Clinical and Radiographic Outcomes of Metacarpophalangeal Joint Pyrolytic Carbon Arthroplasty for Osteoarthritis

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Purpose To determine the effectiveness of pyrolytic carbon arthroplasty for the management of primary osteoarthritis of the metacarpophalangeal joint.

Methods A retrospective review of 11 pyrolytic carbon arthroplasties for osteoarthritis of the metacarpophalangeal joint, performed by a single surgeon, was conducted. All patients returned for clinical assessment at a minimum of 2 years after surgery. Evaluation included range of motion, pain and functional scores, and patient satisfaction. Validated outcome measures included the Michigan Hand Questionnaire and Quick Disabilities of the Arm, Shoulder, and Hand. Radiographs were assessed for implant failure, loosening, migration, and subsidence.

Results The average follow-up was 4 years (minimum 2 y). The arc of motion significantly improved from 62° before surgery to 76° after surgery. Grip strength decreased slightly compared to the contralateral side (average, 3 kg). The average pain score was 1 on a 10-point visual analog scale. All but 1 patient were fully satisfied at final follow-up. All patients who were working before surgery returned to work after surgery. The Michigan Hand Questionnaire average score was 80, and the Quick Disabilities of the Arm, Shoulder, and Hand average score was 22. Two patients experienced persistent, asymptomatic squeaking and clicking, and 1 patient reported extensor tendon subluxation. One joint had conversion to arthrodesis for continued, unexplained pain. All surviving implants had a surrounding lucency on radiographs. The average subsidence was 3 mm; there was no implant migration, fracture, or dislocation.

Conclusions Pyrolytic carbon arthroplasties of the metacarpophalangeal joint resulted in satisfactory outcomes at average 4-year follow-up, with improved joint motion, good pain relief and satisfaction, and few complications. Radiographic outcomes revealed a consistent, asymptomatic surrounding lucency with no evidence of implant failure or migration. (J Hand Surg 2013;38A:537–543. Copyright © 2013 by the American Society for Surgery of the Hand. All rights reserved.)

Type of study/level of evidence Therapeutic IV.

Key words Arthroplasty, metacarpophalangeal joint, osteoarthritis, pyrolytic carbon.
Osteoarthritis (OA) of the metacarpophalangeal (MCP) joint is uncommon. Overall hand function is dependent on the MCP joint mobility, and OA can result in stiffness, pain, and deformity. To maintain and optimize hand function, treatment of MCP joint arthritis might be necessary. Initial treatment includes nonsurgical modalities, such as activity modification, anti-inflammator y medication, and corticosteroid injections. If these techniques are ineffective, more invasive treatments such as arthroscopy, arthroplasty, or arthrodesis might be required.1

Pyrolytic carbon implants have excellent biomaterial properties and have been used for joint arthroplasty in the small joints of the hand for the past few decades.1–7 The implant is formed by pyrolysis of a hydrocarbon gas and is chemically stable, making it compatible with biologic media.8 The implant is stabilized into bone by initial impaction and then fixed by appositional growth.9 The initial results of pyrolytic carbon arthroplasty of the MCP joints produced satisfactory outcomes in a mixed arthritic population.2 This was followed up with a long-term study revealing similar encouraging results,3 with a calculated survivorship of 80% at 5 and 10 years.

To date, there is little evidence specifically investigating the results and clinical outcomes of patients with OA of the MCP joint treated with pyrolytic carbon arthroplasty.3–5 Previously reported studies present a mixed population with multiple etiologies of arthritis.3,5 Our study was conducted to investigate the longer-term outcomes of pyrolytic carbon arthroplasties of the MCP joint for osteoarthritis. We hypothesized that patients would have satisfactory results, both clinically and radiographically, at a minimum of 2 years of follow-up.

**MATERIALS AND METHODS**

All patients who had arthroplasty for OA of the MCP joint with a pyrolytic carbon implant before 2010 by a single surgeon (P.J.S.) were reviewed. The study was approved by the local institutional review board. The indication for the surgery was pain that was unresponsive to conservative treatment, including activity modification, anti-inflammatory medication, and steroid injections. Inclusion criteria were a primary diagnosis of OA of the MCP joint (Fig. 1) and a minimum follow-up of 2 years. Patients with inflammatory arthropathy and posttraumatic arthritis were excluded, as were patients with deficient collateral ligaments. The pyrolytic carbon arthroplasty was performed in 11 MCP joints in the 9 patients who met the inclusion criteria. The follow-up evaluation was carried out by an independent observer (L.B.W.) who was not involved in the care of these patients.

