Fifty consecutive patients with late infected total knee arthroplasties were treated by debridement and removal of all components and cement, preserving the collateral ligaments. At the time of debridement, an articulating spacer was made to allow partial weightbearing and range of motion of the knee during rehabilitation. This spacer was implanted using antibiotic-impregnated bone cement. For this purpose, 4.8 g powdered tobramycin was mixed with 40 g Simplex cement. Cement was applied early to the components, but applied late to the femur, tibia, and patella to allow molding to the defects and bone without adherence to bone. Patients had tailored intravenous antibiotic therapy for 6 weeks for treatment of various gram-positive and gram-negative organisms. All patients had cemented revision total knee arthroplasty using antibiotic-impregnated cement with standard cementing techniques. Range of motion before reimplantation was 6°–91°. Followup averaged 73 months (range, 24–150 months). The average modified Hospital for Special Surgery knee score after revision was 89 points (range, 70–100 points) with 90% good to excellent results, excluding the results of patients with reinfection. Range of motion after reimplantation was 4°–104°. Six patients had recurrences of infection, and one patient with a poor postoperative range of motion had a fusion. Use of an articulating spacer achieved soft tissue compliance, allowed for ease of operation, reduced postoperative pain, improved function, and eradicated infection equal to standards reported in the literature.

Level of Evidence: Therapeutic study, Level IV (case series—no, or historical controls)

With improved instrumentation and surgical technique, total knee arthroplasty (TKA) has become a reliable and reproducible procedure for pain relief and restoration of function in knees with arthritis.1,2,4,24,26,31,43,47 However, despite continued improvements, complications occur with this procedure.8,15,41,42 One of the most devastating and costly complications of TKA is deep infection. The infection rate in TKA has ranged from less than 1% to as much as 23%,17,23,40 with higher rates reported for hinged prostheses.9,22,37 Prophylactic perioperative antibiotics have been very effective in decreasing the rates of deep infection.12,53 Some authors have reported the overall deep infection rate to be approximately 1–2%.40,44,48,54

Treatment of infected total joint arthroplasty has been controversial, and many options are available,8,23,35,39,41 including chronic suppressive antibiotics, irrigation and debridement with retention of components, resection arthroplasty, arthrodesis, one-stage reimplantation, two-stage reimplantation (early or late), and amputation. The choice of treatment depends on many variables, including chronicity of the infection, host factors (age, health, immunologic compromise), and virulence of the infecting organism. Treatment with antibiotics only has been reserved for the poorest of hosts, including those thought to be medically unable to have surgery. This treatment has had little reported success in eradicating infection.32

Debridement and retention of components has been successful in treating acute infections in a high percentage

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of patients, but has been shown in several series to be unsuccessful in treating chronic infections.\textsuperscript{3,6,16,19,46} The best function has been obtained by reimplantation of components. Single-stage exchange arthroplasty has been successful in isolated cases or small series,\textsuperscript{3,5,13,14,16,34,49} and has the advantage of less surgery, ability to maintain motion and soft tissue health, and lower cost, but generally has not had adequate results in a larger series.\textsuperscript{29} The best results for eradication of infection and maintenance of function have been seen with two-stage reimplantation.\textsuperscript{2,4,9,27,28,45,50–52,58} Early reimplantation, within 2 weeks of joint removal and debridement, has been 35–48% successful in eradicating infection.\textsuperscript{36,38,40} Early series with the use of antibiotic-impregnated cement block spacers were encouraging with reported success rates of 81–100%.\textsuperscript{3,4,27,45,50,52} However, reimplantation was difficult, secondary to contracted soft tissues and poor bone stock. As a result, complications were significant.

Reports of using antibiotic beads or block antibiotic cement spacers to maintain joint space and keep the collateral ligaments from becoming contracted began being published in the late 1980s and early 1990s.\textsuperscript{23,7,30,51,52} Not only was the cement used as a spacer, but it also delivered high-dose local antibiotics to the knee in concentrations greater than could be achieved with intravenous administration. This regimen of using antibiotic-impregnated cement spacers and intravenous antibiotics with delayed exchange arthroplasty has been considered state-of-the-art in cases of infected TKAs and has reported success rates of 88–96% in eradicating infection.\textsuperscript{2,3,51,52}

We present additional followup of a technique described earlier using a method of staged debridement and reimplantation with an articulating spacer that allows delivery of high local concentrations of antibiotics while giving patients a functional joint before a second-stage reimplantation.\textsuperscript{20} Our goal was to determine if this technique would allow ease of revision surgery at the time of reimplantation, improved postoperative pain and function, and acceptable eradication of infection equal to rates reported in published studies.

