

Fig. 7 Axial, distal-to-proximal view of the congruency of the hybrid DRUJ, right side, in full supination (A), mid rotation (B), and full pronation (C). The congruency is reasonable, although not perfect. DRUJ, distal radio ulnar joint.

intact ulnar styloid and triangular fibro cartilage complex (TFCC) using a microvascular head of MT2 perpendicularly oriented with excellent mid-term results.¹³ These authors recognized the need to place the head of the MT2 perpendicularly to the ulna for optimal articular congruency. The vascular anatomy of the second toe and MT2 has been reported previously.^{14–16} The first dorsal metatarsal artery gives off several musculoperiosteal branches to the MT2 and, although not specifically studied in the present article, it is reasonable to assume that after careful

limited periosteal stripping, the two segments of the osteotomized MT2 would retain adequate vascularity. Further research in this regard is warranted.

The morphometric results of the present study show the similar radius of curvature of the best-fit cylinder of the distal ulna and the head of MT2 within the same individuals. The height of the MT2 cylinder was statistically larger, although the normal proximoradial slope of the sigmoid notch in the coronal plane would accommodate this extra height. After correction of the different orientation of the cylinders with the metatarsal osteotomy, the anatomic resemblance between the two bones and the congruity of the hybrid DRUJ were improved (→ Figs. 7A–C). This similarity would contribute to the transversal stability of the forearm, a major consideration in DRUJ reconstruction. The maximum length of 65 mm would allow for the reconstruction of most distal ulnar defects.

Because the technique proposed would be an autologous hemiarthroplasty, sigmoid notch integrity is a prerequisite, as it is in implant hemiarthroplasties. Potential indications for this technique would be acute traumatic or oncologic loss of the ulnar head, DRUJ degeneration in young patients, and postresection (Darrach) DRUJ instability. As suggested by the cadaveric simulation, periosteal stripping should be limited. In setting and fixation of the bone would be relatively straightforward and vascular anastomoses could be readily performed to the ulnar vessels. The subcutaneous position of the distal ulna allows for using a skin monitor in the free flap. Ligament stability would be a matter of concern in these reconstructions. Simply suturing the remnants of the TFCC to the lateral collateral ligaments of the head of MT2 may not provide enough stability. Moreover, the position of the collateral ligament after the osteotomy does not match the normal fovea in the native distal ulna. Formal ligament reconstruction would be necessary. Immediate ligament reconstruction would probably risk the vascularization of the head of the MT2, and could be performed secondarily, once the bone is healed, should instability occur. The need for a relatively well-preserved sigmoid notch would limit the potential indications. In an attempt to overcome these limitations, that is, the need for secondary ligament reconstruction and a well-preserved sigmoid notch, the whole second metatarsophalangeal (MP) joint has been investigated in biomechanic studies and a clinical case.^{17,18} The lateral range of motion of the second MP joint was used to restore pronation–supination. The authors are currently investigating the biomechanics of the osteotomized MT2 with MP joint for complete DRUJ replacement.

The present study has significant limitations. The measurements were performed in reconstructed 3D CT scans and thus the cartilage was not included. Anatomical studies in specimens with intact cartilage would improve our knowledge. The head of MT2 is not perfectly cylindrical, and assimilating it to a cylinder makes measurements inaccurate. Ipsilateral bones were used in the anatomical study. Probably the difference between the ipsilateral and contralateral donors should be investigated in a fresh cadaver study, along with the optimization of the inseting. The fresh cadaver simulation in the present study was only aimed at evaluating the amount of periosteal stripping necessary to perform the osteotomy and fixation. Further vascular studies are needed.

In conclusion, the head of the MT2 was found to have a similar roughly cylindrical morphology to that of the ulnar head, with a different orientation. This difference could be overcome with an osteotomy in dry specimens and a fresh cadaver. A construct relatively resembling the distal ulna could be obtained and it could have potential as a vascularized osteochondral transfer for distal ulna reconstruction.

Conflict of Interest

None.

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