

Treatment of Advanced Lunate Bone Necrosis by Individualized Bone Cement Prosthetic Replacement

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Research Article

Keywords: Lunate bone, Bone necrosis, Bone cement, Prosthesis, Clinical effect

Posted Date: March 24th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-300865/v1>

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Abstract

Objective: The aim of this study is to prospectively analyze the clinical effect of an individualized bone cement prosthetic replacement in treating advanced lunate bone necrosis.

Methods: Since 2006, a total of 19 Lichtman stage III and IV aseptic lunate bone necrosis patients with a wrist height ratio ≥ 0.5 were included, the last visit time was three years after operation. The statistically significant differences in range of motion, (Visual Analogue Scale/Score, VAS) score, Cooney score, grasp force, wrist height ratio (to the capitate bone), and radio scaphoid angle of the affected wrist joint were observed before the operation and at the last visit ($p < 0.05$).

Results: There were no statistically significant differences in the axial line and maximum diameter of the lunate bone between the healthy side and the affected side ($p > 0.05$).

Conclusion: The surgical method can restore the original anatomic structure of wrist joint, play an important role in recovering the movement function of wrist joint, and has a significant effect on wrist pain and few complications.

Background

Wrist lunate bone necrosis is one of the main causes of wrist joint pain¹. Once it occurs, and in the event that no timely treatment is available, ischemic necrosis of the lunate bone will induce lunate bone fracture, atrophy and flattening, proximal row carpal collapse, and secondary intercarpal arthritis². It will also result in wrist joint pain, significant movement limitations, and a decrease in grasp force in the wrist during later stages, which will seriously influence a patient's work and quality of life³. The therapeutic goal of lunate bone necrosis is to preserve the bone's normal structure, restore motion function, and relieve the clinical symptoms of the wrist joint⁴. Uniform and standard operating methods that treat lunate bone necrosis are currently lacking. Such methods primarily include revascularization, biomechanical treatment, simple resection, and replacement⁵, but their clinical effects are highly variable. Based on the anatomic and biomechanical characteristics of the wrist joint, and when combining the physical and chemical properties of bone cement, we independently designed a individualized bone cement prosthesis for implantation to replace necrotic lunate bone. The aim of this study is to investigate the clinical effect of an individualized bone cement prosthetic replacement in treating advanced lunate bone necrosis, as well as to establish a new treatment for lunate bone necrosis. We prospectively analyzed the clinical data of 19 patients with advanced lunate bone necrosis who were admitted to our

department from July 2006. The evaluation indicators included clinical examination, radiological examination, and assessment of complications.

Materials And Methods

1.1 Study objectives

This prospective study was approved by the Ethics Committee of Southwest Hospital. Prior to the operation, all patients received conventional X-ray, computed tomography (CT), and magnetic resonance imaging (MRI) examinations, and they were also evaluated using Cooney scores, Visual Analog Scale (VAS) scores, and a conventional admission evaluation.

1.1.1 Inclusion criteria

Patients were included in the study if they met the following requirements: (1) Lichtman stage III and IV aseptic lunate bone necrosis; (2) a wrist height ratio (to the capitate bone) ≥ 0.5 ; (3) no response to conservative treatment for ≥ 6 months (including drug treatment, local blockage, and physical rehabilitation); and (4) provision of informed consent (where patients were unable to do so, their family members provided informed consent).

1.1.2 Exclusion criteria

Patients were excluded from the study for the following reasons: (1) they were diagnosed with serious medical disorders; (2) they had a wrist joint infection; or (3) the patients and their family members failed to provide informed consent; (4) the follow-up time was less than 12 month.