The average age of the patient at the time of arthroplasty surgery was 62 years (range, 40–73 y). Four of the 9 patients were women. Two patients had replacements in both middle fingers. Arthroplasties were performed in 3 index fingers and 8 middle fingers.

**Surgical technique**

All procedures were performed as outpatient procedures, using either regional block or general anesthesia. The joint is approached through a dorsal longitudinal extensor splitting incision followed by division of the joint capsule. The metacarpal head is penetrated just dorsal to the mid-axial line with a starting awl. Next, an alignment awl is inserted down the medullary canal of the metacarpal, using fluoroscopic guidance to ensure that it is centered in the canal in both the coronal and sagittal planes. A sagittal saw is then used to make the osteotomy, 1 to 2 mm distal to the collateral ligaments. The joint is then flexed, and the starter awl is placed into the base of the proximal phalanx slightly dorsal to the mid-axial line. The alignment awl with cutting guide is then placed into the phalanx under fluoroscopic guidance, and an osteotomy to remove a wafer of bone from
the base of the proximal phalanx is performed with an oscillating saw. The metacarpal and phalanx are then broached sequentially until the largest size possible can be fully seated. The trial implants are then inserted so that the collars of both implants are flush with the bone edges. The joint is then assessed clinically and evaluated fluoroscopically for range of motion, stability, and alignment. The dorsal capsule and extensor mechanism are closed with nonabsorbable sutures. The hand is placed into a volar forearm-based splint with the digits in full extension.

Postoperative rehabilitation
The patient is seen by the hand therapist at the first postoperative visit at 10 to 14 days, when edema control is begun using an elastic garment. A removable splint is fabricated to maintain the MCP joint in full extension, and active interphalangeal joint range of motion is encouraged. Short arc motion protocol of the MCP joints starting at 30° is begun at 3 weeks, 3 to 4 times per day. Flexion is gradually increased to 10° each following week. The static splint is worn at all times for 6 weeks when the patient is not exercising. The patient can then remove the splint for light activities. Gentle strengthening is initiated at 8 to 10 weeks. Finally, daytime splitting is discontinued at 10 to 12 weeks, but the patient continues night splinting for 3 to 6 months.

Objective analysis
All patients were asked to return for follow-up clinical evaluation. Active range of motion was measured with a hand-held goniometer (Innomed, Savannah, GA), including full flexion and extension. Preoperative motion was obtained from the medical record. Any coronal plane deviation was also noted and measured. Grip strength was measured on both the involved and uninvolved hand, using a hand-held dynamometer (Sammons Preston, Bolingbrook, IL).

Complications were defined as loosening, squeaking, fracture, wound-healing problems, extensor tendon problems, or need for additional corrective surgery (excluding revision of implant or arthrodesis). Failure was defined as revision of the implant or arthrodesis.

Radiographic analysis
All patients had immediate postoperative radiographs. At final follow-up, posteroanterior and true lateral radiographs were obtained for 8 of the 10 joints that had survived. One patient, who had had bilateral arthroplasties, was unable to return for radiographs because of a medical condition.

There are no standardized radiographic assessment tools for small joint arthroplasty. We chose to assess implant subsidence on the posteroanterior view. This was determined by measuring from the highest point of the implant articular surface to the base of the metacarpal or to the articular surface of the proximal phalanx at the proximal interphalangeal joint. The amount of subsidence was the calculated difference between the final follow-up radiograph measurements and the immediate postoperative radiographs. All measurements were made using the digital caliper of the electronic picture archiving and communication system. Prosthetic lucency was measured for all implant components as well. All implants have a surrounding 0.5 to 1.0 mm pyrolytic carbon coating and are expected to have this amount of periprosthetic lucency on radiographs according to the manufacturer’s pamphlet. Alignment of the implant was critically assessed for any migration, tilt, dislocation, or fracture.