**MATERIALS AND METHODS**

Fifty patients with chronic deep infection greater than 6 weeks duration involving a TKA (Fig 1) and presenting to us between April 1989 and February 2001 were included in this IRB-approved, retrospective, chart review study. Thirty-eight patients (76%) had a confirmed diagnosis of deep infection by positive cultures obtained by preoperative aspiration of the knee or by intraoperative cultures. The other 12 (24%) patients who had cloudy or purulent joint fluid by aspiration, elevated sedimentation rate, elevated C-reactive protein, and abnormal complete blood count were deemed to have a chronically infected knee. Furthermore, these patients had proven acute inflammation histologically at the time of surgery. Patients with negative cultures were treated by our infectious disease colleagues for the most likely organism with a specific antibiotic regimen (Table 1). The study group included 25 men (50%) and 25 women (50%). The right knee was infected in 27 patients (54%), and the left knee was infected in 23 patients (46%). The average age of the patients was 67 years (range, 38–92 years).

The surgical protocol consisted of a two-stage procedure with delayed reimplantation. The first stage involved irrigation and debridement of all necrotic tissue, synovectomy, and removal of all components and cement. After adequate debridement, an articulating spacer was devised. The articulating spacer was made by cleaning and autoclaving the removed femoral component. This was reinserted during the same operation and articulated with a new tibial polyethylene insert and sometimes a new all-polyethylene patella component with the pegs removed (40%). A thin tibial polyethylene insert (Centerpulse Orthopaedics, Austin, TX) was used rather than an all-polyethylene tibial component so that a large amount of antibiotic-impregnated cement could be placed between the insert and bone (Fig 2). Simplex-P cement (Howmedica, Rutherford, NJ) was mixed with powdered tobramycin in a ratio of 4.8 g tobramycin to 40 g cement. After the first batch of antibiotic cement was mixed, the nonarticulating-
The component then was implanted perpendicular to the long axis of the tibia with approximately 8° posterior slope using a tibial alignment jig. Care was taken to not allow the cement to adhere to the bony surfaces by occasionally toggling the component until the cement was fully cured. This was repeated for the femur and patella (if used) with a second batch of antibiotic cement. The limb was taken to full extension in correct alignment.21 The remaining patients had a standard insert preserved with a deep-dish, ultracongruent tibial component for posterior stabilization. Minimal bony preparation was required or used. All knees had patellar arthrotomy and a quadriceps snip to assist in exposure. Surgery planning with primary care medical clearance. All knees were exposed through the previous incision using a medial parapatellar arthrotomy and a quadriceps snip to assist in exposure. No tibial tubercle osteotomy was required or used. All knees had received a primary or revision component based on bone loss. Patients generally were ambulating by the second postoperative day with a walker or crutches allowing 50% weightbearing on the affected limb. After removal of the plaster shell and compressive dressing, continuous passive motion was begun, and the knee was allowed gentle but full unrestricted range of motion (ROM) under the guidance of a physiotherapist. On admission to the hospital, consultation was obtained from the infectious disease service. Patients were administered a 6-week regimen of tailored intravenous antibiotic therapy based on culture results, clinical anecdotal evidence, blood count, Westergren sedimentation rate, C-reactive protein, radiographs, and recommendation by the infectious disease service. Several patients in this series received additional oral antibiotics after the intravenous regimen based on recommendations of the infectious disease service.

