Introduction
Total knee arthroplasty (TKA) is performed to alleviate pain and restore function, motion, and anatomical alignment to the lower limb. Of these objectives, restoration of anatomical alignment between the femur and tibia is accomplished least consistently with primary TKA.

An osteoarthritic knee typically has disproportionate cartilage wear in the two tibiofemoral compartments that is skewed consistent with its angular deformity. Subjects with a varus tibiofemoral deformity tend to overload the medial compartment relative to the lateral compartment whereas those with the considerably rarer valgus tibiofemoral deformity tend to overload the lateral compartment. With either angular deformity, the mechanical weightbearing axis that connects the centers of the hip and ankle in stance will usually pass through the overloaded compartment. During primary TKA, the surgeon attempts to restore anatomical alignment between the tibia and femur through bone resection and soft tissue balancing such that the mechanical axis passes through the center of the knee.

In this study, we examined retrieved cruciate-retaining inserts from a single fixed-bearing TKA design to evaluate how surgical placement of the mechanical weightbearing axis impacted wear of the polyethylene bearing. We hypothesized that wear would continue to be biased in the direction of the pre-existent osteoarthritis when the mechanical axis remained biased towards the overloaded compartment.

Methods
Studied were 54 knees that met the following criteria: 1) standard posterior cruciate-retaining Anatomic Modular Knee (DePuy, a J&J Company, Warsaw, Indiana) insert revised for wear or osteolysis, 2) insert had been implanted into an osteoarthritic knee with no prior arthroplasty or osteotomy, and 3) patient had a single-leg standing anteroposterior radiograph (35x43 cm) before TKA and a standing long-leg anteroposterior radiograph (35x129 cm) at 4 months after TKA.

On the 4-month long-leg radiograph, a line was drawn connecting the centers of the hip and ankle to approximate the mechanical weightbearing axis of the affected limb. Medial offset of this line from the center of the tibial component was measured at the joint line. Tibiofemoral angles were measured directly from the preoperative and 4-month radiographs after drawing lines through the long axes of the femur and tibia.

Laboratory analysis of the retrieved inserts was performed to quantify the magnitude and define the location of maximum wear within each compartment. With calipers, we measured the minimum remaining polyethylene thickness and the distances from the minimum thickness point to the anterior-most and medial-most edges of the insert. Since this system features 5 tibial component sizes, we normalized the positional measurements to a single size using the standard anteroposterior and mediolateral dimensions of the retrieved insert and the most common size (Size 3). The maximum wear depth in each compartment was computed as the difference between its original minimum thickness and its minimum thickness at explantation. Wear rates for each compartment were estimated by dividing the maximum wear depth by years spent in situ. The rate of asymmetric wear was estimated by subtracting the lateral compartment wear rate from the medial compartment wear rate.

Results
Preoperatively, 46 knees had varus osteoarthritis (tibiofemoral angle < 5° valgus) and 6 had valgus osteoarthritis (tibiofemoral angle > 10° valgus). Mean time in situ was 7 (1 to 15) years. Mean wear rates for the medial and lateral compartments were 0.5 (0.0 to 3.3) mm/year and 0.3 (0.0 to 2.0) mm/year, respectively. Asymmetric wear rates averaged 0.2 (-0.9 to 2.8) mm/year.

Varus knees (n=46). On the 4-month radiographs, the mechanical axis lied at an average of 3 mm medial to the knee center (21 mm lateral to 27 mm medial) and the tibiofemoral angle averaged 6° valgus (2° to 12° valgus). Spearman’s correlation analysis revealed that as the mechanical axis was placed increasingly medial (or decreasingly lateral) to the knee center: 1) medial compartment wear rate increased (p=0.01, correlation=0.51), 2) asymmetric wear rate increased (p=0.01, correlation=0.67), and 3) point of maximum wear depth moved nearer the medial edge of the insert (p=0.01, correlation=0.46). Owing to the natural connection between tibiofemoral angulation and the mechanical axis location (p<0.01, correlation=0.88), a lesser 4-month tibiofemoral angle also correlated with increasing medial compartment (p<0.01, correlation=0.42) and asymmetric (p<0.01, correlation=0.58) wear rates and a more medial location of maximum wear (p<0.01, correlation=0.36), though the correlations were weaker relative to those that these variables had with the location of the mechanical axis. Of 31 inserts where the mechanical axis was placed medial to or through the knee center, 30 (97%) had more medial compartment wear than lateral compartment wear and 23 (74%) had an asymmetric wear rate above 0.2 mm/year (27/31 had an asymmetric wear rate > 0.1 mm/year). Of 15 inserts where the mechanical axis was placed lateral to the knee center, 10 (67%) had greater medial compartment wear than lateral compartment wear but only 4 (27%) had an asymmetric wear rate above 0.2 mm/year in absolute magnitude (7/15 had an asymmetric wear rate > 0.1 mm/year in absolute magnitude). The 31 knees with a medially-offset or centered mechanical axis had a greater wear rate in the more worn compartment than did the 15 with a laterally-offset mechanical axis (p=0.04, Mann-Whitney U-test), while the respective wear rates in the less worn compartment were similar (p=0.92, Mann-Whitney U-test).

Discussion
In knees with varus osteoarthritides, more medial placement of the mechanical weightbearing axis ultimately resulted in greater medial compartment wear rates, greater asymmetry in the wear rates of the medial and lateral compartments, and eccentric wear skewed nearer the medial edge of the insert.

Increased medial compartment wear rates arouse concerns of faster polyethylene debris generation and eventual wear-through. Asymmetry in the wear of the medial and lateral compartments leads to a gradual loss of anatomical tibiofemoral alignment. Eccentric wear of the polyethylene tibial insert carries a number of adverse consequences. When the medial condyle of the femoral component wore towards the medial edge of the insert, we often noted metal-on-metal wear between its lateral condyle and the head of the cylindrical locking pin that joined the insert to the central stem of the baseplate. We also observed polyethylene fragmentation and dissociation at the medial edge of the bearing that permitted contact between the femoral component and baseplate. Eccentric wear also permits edge loading, which is considered detrimental to the durability of tibial fixation.

Chief among the limitations of the current study is that the population under analysis was restricted to failed arthroplasties. We have yet to evaluate the impact of mechanical axis placement in components that remain in situ or those that have been explanted for other reasons. Analysis of components in situ presents a challenge in that wear must be quantified radiographically. Thus, while we have identified definite untoward wear outcomes related to mechanical axis placement in this design, we have yet to evaluate the effect of mechanical axis placement on our overall clinical outcome.

Analyzing retrieved inserts of this minimally-constrained posterior cruciate-retaining design leads us to believe that placing the mechanical axis through the center or to the lateral side of varus knees may be a preferable approach to placing the mechanical axis through the center or permitting it to remain on the medial side. The surgical trade-off is that additional bone resection may be required to achieve greater lateralization of the mechanical weightbearing axis.