Ulnar Groove Plasty Guided by a 3D Printing Technique for Moderate to Severe Cubital Tunnel Syndrome Caused by Elbow Osteoarthritis

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Background:
The purpose of this study was to explore the feasibility of ulnar groove plasty guided by a three-dimensional (3D) printing technique for treatment of moderate to severe cubital tunnel syndrome (CuTS) caused by elbow osteoarthritis.

Material/Methods:
Patients with moderate to severe CuTS secondary to osteoarthritis of the elbow were enrolled in our hospital from April 2015 to March 2018. Based on a previously proposed “elbow canal index”, a 1: 1 model of the elbow joint was printed using CT image data collected preoperatively. After computer-aided measurement, the standard for enlargement of the ulnar nerve groove was calculated and a personalized “trial model” was created by 3D reconstruction. After intraoperative exposure of the ulnar nerve sulcus, the proliferative osteoid was burried with a grinding drill, and the cubital enlargement was verified by the trial model. The ulnar nerve was decompressed and reincorporated into the enlarged cubital canal, and the Osborne ligament was zig-zag elongated and reconstructed.

Results:
None of the patients reported experiencing medial elbow instability, medial elbow pain, ulnar nerve subluxation, flexor-pronator weakness, or incision infection. There was significant improvement of the motor nerve conduction velocity, sensory nerve conduction velocity, two-point discrimination of the little finger, grip strength, pinch strength of the thumb and index finger, VAS score, and DASH score in this study (P<0.001).

Conclusions:
Ulnar groove plasty guided by a 3D printing technique may be another effective treatment of moderate to severe CuTS caused by elbow osteoarthritis.

Keywords:
Cubital Tunnel Syndrome • Imaging, Three-Dimensional • Osteoarthritis

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CLINICAL RESEARCH

Background

Cubital tunnel syndrome (CuTS) is the second most common peripheral nerve compression disease after carpal tunnel syndrome [1]. Moderate to severe CuTS can seriously affect the daily life of patients [2]. Ulnar groove narrowing caused by elbow osteoarthritis can lead to ulnar palsy, and CuTS associated with osteoarthritis of the elbow arises from shallowness or narrowness of the ulnar groove mediated by degenerative osteophytes originating in the humeroulnar joint underneath the ulnar nerve [3]. The critical point for treatment is to reduce friction and traction of the ulnar nerve at the elbow. Anterior transposition of the ulnar nerve moves the ulnar nerve anterior to the ulnohumeral axis, which is associated with more surgical incision complications, such as deep infection and loss of sensation, compared with decompression [4, 5]. Ulnar groove plasty is indicated for narrowing of the cubital tunnel by the osteophytes [6] and can effectively preserve the integrity of the medial epicondyle of the humerus and the attachment point of the medial collateral ligament in the elbow joint. Three-dimensional (3D) printing techniques have a wide range of applications and have gained unprecedented recognition in the medical community. Such techniques can be used for anatomical models, preoperative planning, or implants [7].

In this study, we aimed to determine the feasibility of ulnar groove plasty guided by a 3D printing technique in the treatment of moderate to severe CuTS caused by elbow osteoarthritis.

Material and Methods

Compliance with Ethics Standards

This study received ethics approval from the institutional review board of our hospital, the Ethics Committee of Cangzhou Hospital of Integrated Traditional Chinese and Western Medicine, Hebei Province, approval number 2015034, March 10, 2015. Only patients who met the criteria and provided consent were selected to participate in the study.

Patients

The inclusion criteria were: (1) patients with moderate to severe CuTS (modified McGowan grade IIa/IIb/III [8, 9]) caused by elbow osteoarthritis and (2) treatment between April 2015 to March 2018. Modified McGowan grades [8] were determined as follows: A patient with symptoms without abnormal objective findings was classified as grade I. Grade IIa neuropathy was characterized by intrinsic weakness, with incomplete wasting and abnormality of moving 2 PD, and good intrinsic strength without detectable atrophy. Grade IIb demonstrated intrinsic weakness, with incomplete wasting and abnormality of moving 2 PD, and only fair intrinsic strength with intrinsic atrophy. Grade III presented with neuropathy with disabling symptoms, profound motor weakness, marked intrinsic atrophy, and profound sensory disturbances.

The exclusion criteria were: (1) a double-crush lesion such as Guyon’s tunnel compression, cervical radiculopathy, or thoracic outlet syndrome; (2) systemic diseases such as rheumatoid arthritis, diabetes mellitus, or chronic renal insufficiency; or (3) traumatic ulnar nerve injury.