1.2 Operative methods

The operation for all included patients was performed by a chief physician with over 15 years of clinical experience. Antibiotics were intravenously infused to prevent infection 30 minutes prior to the operation. Anesthesia using brachial plexus blocks or general anesthesia was selected according to the patient's physical condition. Following conventional disinfection and draping, a 3–5 cm longitudinal incision was made on the dorsal part of the wrist joint with the lunate bone at the center; the skin, subcutaneous tissues, and dorsal extensor retinaculum of the wrist were dissected layer by layer to expose the articular capsule of the lunate bone. The articular capsule was cut open longitudinally; the ligaments surrounding the lunate bone were cut off to expose the necrotic lunate bone; the necrotic, inflammatory tissues surrounding the lunate bone were cleared; the lunate bone was completely removed (Fig. 1A); and then fill the non-curing bone cement into the anatomical position of lunate bone (Fig. 1B); and then make the wrist joint repeatedly subject to ulnar and radial deviation, dorsiflexion and flexion to reached their normal ranges during the bone cement's curing stage, and the bone cement was subsequently shaped. A C-arm perspective was used to confirm whether the bone cement prosthesis matched the original bone, and that the prosthesis had not detached during dorsal extension, palmar flexion, ulnar deviation, or radial deviation of the wrist joint. Thereafter, the dorsal articular capsule and the dorsal extensor retinaculum of

the wrist joint were sutured layer by layer. Following the operation, a continuous ice compress was applied for 3–5 days; the drainage catheter was removed after 24–48 hours and the suture was removed at 14 days. The wrist joint was fixed in a functional position with a plaster slab for 4 weeks, and functional exercises promoting finger extension and flexion were encouraged.

1.3 Postoperative examination

1. 1.3.1 Clinical examination: This evaluation was performed at 6 weeks, 3 months, 6 months, 12 months, thereafter once per year, and at the last visit after the operation. The evaluation indicators for wrist joint function included range of motion (ROM) of the wrist joint-i.e., extension and flexion, ulnar deviation, and radial deviation; hand grasp force, which was measured three times for each side using a Jamar meter (the results were averaged); and the degree of wrist joint pain at resting state and after loading. The pain and function of the wrist joint were evaluated using Cooney and VAS scores (excellent: 0–2 scores, good: 3–5 scores, acceptable: 6–8 scores, and bad: >8 scores). Hand function was divided into one of four levels: level I, normal function; level II, mild dysfunction; level III, significant limitations; and level IV, extreme limitations.
2. 1.3.2 Radiological examination: At 3 months, 6 months, 12 months, thereafter once per year, and at the last visit after the operation, wrist joint PA and LAT X-ray scans were performed to evaluate the wrist height ratio (to the capitate bone) and the radio scaphoid angle, as well as to determine whether there was osteoarthritis in the adjacent joint. At the last visit, three-dimensional CT and X-ray examinations of the healthy and affected sides of the wrist joint were performed to comparatively analyze the anatomic suitability of the lunate bone, which included assessing the axial line and maximum diameter of the bone.
3. 1.3.3 Assessment of complications: Early complications following surgery included wound infection and skin necrosis, while late complications included nerve injury and osteoarthritis of the adjacent joint (radiocarpal and midcarpal joint) in Lichtman stage III patients.

1.4 Statistical analysis

If the data were normally distributed according to the Shapiro-Wilk test, the data were presented as means with standard deviations (SD); whereas non-parametric data were shown as the median and interquartile range (IQR). Statistical comparisons were performed using paired t-test. $P < 0.05$ suggested that a difference was considered as statistically significant.

Results

There were a total of 19 patients of aseptic lunate bone necrosis (patients' mean age: 36.4 [range: 17–59] years), including 13 males and six females; these patients were followed up for 69.4(range: 36–120) months. There were 12 patients of right wrist lunate bone necrosis and seven patients of left wrist lunate bone necrosis; ten patients of Lichtman stage III and nine patients of Lichtman stage IV; and ten patients

with a history of trauma, two patients with a history of rheumatoid arthropathy, and seven patients with no special history. The course of the disease prior to the operation was 21.9 (range: 3–72) months.

