A Review Paper

Modular Bicompartmental Knee Arthroplasty With Robotic Arm Assistance

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Abstract

Modular bicompartmental arthroplasty is an emerging knee-resurfacing approach that provides a conservative alternative to total knee arthroplasty. Isolated bicompartmental arthritis involving the medial or lateral and patellofemoral compartments, but with no significant deformity or bone deficiency, preserved motion, and intact cruciate ligaments, can be effectively managed with this treatment method. For the many young and active patients with isolated bicompartmental arthritis, given the potential durability of the procedure and the prosthesis, it is appropriate to use an approach that is more conservative than total knee arthroplasty.

Robotic arm assistance for modular bicompartmental arthroplasty optimizes component position and alignment, which may improve system performance and long-term durability.

In addition, a percentage of patients who undergo isolated unicompartmental or patellofemoral arthroplasty may later develop progressive arthritis in an unresurfaced compartment. Their cases may be effectively managed with a staged modular approach to resurfacing the degenerating compartment, but additional study is needed.

Tissue-sparing knee surgery—isolated unicompartmental knee arthroplasty (UKA) or patellofemoral arthroplasty (PFA)—is enjoying its highest level of interest and enthusiastic endorsement since first introduced 3 decades ago. Historically, UKAs and PFAs were performed in substantial numbers only at select centers; elsewhere, they were often dismissed in favor of total knee arthroplasties (TKAs), periarticular osteotomies, or patellectomies. Today, selective compartmental resurfacing (UKA, PFA) is being performed more broadly, as surgeons gain confidence in outcomes. The evolutionary changes in technology and minimally invasive surgical approaches, and the wider endorsement of partial knee resurfacing, have expanded even further the contemporary concept in tissue-sparing knee arthroplasty to include bicompartmental arthroplasty (Figure 1).

The rationale behind this strategy and approach to knee arthroplasty is twofold. First, many patients who undergo TKA have isolated bicompartmental arthritis involving the medial and patellofemoral compartments or the lateral and patellofemoral compartments and have no significant deformity, excellent motion, and intact cruciate ligaments (Figures 2A-2C). As many of these patients are young and active, an approach that is more conservative than TKA seems appropriate, particularly given the potential durability of the procedure and the implant. Second, a percentage of patients who undergo PFA later develop progressive tibiofemoral arthritis and are often converted to TKA rather than offered a modular approach to resurfacing the degenerating compartment. Similarly, several UKAs fail as a result of patellofemoral arthritis, and the knees are also often converted to TKA. Despite the intuitive, rational philosophy behind a modular stepwise approach to resurfacing, we have scant data comparing outcomes of this approach with outcomes of conversion to TKA.

"...implanting a modular bicompartmental resurfacing device, with or without robotics, is technically easier than implanting a monolithic device."

Selective compartmental knee resurfacing based on specific arthritis patterns has been used over the years and is not a novel concept, but its results have not been clearly defined. Argenson and colleagues[1] reported on a series of 183 PFAs, 104 of which were performed in conjunction with UKA. Although outcomes were satisfactory in 84% of the overall results, clinical results in the subset of patients who underwent simultaneous PFA–UKA were not distinguished from overall clinical results. Cartier and colleagues[2] reported on a series of 72 PFAs, 36 of which were performed in conjunction with UKA (30 medial, 6 lateral). Although 85% of the overall results were good or excellent, the data did not specifically address the group that underwent bicompartmental arthroplasty. Neither study

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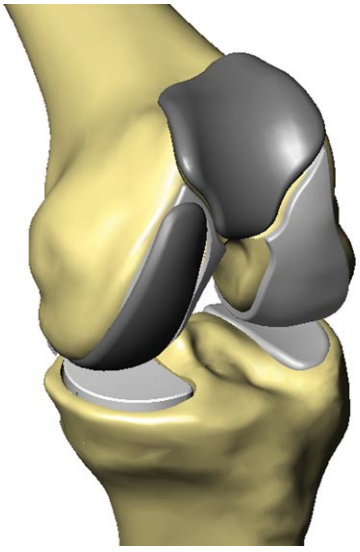

Figure 1. Modular bicompartmental arthroplasty of medial compartment and trochlear surfaces (patella removed). Image courtesy of MAKO Surgical Corp.

provided results specifically for patients who underwent bicompartmental arthroplasty, but there was no specific mention of problems related to use of the modular approach to bicompartmental resurfacing. Given the satisfactory results, modular bicompartmental resurfacing combined with the precision of robotically guided surgical techniques is an attractive option for treating bicompartmental arthritis.