Preoperative Assessments

General information such as sex, affected extremity, age, symptom duration, and modified McGowan grade was collected. All patients underwent preoperative X-ray and computed tomography (CT) examinations of the elbow. The Tinel sign, Froment sign, Wartenberg sign, and elbow flexion test were routinely performed. The motor nerve conduction velocity, sensory nerve conduction velocity, two-point discrimination of the little finger, grip strength, pinch strength of the thumb and index finger, VAS score, and DASH score were used as the primary outcomes. Two-point discrimination of the little finger was measured using Jamar’s two-point sensory discriminator (Jamar® SANNYI Healthcare Corporation, Guiyang, China). Grip strength of the thumb and index finger was measured using hydraulic grip meter (Jamar® SANNYI Healthcare Corporation, Guiyang, China). Pinch strength of the thumb and index finger was measured using a mechanical pinch meter (Jamar® SANNYI Healthcare Corporation, Guiyang, China). Postoperative complications, such as medial elbow instability, medial elbow pain, ulnar nerve subluxation, flexor-pronator weakness, and incision infection, were recorded. Patients were followed up for at least 12 months.

3D Printing Technique

Firstly, CT data of the affected elbow joint were collected and stored in DICOM format. Secondly, the two-dimensional CT scan data in DICOM format was input into Mimics 19.0 for editing and 3D reconstruction. Among them, image editing included image segmentation, visualization, and registration. 3D reconstruction is a discrete and approximate 3D model simulation of the surface of the original object by a large number of triangular faces of various shapes and sizes. Based on the bone mineral density of CT scan data of patients, the brush threshold was filled to make the elbow more complete. Then, the elbow joint was connected with the connecting column and combined into a whole with Boolean operation to prevent fracture during post-processing. The surface of the model was simply smooth and finally output in STL format (Figure 1). Thirdly, based on a previously proposed “elbow canal index”, the exported STL format data was used by the rapid prototyping machine (KINGS 3D Printing Technology Co., Ltd., Shenzhen, China) and then imported into
Materialise Magics 21.0 3D Print Suite for model repair (shell, hole, method phase, overlapping triangles, sharp triangles), then the model was placed and supported, and the support was processed to ensure the support strength. Subsequently, slices were processed and imported to a 3D printer, and a 1:1 test model was printed. Finally, the printed “trial model” was sterilized with ethylene oxide sterilization for later use (Figure 2). All costs of 3D reconstruction were fully reimbursed by China Basic Medical Insurance (approximately $250 U.S. dollars per patient).

Surgical Technique

All operations were performed by the same group of senior attending physicians. All patients received surgery under brachial plexus block anesthesia with an inflatable tourniquet control. The upper limbs were abducted on the operating table. A 10-cm curvilinear incision was made between the medial epicondyle of the humerus and the olecranon of the ulna. The incision was centered on the medial epicondyle and extended 5 cm in both the distal and proximal directions. Special attention was paid to protection of the branches of the medial antebrachial cutaneous nerve during the operation. The ulnar nerve was identified and the cubital tunnel was opened by dissecting the Osborne ligament with a Z-line incision and the remaining retinaculum. Decompression was thoroughly performed from the Struther arcade and medial intermuscular septum to the deep flexor-pronator aponeurosis until there was no point of compression. The ulnar nerve was pulled posteriorly and the joint capsule was cut at the olecranon attachment to expose the ulnar nerve groove (Figure 3). The posterior bundle of the medial ulnar collateral ligament must be protected as a result of secondary restraint against valgus instability [10]. The ulnar
nerve groove was deepened and widened with a high-speed grinding drill (Figure 4), and the degree of bone grinding was verified by a "trial model" with ethylene oxide sterilization (Figure 5). The operation was repeated until the trial model had a close fit. The bone fragment was washed, bone wax was applied to the bone wound for hemostasis, and the periosteum and joint capsule were sewn back in place. If the periosteum was not wide enough to cover the deepened cubital tunnel, we replenished it with the fascial tissue or with a section of Osborne ligament. The ulnar nerve was decompressed and reincorporated into the enlarged cubital tunnel, and the Osborne ligament was zig-zag elongated and reconstructed (Figure 6). After re-confirmation that the ulnar nerve could slide forward and backward by >2 mm in the reconstructed cubital tunnel and had no compression during passive flexion and extension of the elbow joint, the incisions were sutured layer by layer after hemostasis. The elbow joint was immobilized at 45° flexion with a long-arm plaster cast after the operation, and the cast was removed after 3 weeks.

**Statistical Analysis**

All statistical analyses were performed using SPSS 21.0 software (SPSS, Inc., Chicago, USA). Continuous variables are expressed as mean (SD) for normally distributed data or median (interquartile range) for non-normally distributed data, while
Categorical variables are expressed as frequency (percentage). Data for continuous variables were compared preoperatively and postoperatively by a paired-sample t test (or two-sample Wilcoxon parametric test), while data for categorical variables were compared preoperatively and postoperatively by the Pearson chi-square test (or Fisher’s exact test). Values of $P<0.05$ were considered statistically significant.