Subjective analysis
The Michigan Hand Outcomes Questionnaire (MHQ) was used for assessing subjective outcome. This is a validated and reliable outcomes instrument that involves 67 questions assessing hand function, activities of daily living, pain, work performance, appearance, and patient satisfaction. Raw scores are converted to a 0 to 100 point scale, where higher scores indicate a better outcome. Each patient also completed the Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH), a validated outcome questionnaire to assess physical function and symptoms of the affected extremity, with 0 being no disability and 100 being total disability. A 10-point pain visual analog scale was used to assess amount of pain at the final follow-up (0, no pain; 10, horrible pain). A questionnaire developed for a previous study was used and modified for the digit, specifically assessing the severity of the involved MCP joint pain, satisfaction, use of pain medication, and return to employment. All subjective analysis was performed at the time of follow-up. No preoperative subjective evaluations were obtained.

Statistical analysis
Statistical analysis was performed using the paired Student’s t-test. A P value of < .05 was set as statistical significance.

RESULTS
The average follow-up period was 4 years (range, 27–72 mo). Twelve patients were initially identified for inclusion. Three patients were lost to follow-up. Two patients were unable to be contacted, and one refused to
TABLE 1. Objective Outcomes

<table>
<thead>
<tr>
<th>Subject</th>
<th>Preoperative Extension</th>
<th>Postoperative Extension*</th>
<th>Preoperative Flexion</th>
<th>Postoperative Flexion</th>
<th>Contralateral Grip (kg)</th>
<th>Operative Hand Grip (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>-30</td>
<td>70</td>
<td>75</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>-10</td>
<td>60</td>
<td>50</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>75</td>
<td>26</td>
<td>23</td>
</tr>
<tr>
<td>4 (right)</td>
<td>0</td>
<td>-30</td>
<td>80</td>
<td>75</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>4 (left)</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>70</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>-10</td>
<td>70</td>
<td>65</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>0</td>
<td>60</td>
<td>80</td>
<td>50</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>0</td>
<td>60</td>
<td>65</td>
<td>38</td>
<td>36</td>
</tr>
<tr>
<td>8 (right)</td>
<td>0</td>
<td>0</td>
<td>70</td>
<td>70</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>8 (left)</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>55</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA, not applicable given bilateral involvement.

Objective outcomes for each individual subject. Subjects 4 and 8 had bilateral involvement.
*Negative values indicate hyperextension.

return for evaluation because of medical problems, leaving 9 patients (11 joints) for final analysis.

The average arc of MCP joint motion significantly increased from 62° before surgery to 76° after surgery, an average improvement of 14° (range, loss of 5° to gain of 35°) ($P = .012$). The average MCP joint extension was $2°$ of hyperextension (range, 15° to 0°) before surgery and 8° of hyperextension (range, 30° hyperextension to 0°) after surgery ($P > .05$). The average flexion increased from 65° (range, 60° to 80°) before surgery to 68° (range, 50° to 80°) after surgery ($P > .05$). One patient had decreased motion, with a loss of 5°, and one had no change in motion (Table 1).

Grip strength, compared to the contralateral hand, revealed a significant average decrease in strength of 3 kg (range, 0 kg to 6 kg) ($P = .02$). Grip strength was not assessed in the 2 patients with bilateral hand involvement (Table 1).

The survival rate was 91%, 10 of 11 joints. There was 1 failure; this patient had limited MCP range of motion (30° to 90°), squeaking, and continued unexplained pain after arthroplasty that did not resolve with conservative treatment. Arthrodesis was performed 7 months after the first surgery.

There were 2 complications in the surviving arthroplasties. One MCP joint had stiffness after surgery, which did not resolve with therapy; a subsequent volar plate release was performed. This patient remained dissatisfied, even with improved motion. She continued to complain of nonpainful clicking but requested no additional surgery. A second patient had extensor tendon subluxation noted during therapy 1 month after surgery. This patient was satisfied and did not request any additional surgery.