There were statistically significant differences found in terms of wrist joint range of motion and grasp force between the preoperative period and the last follow up visit ($p < 0.05$), but there was no statistically significant difference between the healthy side and the affected side ($p > 0.05$). The average wrist height ratio (to the capitate bone) of the affected side was 1.32 before the operation and 1.56 at the last visit, and the difference between the two time points was statistically significant ($p < 0.05$); however, the difference between the affected side and the healthy side at the last visit was not statistically significant ($p > 0.05$). The average radio scaphoid angle of the affected side was 68° before the operation and 51° at the last visit, and the difference between the two time points was statistically significant ($p < 0.05$); however, the difference between the affected side and the healthy side at the last visit was not statistically significant ($p > 0.05$) (Table 1). At the last visit, there were no statistically significant differences in the axial line and the maximum diameter of the lunate bone between the healthy side and the affected side ($p > 0.05$) (Table 2) (Fig. 2).

Table 1

Comparison of wrist joint ROM, grasp force, wrist height ratio and radioscaploid angle(n = 19)(mean;SD)

	Affected side		Healthy side		
	Preoperative	At the last visit	p-value	At the last visit	p-value
Dorsal extension ($^\circ$)	34(SD11)	55(SD6)	< 0.001	56(SD6)	0.052
Palmar flexion ($^\circ$)	30(SD10)	51(SD8)	0.001	52(SD6)	0.114
Ulnar deviation ($^\circ$)	11(SD4)	24(SD5)	0.004	24(SD4)	0.119
Radial deviation ($^\circ$)	8(SD2)	17(SD2)	< 0.001	18(SD3)	0.088
RA($^\circ$)	68(SD4)	51(SD2)	0.026	51(SD2)	0.281
WHR (To CB)	1.32(SD0.09)	1.56(SD0.07)	0.014	1.57(SD0.07)	0.190
Grasp force (kg)	22.2(SD4.19)	33.9(SD3.9)	< 0.001	34(SD3)	0.061
* Compared with preoperative, $p < 0.05$; compared with the healthy side, $p > 0.05$; Wrist height ratio (to capitate bone):WHR (To CB);Radioscaploid angle:RA;SD: standard deviation; ROM: range of motion.					

Table 2
Comparison of the lunate bone's anatomic suitability between the healthy side and the affected side,(n = 19)

	Affected side	Healthy side	P-value
Axial line of the lunate bone(mm)	8.27(SD1.13)	8.31(SD1.20)	0.544
Maximum diameter(mm)	14.74(SD1.89)	14.81(SD1.87)	0.225
*compared with the healthy side p > 0.05;SD: standard deviation.			

Wrist joint pain during the resting state disappeared in fourteen patients; soreness in the wrist joint following heavy exercise was improved in four patients, and it was improved but recurred at 12 months postoperatively in one patient. With respect to VAS score for wrist joint pain and Cooney score for wrist joint function of the affected side, there were statistically significant differences before the operation and at the last visit ($p < 0.05$). For VAS score, 16 patients were excellent, two patients were good, and one patients was bad; for Cooney score, 16 patients were excellent and two patients were good, with an excellent-good rate being 95%. In terms of the use of the affected hand, 17 patients exhibited normal function and two patients had mild dysfunction. None of the Lichtman stage III patients experienced wound infection, skin necrosis, or nerve injury, while one patient experienced osteoarthritis of the midcarpal joint.

Discussion

There are many treatment that are currently available for aseptic lunate bone necrosis⁶. Simple lunate bone resection can cause carpal bone disarrangement, capitate bone depression, and intractable pain of the wrist joint⁷; therefore, lunate bone resection and replacement becomes a good therapeutic option for lunate bone necrosis. Many implantable substitutes are available following lunate bone resection, such as capitate bone displacement, lentiform bone displacement,metal ball,tendon ball,titanium alloy prosthesis, and so on⁸, but the replacement surgeries for capitate bone displacement and lentiform bone displacement are complicated to perform, and they may damage the structures and partial functions of the wrist joint⁹. The hard metal ball easily wears out based on the adjacent carpal bone, while the soft tendon ball and arc transparent cartilage easily result in the instability of the wrist joint after implantation¹⁰. Moreover, a titanium alloy prosthesis is expensive and must be customized in advance; its size is difficult to adjust, and there is difficulty associated with its simulation¹¹. Conversely, bone cement is characterized by its stable physical and chemical properties; its shape and size can be adjusted during the operation. Bone cement can be shaped and sized in such a way that it is basically coincident to the patient's original lunate; it also matches the physiological characteristics of the wrist joint. In addition, bone cement can maintain its original elasticity for a long period of time, and it prevents itself from deformation, corrosion, and absorption¹².