**Results**

Of 46 patients initially recruited to this study, 40 were available for 12-month follow-up. General information such as sex, affected extremity, age, and symptom duration is shown in **Table 1**. All patients underwent follow-up for 12-18 months (mean: 15.1 (SD 1.5) months). None of the patients reported having medial elbow instability, medial elbow pain, ulnar nerve subluxation, flexor-pronator weakness, or incision infection. **Table 2** shows a comparison of modified McGowan classifications in all patients.

| Demographics               | Number |
|----------------------------|--------|
| Patients                   | 40     |
| Sex (Male: Female)         | 32: 8  |
| Affected extremity (right: left) | 26: 14 |
| Age (years)                | 56.5 (SD 4.6) |
| Duration of symptoms (month) | 26.1 (SD 2.9) |
| Follow-up period (month)   | 15.1 (SD 1.5) |

**Table 2.** Comparison of modified McGowan classification in all patients.

| Modified McGowan classification | Preoperative | 12-month follow up |
|---------------------------------|--------------|--------------------|
| Grade I                         | 0            | 6                  |
| Grade IIa                       | 18           | 12                 |
| Grade IIb                       | 13           | 9                  |
| Grade III                       | 9            | 3                  |

The findings for the primary outcomes are shown in **Table 3**. The motor nerve conduction velocity was 28.7 (SD 2.7) m/s preoperatively and 44.0 (SD 3.8) m/s postoperatively. There were significant differences between before and after treatment ($t=-24.850$, $P<0.001$), indicating significant improvement of the motor nerve conduction velocity. The sensory nerve conduction velocity was 24.0 (2.0) m/s preoperatively and 40.0 (2.0) m/s postoperatively. There were significant differences between before and after treatment ($Z=-5.532$, $P<0.001$), suggesting significant improvement of the sensory nerve conduction velocity. The two-point discrimination of the little finger was 14.0 (2.8) mm preoperatively and 6.0 (1.0) mm postoperatively. There were significant differences between before and after treatment ($Z=-5.695$, $P<0.001$), demonstrating significant improvement of the two-point discrimination. The grip strength was 25.1 (SD 2.1) N preoperatively and 35.6 (SD 2.7) N postoperatively. There were significant differences between before and after treatment ($t=-52.554$, $P<0.001$), revealing significant improvement of the grip strength. The lateral pinch power of the thumb and index finger was 17.0 (1.0) N preoperatively and...
Table 3. Outcomes related to ulnar groove plasty guided by 3D printing technique.

| Outcomes                              | Preoperative | 12-month follow up | t/Z   | P     |
|---------------------------------------|--------------|--------------------|-------|-------|
| Motor nerve conduction velocity (m/s) | 28.7 (SD 2.7) | 44.0 (SD 3.8)      | -24.850 | <0.001* |
| Sensory nerve conduction velocity (m/s)| 24.0 (2.0)   | 40.0 (2.0)         | -5.532 | <0.001* |
| Two-point discrimination (mm)         | 14.0 (2.8)   | 6.0 (1.0)          | -5.695 | <0.001* |
| Grip strength (N)                     | 25.1 (SD 2.1) | 35.6 (SD 2.7)      | -5.254 | <0.001* |
| Lateral pinch power (N)               | 17.0 (1.0)   | 22.0 (2.0)         | -5.514 | <0.001* |
| VAS score                             | 2.0 (2.0)    | 2.0 (1.0)          | -5.619 | <0.001* |
| DASH score                            | 85.3 (SD 4.6) | 66.9 (SD 5.0)      | 29.765 | <0.001* |

VAS – visual analog scale; DASH – disabilities of the arm, shoulder and hand; * P<0.05.

22.0 (2.0) N postoperatively. There were significant differences between before and after treatment (t=52.554, P<0.001), implying significant improvement of the lateral pinch power. The VAS score was 6.0 (2.0) preoperatively and 2.0 (1.0) postoperatively. There were significant differences between before and after treatment (t=5.619, P<0.001), confirming significant improvement in the VAS score. The DASH score was 85.3 (SD 4.6) preoperatively and 66.9 (SD 5.0) postoperatively. There were significant differences between before and after treatment (t=29.765, P<0.001), indicating a significant improvement in the DASH score.

Discussion

The incidence of CuTS is 25/100 000 person-years in men and 19/100 000 person-years in women [11]. Compared with patients with carpal tunnel syndrome, patients with CuTS often seek treatment after the disease worsens [12]. Chronic impairment of ulnar nerve function may lead to permanent loss of sensation and fine motor function of the hand. Non-surgical treatment is initially recommended for mild to moderate CuTS [13-15]. Splint immobilization and nerve gliding exercises can effectively reduce ulnar nerve compression and tension by limiting the activity of the elbow joint. Neurotrophic drugs, such as vitamin B1, vitamin B6, and vitamin B12, are also used to improve microcirculation in the nerve.