Before the second-stage reimplantation, most patients had completed antibiotic therapy for 2 weeks. No repeat aspirations were done before the second-stage reimplantation. On average, the reimplantation occurred at 12 weeks (range, 4–58 weeks). Variability in reimplantation was associated with circuitous circumstances such as tertiary referral network and coordination of surgery planning with primary care medical clearance. All knees were exposed through the previous incision using a medial parapatellar arthrotomy and a quadriceps snip to assist in exposure. No tibial tubercle osteotomy was required or used. All knees had retained the collateral ligaments at the previous debridement and, therefore, no constrained prostheses were needed. All patients received a primary or revision component based on bone loss. The soft tissues surrounding the articulating spacers seemed supple and healthy in all cases. Bone quality was good in all cases. Tissue was obtained for culture and frozen section. The frozen sections (< 5 polymorphonuclear leukocytes per high power field).33 None showed acute inflammation, and therefore no repeat aspirations were done before the second-stage reimplantation. On average, the reimplantation occurred at 12 weeks (range, 4–58 weeks). Variability in reimplantation was associated with circuitous circumstances such as tertiary referral network and coordination of surgery planning with primary care medical clearance. All knees were exposed through the previous incision using a medial parapatellar arthrotomy and a quadriceps snip to assist in exposure. No tibial tubercle osteotomy was required or used. All knees had retained the collateral ligaments at the previous debridement and, therefore, no constrained prostheses were needed. All patients received a primary or revision component based on bone loss. The soft tissues surrounding the articulating spacers seemed supple and healthy in all cases. Bone quality was good in all cases. Tissue was obtained for culture and frozen section. The decision to proceed with reimplantation was based on results of the frozen sections (< 5 polymorphonuclear leukocytes per high power field).33 None showed acute inflammation, and therefore all were reimplanted at the second stage as planned. After debridement, the knees of most patients (72%) were implanted with a deep-dish, ultracongruent tibial component for posterior stabilization.21 The remaining patients had a standard insert preserving the native posterior cruciate ligament. Minimal bony preparation was needed to accept the new components. All components were cemented using antibiotic-impregnated cement in a ratio of 1.2 g tobramycin to 40 g Simplex-P cement.

### Table 1. Infecting Organisms and Antibiotic Treatment

<table>
<thead>
<tr>
<th>Number of Patients</th>
<th>Percentage of Patients</th>
<th>Organism</th>
<th>Intravenous Antibiotics</th>
<th>Oral Antibiotics</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4%</td>
<td>Enterococcus</td>
<td>Vancomycin, cefazolin</td>
<td>Cefalexin</td>
</tr>
<tr>
<td>1</td>
<td>2%</td>
<td>Klebsiella</td>
<td>Cefoxitin</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4%</td>
<td>Methicillin-resistant Staphylococcus aureus</td>
<td>Vancomycin, cefazolin, clindamycin, rifampin, cefazidine, ciprofloxacin, nafcillin</td>
<td>Vancomycin, rifampin, ceftazolin, ciprofloxacin, nafcillin</td>
</tr>
<tr>
<td>13</td>
<td>26%</td>
<td>Staphylococcus aureus</td>
<td>Vancomycin, cefazolin, clindamycin, rifampin, cefazidine, ciprofloxacin, nafcillin</td>
<td>Rifampin, cephalexin, cefeitoxime</td>
</tr>
<tr>
<td>11</td>
<td>22%</td>
<td>Staphylococcus epidermidis</td>
<td>Ceftriaxone, gentamicin, vancomycin, cefazolin, nafcillin</td>
<td>Cephalexin, rifampin</td>
</tr>
<tr>
<td>4</td>
<td>8%</td>
<td>Streptococcus</td>
<td>Imipenem, penicillin</td>
<td></td>
</tr>
</tbody>
</table>

Multiple infecting

| 1                 | 2%                     | Escherichia coli, Staphylococcus aureus, Klebsiella | Clindamycin                                                | Cephalexin               |
| 2                 | 4%                     | Group B Streptococcus, Staphylococcus aureus       | Ceftriaxone, metronidazole, gentamicin                    | Penicillin               |
| 1                 | 2%                     | Staphylococcus epidermidis, Streptococcus           | Cefazolin, rifampin                                       |                           |
| 13                | 26%                    | None                                           | Ciprofloxacin, vancomycin                                  |                           |
RESULTS

Most patients were elderly, and many had multiple medical problems. The average age was 67 years (range, 38–92 years). The most common predisposing factor for infection was the diagnosis of diabetes mellitus and a history of multiple operations. Two patients had rheumatoid arthritis and were taking chronic steroids, and one patient had chronic urinary tract infections, although the infecting organisms were Enterococcus and Staphylococcus aureus.

It was observed during the reimplantation stage that all spacers were stable but removed easily by gentle tapping with a mallet and punch (Fig 3). During the operation, soft tissues were compliant in all 50 patients, with minimal adhesions, allowing excellent exposure for reimplantation. The operative tourniquet times averaged 77 minutes (range, 42–119 minutes) for the debridement and antibiotic spacer placement stage, and 73 minutes (range, 33–120 minutes) for the reimplantation. Tourniquets routinely were released before closure of the wound to obtain hemostasis.