The surgical replacement of lunate bone using bone cement prosthesis has the following advantages: (1) one can replace the original necrotic lunate bone with bone cement, which restores the normal anatomy of the wrist joint; (2) this surgery is simple to perform, so it can be used in all hospitals; (3) the fixation time of the wrist joint is short (it does not exceed six weeks), so patients can promptly return to work; and (4) the lunate prosthesis is an important support structure for avoiding the collapse of proximal row carpal bones, thus it can play a role in preventing the collapse of wrist joint and proximal row carpal bones. It should be noted that during the operation, one must pay attention to the design of the prosthesis, and one should also design the width, height, and concave side of the lunate bone according to the geometric shape of a healthy lunate bone, so as to maintain the original size as much as possible. During the heating of bone cement, we avoid the contact between bone cement and the adjacent joints as possible mainly by retracting the articular space, and wash the bone cement prosthesis with the ice physiological saline to prevent the adjacent structures from the heat damage caused by bone cement. After implantation of lunate bone cement prosthesis, mainly the total repair of articular joint was performed, without the repair and reconstruction of SL and LT ligaments. This is because the prosthetic stabilization is predominantly determined by two factors: the mutual gomphosis of the prosthetic concave structure and the adjacent bony structure; and the resistance from the adjacent articular capsule and tendons. To prevent the detachment of lunate prosthesis in the early stage, attention shall be paid to the repair and suturing of articular capsule during operation; after operation, the plaster immobilization in the functional position shall be performed to avoid the detachment of lunate prosthesis caused by wrist movement and facilitate the repair of articular capsule and adjacent soft tissues. After operation, the wrist joint was fixed at the functional position with plaster for four weeks, because we believed that soft tissues surrounding lunate bone nearly healed to prevent the prolapse of lunate bone at four weeks postoperatively, and the removal of plaster at this time point could facilitate early functional exercise of wrist joint. If the fixation was kept for six weeks, the wrist joint would lose most of its function.

Swanson¹³ replaced lunate bone with a silicone rubber prosthesis, long-term prosthesis fractures and detachments from other carpal bone easily occurred, this was accompanied by serious foreign-body inflammatory reactions and synovitis. Daecke et al¹⁴ treated 21 patients with Lichtman stage III–IV ischemic lunate bone necrosis by lunate bone resection and lunate fossa filling with a vascularized bone flap, and during follow-up period, the authors found that the imaging examination indicated lentiform bone atrophy and flattening in five patients, lentiform bone sclerosis in ten patients, lentiform bone dislocation in two patients, lentiform bone fracture in one patient, and osteoarthritis or carpal bone collapse in ten patients. We treated 19 patients of advanced lunate bone necrosis using a individualized bone cement prosthetic replacement. these patients were followed up for mean 37.8 months At the last visit, wrist joint pain was markedly relieved, and the range of motion and grasp force were both increased. As confirmed by imaging examinations (X-ray examination and 3D CT), the bone cement prosthesis of the lunate bone had good anatomic suitability and was not broken or detached from other carpal bone, and there was no heat-induced damage to the cartilage in the lunate fossa. If wrist joint pain was observed during follow-up, local immobilization or motion reduction was the preferred treatment, followed by oral non-steroidal anti-inflammatory drugs. We found no surgical failure in the patients followed up, so

we could not earn the relevant experience. If a surgical failure happens, we will remove the prosthesis and then perform proximal row wrist arthrodesis for serious damage to wrist joint, or simply remove the prosthesis and/or then perform other surgeries for slight damage to wrist joint. However, this preliminary study did not include a control group, and the follow-up period only encompassed a hot period of time.

Conclusions

The individualized bone cement prosthetic replacement is simple to operate, can restore the original anatomic structure of wrist joint, play an important role in recovering the movement function of wrist joint, and has a significant effect on wrist pain and few complications. Therefore, it is a highly recommended therapy for advanced lunate necrosis.