Subjective assessment revealed positive results in 8 of the 9 patients (Table 2). The average MHQ score was 80 (range, 31–97). The average QuickDASH score was 22 (range, 0–50). The average 10-point pain visual analog scale score was 1 (range, 0–4). One patient reported moderate daily pain, whereas the others reported mild to no pain. Only 1 patient took analgesics for finger joint pain. The 5 patients who were working at the time of surgery returned to work without restrictions. The remaining patients were either retired or not working. Eight patients were satisfied or very satisfied.

TABLE 2. Subjective Outcomes

<table>
<thead>
<tr>
<th>Subject</th>
<th>QuickDASH</th>
<th>Pain</th>
<th>VAS</th>
<th>MHQ</th>
<th>Level of Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>2</td>
<td>31</td>
<td></td>
<td>Dissatisfied</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>0</td>
<td>97</td>
<td></td>
<td>Very satisfied</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>0</td>
<td>93</td>
<td></td>
<td>Very satisfied</td>
</tr>
<tr>
<td>4 (right)</td>
<td>50</td>
<td>0</td>
<td>77</td>
<td></td>
<td>Very satisfied</td>
</tr>
<tr>
<td>4 (left)</td>
<td>50</td>
<td>0</td>
<td>78</td>
<td></td>
<td>Very satisfied</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>99</td>
<td></td>
<td>Very satisfied</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>2</td>
<td>82</td>
<td></td>
<td>Satisfied</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>93</td>
<td></td>
<td>Very satisfied</td>
</tr>
<tr>
<td>8 (right)</td>
<td>25</td>
<td>2</td>
<td>95</td>
<td></td>
<td>Satisfied</td>
</tr>
<tr>
<td>8 (left)</td>
<td>25</td>
<td>4</td>
<td>86</td>
<td></td>
<td>Satisfied</td>
</tr>
</tbody>
</table>

Subjective outcomes for each individual subject. VAS, visual analog scale.

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and one (who had had volar plate release) was dissatisfied and had an MHQ score of 31.

All radiographs revealed asymptomatic subsidence and lucency. The average combined subsidence from both the metacarpal and phalanx was a total of 3 mm. The range of subsidence was 1 to 4 mm for the metacarpal and 0 to 2 mm for the phalanx. There was no progression of the periprosthetic lucency at final follow-up; 1 mm lucency was observed around all implants, as was seen immediately after surgery. The lucency was more distinct and clearly defined in all late postoperative images compared to those obtained immediately after surgery (Figs. 2 and 3). There was no migration or coronal angulation of implants at final follow-up. There were no implant fractures or dislocations.

DISCUSSION

Arthroplasty is the optimal surgical option to treat OA at the MCP joint of the fingers when conservative treatment fails. Although arthrodesis is a reasonable treatment alternative, arthroplasty is favored for index through small finger MCP joints to preserve digit motion and hand function.\(^1\) Arthroplasty options include both silicone spacers and resurfacing implants, such as pyrolytic carbon. The silicone arthroplasty acts as a spacer and relies on soft tissue to provide stability; it is used in both OA and rheumatoid arthritis. Unfortunately, these implants are prone to fracture and can produce destructive silicone synovitis at long-term follow-up.\(^{14}\)

There is sparse literature concerning the results of silicone arthroplasty for the treatment of MCP joint OA. Rettig et al. presented the results of 13 arthroplasties (12 patients) at an average of 40 months of follow-up.\(^{15}\) The authors found good to excellent results in all patients, with 9 patients reporting a 75% gain in functional improvement and an overall increase in MCP flexion. Final radiographs revealed good alignment without subluxation. There was 1 arthroplasty failure secondary to fracture, and the joint had revision 35 months after surgery. A more recent study\(^{16}\) in 2009 reported similar results in 13 MCP joints (8 patients) replaced with silicone implants. At an average of 4 years (minimum, 1 y) these patients had good to excellent pain relief, with 90% satisfaction. The short-term follow-up results seen with OA are satisfactory, but the long-term outcomes are unknown and need to be analyzed given the failure of silicone implants seen with rheumatoid arthritis (RA).\(^{14}\)

In contrast to constrained silicone implants, pyrolytic carbon arthroplasties are an unconstrained (resurfacing) implant that, by design, produce less stress at the implant-bone interface. However, with compromised soft tissues and collateral ligaments, seen with trauma or
inflammatory arthropathies, the stability and alignment of the arthroplasty is at risk. In the study by Cook et al, the correction of the ulnar deviation obtained at the time of surgery in the rheumatoid MCP joint was not maintained at long-term follow-up.\(^3\) Thus, in comparison to a joint affected by RA, an osteoarthritic joint is an ideal candidate for a pyrolytic carbon implant, given the stiffness inherent to OA and maintained soft tissue sleeve.