Thirty-eight of the 50 patients had positive identification of an infecting organism on preoperative aspirations or intraoperative culture specimens. The most common infecting organism was the Staphylococcus species with 19 patients having Staphylococcus aureus, and 12 having Staphylococcus epidermidis. Specimens of two patients grew methicillin-resistant Staphylococcus aureus. Streptococcus grew on culture specimens of seven knees, Enterococcus grew on culture specimens of two knees, Klebsiella grew on culture specimens of two knees, and Escherichia coli grew on the culture specimen of one knee. Specimens from four patients had growth of more than one organism; two organisms grew on three specimens, and three organisms grew on one specimen (Table 1).

Because of our large tertiary referral network, it was difficult to determine the exact onset of infection, but it
was greater than 6 weeks in all patients, therefore, all patients were treated for chronic infection. All patients received 6 weeks of tailored intravenous antibiotics suggested by the infectious disease consultant. Staphylococcus aureus generally was treated with cefazolin sodium for 6 weeks, and rifampin frequently was added as an oral adjuvant. Methicillin-resistant Staphylococcus aureus was treated with vancomycin HCl. Staphylococcus epidermidis generally was treated with vancomycin HCl or cefazolin sodium and rifampin as oral adjuvants. Streptococcus species were treated with cefazolin or penicillin. Gram-negative organisms generally were treated with aminoglycosides. No patient had positive cultures at the time of reimplantation. Patients with negative cultures were treated with vancomycin HCl or a vancomycin HCl/ciprofloxacin combination.

Four patients currently are taking cephalixin chronically; two patients were infected with Staphylococcus aureus, one with Staphylococcus epidermidis, and one had multiple organisms.

Modified Hospital for Special Surgery knee scores before debridement averaged 64 points (range, 30–85 points), and postoperative reimplantation knee scores averaged 89 points (range, 70–100 points). All patients had improved scores with an average improvement of 25 points. Excellent results were seen in 70% of patients, good results were seen in 20%, and fair results were seen in 8%. One patient (2%) had a poor result and requested an arthrodesis.

The average arc of motion before reimplantation was 6° extension to 91° flexion. Range of motion at the latest followup averaged 4°–104°, with an average 16° improvement in arc of motion. Pain scores averaged 35 of a possible 40 at the latest followup.

The average followup for this cohort of patients was 74 months (range, 24–150 months). No patients were lost to followup. Eleven patients included in the study have died, with an average followup of 48.5 months before death. The average time the spacer was in place was 12 weeks (range, 4–58 weeks). There were six recurrent infections (12%), none occurring in the patients with negative cultures. These infections occurred at an average of 35 months (range, 7–60 months) after reimplantation. The average age of these six patients was 73 years (range, 60–87 years). Three of the six patients had diabetes mellitus as an underlying chronic disease. The reinfections occurred in two subsets. Two reinfecions occurred within 11 months of reimplantation, and culture specimens grew the same organism. A second group of four patients had recurrence of infection 36, 47, 48, and 60 months, respectively, after reimplantation. Three of these four recurrences had different organisms on the culture specimens at the time of reinfection.

All six of these patients were treated with repeat articulating spacers. Two patients had a second reimplantation and are doing well at 2 years and 9 years after surgery, respectively. One patient died 3 years after the second reimplantation of medical-related issues, but this patient was clinically free of infection. Two patients with recurrent infections died from medical complications in the perioperative period after their second articulating spacer placement. The final patient was treated with a repeat antibiotic spacer by a different surgeon, and this patient has good function.

There were other notable complications in this group of 50 patients. One patient had posterior instability that required revision of the polyethylene insert to an ulnar congruent insert. One patient with continued poor motion had a knee arthrodesis. One patient had a patella dislocation that required patellectomy. One patient had vestibular damage, and had a serum vancomycin peak and trough greater than the therapeutic level. No patient had evidence of renal toxicity. Serum tobramycin levels were therapeutic on postoperative Day 1 and were undetectable by postoperative Day 3, unless the patient received tobramycin as part of the intravenous regimen. Six patients required knee manipulation postoperatively because of poor ROM. No wound healing problems occurred, and no deep vein thrombosis or pulmonary embolus was seen clinically.