One benefit of modular bicompartmental arthroplasty relative to TKA—aside from bone conservation—is kinematic preservation by virtue of retention of the anterior and posterior cruciate ligaments.[3,4] Minimally invasive surgical techniques reduce blood loss, postoperative pain, and hospital stay and accelerate functional recovery. In addition, bicompartmental resurfacing is an option for patients who have bicompartmental disease but do not want to undergo TKA because they perceive it to be the treatment of last resort. Some surgeons have advocated isolated medial UKA with a mobile-bearing implant design for bicompartmental arthritis involving the medial and patellofemoral compartments—in essence disregarding the arthritis and symptoms in the patellofemoral compartment.[5,6] Berend and colleagues[5] and Beard and colleagues[6] found that neither preoperative patellofemoral arthritis nor pain negatively affected the results of UKA with a mobile-bearing implant. On the contrary, others have found that failures caused by anterior knee pain predictably occur when only the medial compartment of the knee is resurfaced when there is also patellofemoral arthritis.[7] As the data regarding mobile-bearing knees in bicompartmental arthritis have not been replicated in other series (particularly those using fixed-bearing implants), and a rational explanation for the apparent elimination of patellofemoral symptoms is elusive, I prefer to use modular bicompartmental arthroplasty (rather than UKA alone) to treat patients with bicompartmental arthritis and symptoms involving both the medial and patellofemoral compartments, but a comparative study of the results of unicompartmental and bicompartmental arthroplasty for bicompartmental arthritis has yet to be conducted.

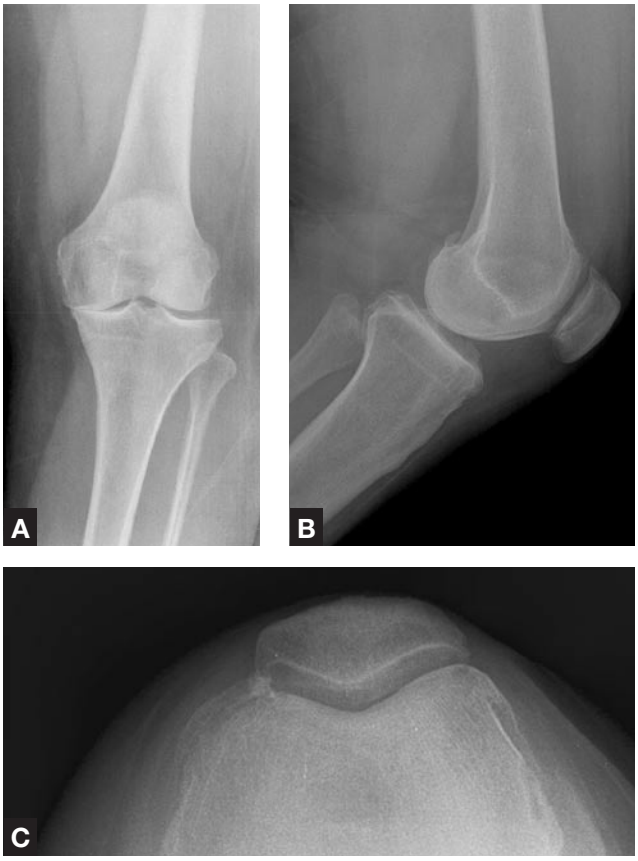

Figure 2. Preoperative anteroposterior (A), lateral (B), and sunrise (C) radiographs of 55-year-old woman with bicompartmental arthritis.

Short-term results are emerging for bicompartmental arthroplasty performed with a relatively new monolithic prosthesis that has a linked trochlear and medial femoral condylar surface and mated patellar and medial tibial plateau components. Proponents have embraced this "conservative" implant as being suited to active, high-demand patients, particularly relatively young patients, provided they have functional anterior cruciate ligament stability, bicompartmental or unicompartmental (medial) arthritis, and no significant deformity. In one series, 95 monolithic bicompartmental arthroplasties were performed by a single surgeon and were followed a mean of 33 months. Explicit details are vague, though 86% of patients were discharged 2 days after surgery, and mean range of motion was 0° to 117° at short-term follow-up. After 2 weeks, most patients were satisfied and walking without an assistive device. The authors reported no cases of patellofemoral pain or clunking.[8]

Although early results with a monolithic device are encouraging, use of a monolithic bicompartmental arthroplasty for trochlear-medial femoral condylar resurfacing faces some challenges. With this philosophical approach to bicompartmental resurfacing, the varus–valgus alignment of the component is determined by the apposition of the lateral transitional edge of the trochlear component with the lateral femoral condyle. Given the variability in coronal alignment and morphology of the distal femur, there