Declarations

Acknowledgments

We acknowledge the assistance of investigators and all subjects for participation in this study.

Funding

This study was supported by the Science Foundation of Southwest Hospital and Science and health joint technology innovation and application development project of Chongqing Health Committee and Chongqing Science and Technology Bureau in 2020.

Availability of data and materials

All data and materials were in full compliance with the journal's policy.

Ethics approval and consent to participate

Compliance with ethical standards

Competing interests

All authors declare that they have no conflicts of interest.

Consent for publication

All patients enrolled into the study agreed the use of patients' data for research.

Authors' contributions

All surgical procedures were carried out by Kang-lai Tang, Cheng-song Yuan, Xuan-Zhang and Mi-duo Mu in this study. The Data measurement of specimens was performed by Lin-Ma , Hua-yong Chen, Tang-Yao and Hong-Tao Li participated in the patient selection, investigation on the outpatient clinic and radiographic assessments, literature search, and data monitoring. Cheng-song Yuan, Hong-xia Zhai and

Jun-Peng Liu completed the statistical analysis and manuscript writing. All authors have read and approved the final manuscript.

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Abbreviations

VAS, Visual Analog Scale;

CT, computed tomography;

MRI, magnetic resonance imaging;

ROM, range of motion.

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Figures

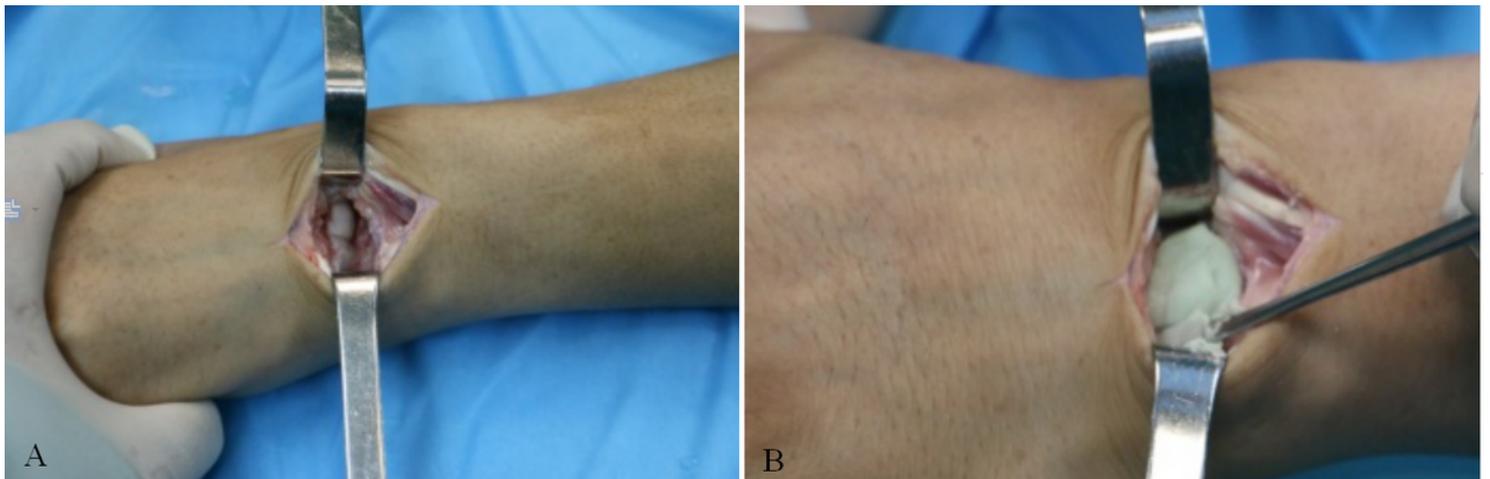


Figure 1

A. Complete removal of the lunate bone; B. The non-curing bone cement was placed into the original anatomical position of lunate bone.



Figure 2

Typical case: A. Preoperative MRI. B. Postoperative X-ray and CT. C. Postoperative

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