DISCUSSION

Two-stage reimplantation has proven to be the most successful method of treating chronic infected TKAs. However, without the use of a spacer, stiffness and ligament contracture can cause significant problems with reimplantation. Boothe and Lotke stated that without the use of a spacer, the exposure and reimplantation is “arduous because of disuse bone atrophy and the difficulty of removing the abundant scar tissue that obliterates the joint space and compromises soft tissue balance”. Windsor et al reported that six patients in their series required a modified V-Y quadricepsplasty for exposure, and Rosenberg et al reported that three patients needed a tibial tubercle osteotomy, two required patellar tendon reconstructions, and two had flap coverage of wounds at the time of reimplantation.

Three types of spacers have been advocated for treatment of chronically infected total knee arthroplasties: block spacers and two types of articulating spacers. One type of articulating spacer is made completely of antibiotic-impregnated cement using preformed molds. The second type, made of metal and plastic coated with antibiotic-impregnated cement, was used in our cohort of patients. Cement spacers act through a time-release mechanism delivering high doses of antibiotic locally to the knee, which cannot be achieved by systemic antibiotics alone.
In 1987, Borden and Gearen first used antibiotic-impregnated cement beads or block spacers for two-stage delayed reimplantation and reported a 90% success rate. Other have had more reliable and less varied results with 90–96% success rates when compared with results without the use of antibiotic-impregnated cement. Wilde and Ruth reported a 90% success rate using this protocol, and Booth and Lotke reported a 96% success rate in eradication of infection. Whiteside reported a 94% success rate in a series of 33 knees treated in this manner.

Although excellent success in eradication of infection has been achieved using block antibiotic-impregnated cement spacers with two-stage delayed reimplantation, there are still several problems. Booth and Lotke reported five patients with severe wound healing problems, and Wilde and Ruth reported three patients with wound healing problems. Rorabeck reported that in using block spacers, “care must be taken to ensure that the block does not move posteriorly or anteriorly because movement can cause pressure on other structures, including the wound.”

Because of joint stiffness, poor ROM, difficulty with exposure at reimplantation, and patient dissatisfaction with long-term immobilization, a protocol for two-stage reimplantation using an articulating spacer was developed. Cadambi et al reported this protocol with a two-stage early reimplantation at 2 weeks with good results. At an average of 29 months followup, they reported 89% of the patients were free of infection.

Hofmann et al reported on early experience with the two-stage articulating spacer technique using tobramycin-impregnated cement. The broad-spectrum coverage and strong effectiveness of tobramycin make it an excellent choice for antibiotic spacers. The serum levels of tobramycin are therapeutic on the first postoperative day, and by the third postoperative day, serum levels are negligible. None of the patients had evidence of renal toxicity in that study or in the current study.

Emerson et al reported on 26 patients treated with static spacers and 22 patients treated with articulating spacers incorporating metal and plastic. The reinfection rates were statistically similar between the two groups at 36 months, 7.6% for the patients with block spacers and 9% for the patients with mobile spacers. Their results showed that the patients with articulating spacers had significantly better average ROM at followup compared with patients who had block spacers (107.8° compared with 93.7°). This also is consistent with our finding of an average improvement in the total arc of motion of 16°.

Fehring et al reported on the use of molded articulating versus static block spacers. They reported a reinfection rate of 12% with the use of a static spacer and a 7% rate with an articulating spacer. Furthermore, 60% of patients with block spacers had unexpected bone loss between stages versus no bone loss in patients who received articulating spacers. The maintenance of bone stock seen in their series with articulating spacers is similar to our findings in which bone stock was not compromised.

Our study shows the continued advantages of using an articulating spacer as described previously. The technique supports wound healing, allowing partial weight-bearing and avoidance of disuse osteoporosis, and easier reimplantation with efficient surgical time equal to that of a primary TKA. The articulating spacer technique allows ease of exposure in that no tibial tubercle osteotomies or quadricepsplasties were used. Furthermore, the 16° improvement in ROM provided improved functional results in our patients.

Implantation of temporary articulating components with antibiotic-impregnated cement during the first phase of treatment is a proven and valuable addition for treatment of an infected TKA. The data presented show that the current protocol of allowing motion and partial weight-bearing during the spacer phase promotes a healthy and supple periartricular soft tissue sleeve, with ease of exposure, allowing a functional joint during the articulating spacer stage.

References