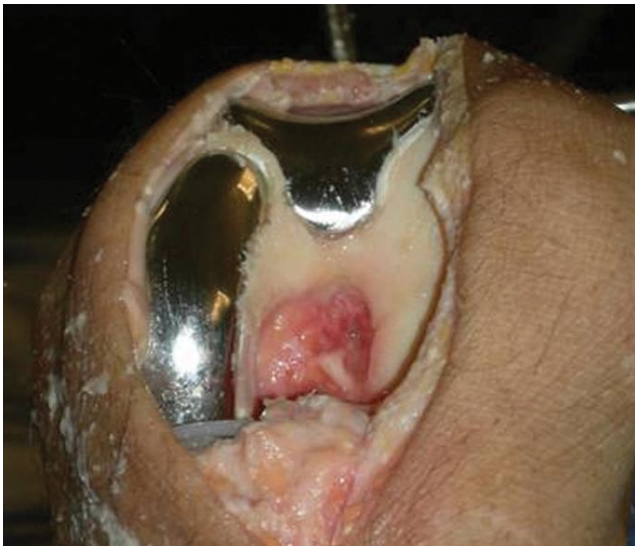

Figure 3. Modular bicompartmental arthroplasty in place after bone preparation with robotic arm assistance.

will be concomitant variability in how the implant can be aligned to ensure that the lateral edge of the trochlear prosthesis is flush with the lateral femoral condyle. Analysis of radiographs of the monolithic implant will certainly show variability in the trochlear orientation relative to the distal femur, with some components in varus, others in valgus, and still others in neutral alignment relative to the femoral mechanical axis. From a technical perspective, it is difficult to routinely achieve both reasonable alignment of the femoral component and a flush transitional edge between the lateral edge of the trochlear component and the articular surface of the lateral femoral condyle. Whether compromise in the alignment or position of either of these areas has deleterious effects on patellar tracking and midterm performance of the implant is not yet known.

The alternative approach to bicompartmental resurfacing, and my preference, is a modular unlinked trochlear and medial femoral condylar prosthesis, which allows individual compartmental resurfacing procedures to be performed "independent" of each other, ensuring appropriate orientation and alignment of the individual components relative to the critical coronal and rotational axes of the distal femur, without having to compromise implant position based on how the component is positioned in the other compartment (Figure 3). This also allows size interchangeability between compartments to accommodate potential variability in femoral geometry and aspect ratios between patients and compartments of the knee.

In addition, my opinion is that implanting a modular bicompartmental resurfacing device, with or without robotics, is technically easier than implanting a monolithic device. The modular approach to bicompartmental resurfacing is also highly compatible with robotic assistance for bone preparation and 3-dimensional preoperative planning. Although using a modular bicompartmental arthroplasty rather than a monolithic prosthesis makes intuitive sense, study results have yet to establish whether one approach is superior to the other.

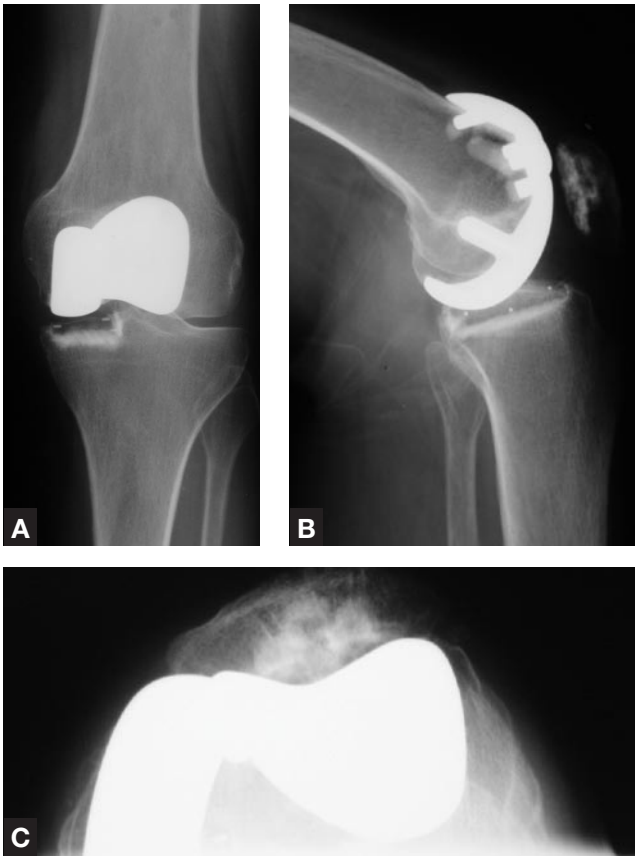

Figure 4. Postoperative anteroposterior (A), lateral (B), and sunrise (C) radiographs after modular bicompartmental arthroplasty.