There is a paucity of literature investigating pyrolytic carbon arthroplasties in the osteoarthritic MCP joint.\(^3\)\(^-\)\(^5\) Most studies combine patients with differing etiologies of arthritis.\(^3\)\(^-\)\(^5\) Cook et al\(^3\) presented long-term follow-up, average 11.7 years, of pyrolytic carbon arthroplasties in MCP joints for 71 joints affected by RA, post-traumatic arthritis, OA, or lupus. They determined through an analysis of survivorship that there was an average failure rate of 2.1% per year and a 5-year survival rate of 82%. Within this cohort, only 4 implants were used for OA.

More recently, Parker et al\(^5\) investigated pyrolytic carbon arthroplasties in a mixed population, including 20 joints affected by OA and 96 by RA. Thirteen of the OA joints were followed up for more than 1 year (average, 18 mo). The authors did not find a statistically significant increase in range of motion at follow-up, but there was an 88% decrease in the pain level in the OA group. The complication rate was 20%; one patient requested (and had) ray amputation for chronic pain. Radiographically, a surrounding lucency was seen in all joints at 1 year, with no reports of loosening or migration of the implant.

A study focused specifically on pyrolytic carbon arthroplasty of the MCP joint for OA was published in 2005 by Nunez and Citron.\(^4\) This study reported on 10 joints with a minimum 1-year follow-up. After surgery, there was an increase in 10° of motion and improvement in pain. Radiographically there were no failures, loosening, or migration of the implant, yet there was a lucency surrounding each one.

The current study was designed to investigate pyrolytic carbon arthroplasties in the osteoarthritic MCP joint at a minimum of 2 years of follow up. Postoperative range of motion improved significantly by 14°, with no change in the location of the arc of motion as seen with RA.\(^1\)\(^4\) There was a slight decrease in grip strength, but this decrease was not thought to be clinically relevant. The most notable finding was the subjective improvement in pain and high patient satisfaction (90%) at an average of 4 years after surgery.

Two patients were not satisfied with the outcome of their surgery. One patient continued to be dissatisfied with her postoperative outcome and range of motion, despite attempts to address her concerns with a volar plate release. The basis of her dissatisfaction was never clear, although she consistently reported adequate post-
operative pain relief. The one failure was in a patient who had limited range of motion and continued, inexplicable pain. We could not determine the cause of the patient’s pain. There was never evidence of sepsis clinically or with laboratory testing; the implants were not loose and were well seated; and there was no clinical evidence of instability. The patient subsequently had revision to arthrodesis.

The radiographic results of the current study parallel those of previous studies. Although there is a predictable periarticular lucency surrounding all implants (Figs. 2, 3), it does not portend frank implant loosening or predestined failure at an average of 4 years. Also, all implants had subsidence, but it did not appear progressive. In contrast to pyrolytic carbon implants in the proximal interphalangeal joints with OA,\(^5,7\) there is an infrequent failure of the implant secondary to fracture, migration, or dislocation of the MCP joints in patients with OA. However, it is unclear whether the radiographic changes seen in the MCP joint will or will not progress with longer-term follow-up resulting in clinical problems.

The limitations of the current investigation stem primarily from the retrospective nature of the study and the small number of joints available for review. The preoperative information was collected retrospectively, and there was no documented preoperative subjective assessment and level of pain. Also, because of the small numbers, the study was not powered, and thus conclusions are made from the trends seen in the data.

Although pyrolytic carbon arthroplasties might not be the solution for all osteoarthritic joints of the hand, we recommend these implants for osteoarthritic MCP joints. Our results reveal an increase in range of motion, good to excellent pain relief, high patient satisfaction, and radiographic survival of the arthroplasty at an average of 4 years after surgery.

REFERENCES


This reprint is provided with the support of Integra LifeSciences.