Surgical intervention should be considered when conservative management is unsuccessful or in patients with advanced CuTS. At present, the surgical methods for CuTS can be divided into 3 categories: in situ decompression, anterior transposition (subcutaneous, submuscular, or intramuscular), and medial epicondylectomy of the humerus [4]. With the increase in the overall amount of surgery performed, decompressions have become much more frequent compared to anterior transposition [1]. Medical epicondylectomy was first described as an option for treatment of CuTS by King and Morgan [16] in the 1950s. It was reported to achieve good improvement of neural function because it eliminates the pulley effect of the medical epicondyde. Total medial epicondylectomy can lead to persistent medial elbow instability, local tenderness, painful subluxation, flexor-pronator weakness, and iatrogenic elbow instability [17,18]. Many modified procedures have successively been proposed. Staples et al [4] reported an oblique osteotomy created on the sagittal and coronal planes of the medial epicondyde of the humerus. The insertion of the medial collateral ligament of the elbow joint should be protected during the operation to prevent iatrogenic elbow instability. This technique allows the ulnar nerve to slide forward on the smooth osteotomy surface, thereby reducing stretching and compression of the nerve. Most anatomists and surgeons believe that mechanical compression, traction, and friction are the main causes of CuTS [19]. Most of the compression points on the ulnar nerve are located at the Osborne ligament or its proximal end [20-22]. The cubital tunnel comprises the posterior part of medial epicondyde of the humerus, the posterior band of the medial trochlear crest and medial collateral ligament, and the fibrous aponeurosis at the top [23]. The 4 walls are tough and lack elasticity. In patients with elbow osteoarthritis, shallowing and narrowing of the ulnar nerve groove through hyperplasia of the posterior condeyle of the medial epicondyde of the humerus lead to stretching and compression of the ulnar nerve, especially during elbow flexion. Therefore, we consider that removal of the hyperplastic bone and shaping of the ulnar nerve groove can relieve the symptoms of ulnar nerve compression. Ulnar groove plasty for friction neuropathy in patients with CuTS was first reported by Akihito et al [24]. The ulnar nerve was replaced into the reconstructed ulnar groove after enlargement and deepening of the groove. Recovery of sensory functions was reported in all patients. The ulnar nerve was stable during the full range of flexion and extension of the elbow without any irritation or adhesion. How much bone needs to be removed for enlargement and deepening of the ulnar nerve groove has not been accurately recorded. Too much resection may affect the stability of the elbow joint, and too little resection may not effectively solve the nerve entrapment. In 2008, Cui et al [25] proposed the concept of the “cubital tunnel index”. The specific calculation method for the cubital tunnel index is...
as follows: over the Hueter line (medial-lateral condyle connection), the cross-section of the humeral shaft (0°) was rotated forward 30° for CT imaging to measure the depth and width of the elbows in the cross-section. The depth/width ratio was calculated and defined as the cubital canal index.

In this study, based on a previously proposed “elbow canal index”, a 1:1 model of the elbow joint was printed using CT image data collected preoperatively. After computer-aided measurement, the standard for enlargement of the ulnar nerve groove was calculated and a personalized “trial model” was created by 3D reconstruction. To the best of our knowledge, this study is the first to combine ulnar groove plasticity and a 3D printing technique for the treatment of moderate to severe CuTS caused by elbow osteoarthritis. After patient follow-up for >12 months, motor nerve conduction velocity, sensory nerve conduction velocity, two-point discrimination of the little finger, grip strength, and pinch strength of the thumb and index finger were significantly improved, without any complications. Compared with partial/total medial epicondylectomy [17,18,26], the present procedure has the major advantage of being without any complications including medial elbow instability, medial elbow pain, ulnar nerve subluxation, and flexor-pronator weakness.

There are several limitations to our study. In addition to potential selection bias because of the limited patient population, we did not compare ulnar groove plasticity guided by the 3D printing technique with any other procedures. Furthermore, there are 3 considerations for the procedure. First, it remains unknown whether the bone wound resulting from the enlargement and deepening of the cubital tunnel will lead to bone hyperplasia and subsequent re-compression of the ulnar nerve. Second, a follow-up period of 12 months seemed to be short for surgical results of the elbow arthritis because it is worrisome that osteophyte formation may recur. Whether it was immediately after surgery or after 12 months of follow-up, the formation of osteophytes has not been found in all patients. Third, cutting the capsule will inevitably cause the joint capsule to communicate with the cubital tunnel, and it is unknown whether the joint fluid leaking into the cubital tunnel will initiate new compression of the ulnar nerve.

Conclusions

In conclusion, ulnar groove plasticity guided by a 3D printing technique may be another effective treatment of moderate to severe CuTS caused by elbow osteoarthritis.

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