In modular bicompartmental resurfacing, the size of the gap between the transitional edge of the trochlear component and the proximal edge of the femoral component of the UKA may vary. The distance may be as little as 1 mm and as large as 15 mm, depending on the distal femoral shape and size. Problems with the transitional gap between the trochlear and condylar prostheses have not been found with independent resurfacing, provided the implants are appropriately positioned flush with or recessed approximately 1 mm relative to the articular cartilage. Prominent edges could result in the patellar prosthesis catching or snapping over the implants and therefore should be avoided. Implant edge prominence can result from technical errors or implant design flaws.[9] Malaligned, malpositioned, improperly sized components and components that do not rest flush with the condylar surfaces can affect patellar tracking and have consequences relative to patellar performance and long-term success of bicompartmental arthroplasty. The advantage of bone preparation with robotic arm assistance for modular bicompartmental arthroplasty is the ability to accurately model the 3-dimensional implant position and orientation from the patient-specific preoperative computed tomography scan and to prepare the bone and position the implants with great precision, optimizing the relationship between the components and enhancing the smooth transition of the patellar prosthesis from the trochlear component onto the femoral condylar component.

I have performed 5 simultaneous modular bicompartmental arthroplasties in 4 patients (mean age, 58 years; range, 48-68 years) with a minimum follow-up of 6 months (range, 6 months to 1 year) and another 6 of these arthroplasties with a follow-up of less than 6 months (Figures 4A-4C). Hospital stay averaged 2 days (range, 1-3 days). Short-term results were favorable. Seventy-five percent of the patients were walking without their canes by 4 weeks. Mean range of motion was 125° at 6 weeks and 140° at 6 months.

Staged Bicompartmental Resurfacing

Another novel option is a staged approach to bicompartmental arthroplasty. One mechanism of long-term failure after UKA is development or progression of symptomatic patellofemoral arthritis.[7,10] Khan and colleagues[10] found that 2 (7%) of 30 knees treated with UKA developed progressive osteoarthritis of the patellofemoral compartment within 10 years. Berger and colleagues[7] found that arthritis-induced patellofemoral symptoms occurred in 1.6% of patients within 10 years of fixed-bearing UKA and in 10% of patients within 15 years. Many of these patients were treated with revision to TKA.

The primary mode of long-term "failure" after PFA is progressive tibiofemoral arthritis. Cartier and colleagues[11] found that 10% (8/79) of PFA patients developed progressive and painful tibiofemoral arthritis at a mean follow-up of 10 years. Nicol and colleagues[12] reported that, because of progressive and symptomatic tibiofemoral arthritis, 12% of 103 consecutive PFAs were revised to TKA after a mean of 55 months (range, 14-95 months). Kooijman and colleagues[13] found that 12 (21%) of 56 knees required additional surgery (proximal tibial osteotomy in 1 case, revision to TKA in 11 cases) to address progressive tibiofemoral arthritis at a mean of 15.6 years (range, 10-21 years) after PFA; no knee was treated with isolated unicompartmental resurfacing for localized progression of medial or lateral arthritis. Argenson and colleagues[14] reported that 25% of PFAs were revised to TKA at a mean of 7.3 years (range, 1-12 years) because of progressive and painful tibiofemoral arthritis.

"Modular bicompartmental arthroplasty with or without robotic assistance is appealing as a conservative and kinematic-preserving approach to knee arthritis..."

In patients with isolated PFA or UKA, progressive degeneration of an unresurfaced compartment of the knee could be treated with staged single-compartment resurfacing (in essence, with staged modular bicompartmental arthroplasty) rather than conversion to TKA. However, published data are lacking, and clinical study of this treatment strategy is needed to establish whether the results of sequential compartmental resurfacing make this a reasonable alternative to revision to TKA when isolated compartment resurfacing has "failed" because of progressive arthritis of one of the unresurfaced compartments of the knee. At this point, it is unclear whether use of the robotic arm technology can be applied in these scenarios, because preoperative planning with computed tomography and intraoperative registration and mapping are affected by the presence of prior PFA and UKA. Although use of the robotic arm technology may be possible in the future, for now conventional techniques of resurfacing must be applied effectively for staged resurfacing of the second compartment.

Conclusions

In appropriately selected patients with limited deformity, intact cruciate ligaments, and appropriate expectations, bicompartmental resurfacing is a legitimate alternative to TKA for arthritis of the medial and patellofemoral compartments. Modular bicompartmental arthroplasty with or without robotic assistance is appealing as a conservative and kinematic-preserving approach to knee arthritis, but additional research and results are needed to provide further support for its broader application.

Author's Disclosure Statement

Dr. Lonner wishes to disclose that he is a paid consultant to MAKO Surgical Corp. and Zimmer. He also notes that he is a shareholder in MAKO Surgical Corp.

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