Less range of motion with resurfacing arthroplasty than with total hip arthroplasty
In vitro examination of 8 designs

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背景下和目的：髋关节表面置换术近年来已经复兴，并且现在是年轻和活跃患者的流行选择。我们使用了一个体外模型来评估表面置换术的活动范围和嵌入特征，并将其与传统全髋关节置换术进行了比较。

方法：8个不同的髋关节置换设计被植入成年复合股骨和骨盆。这些设计被安装在一个三维罗盘上，允许所有运动，并记录了角度和嵌入情况。测试的设计包括Conservé Plus Hip Resurfacing System, Depuy ASR, Birmingham Hip Resurfacing System, Charnley, McKee-Farrar metal-on-metal, SROM Hip metal-on-metal, SROM Hip metal-on-polyethylene, Prodigy metal-on-metal，以及一个自然合成股骨和骨盆关节。股骨内衬在0和20度的前倾位置被测试。

结果：常规关节置换术的活动范围在统计学上显著大于表面置换术。表面置换术在29/30个运动中表现出颈部嵌入。常规关节置换术在41/100个运动中表现出股骨颈部嵌入。

解释：体内的表面置换术范围运动小于常规全髋关节置换术。表面置换系统几乎全部在股骨头颈处嵌入，而常规髋关节置换术则具有一个变化的嵌入模式。我们的发现引起了对早期颈-杯嵌入的担忧，这可能会导致组件松动和股骨颈骨折，这两种情况都观察到在表面关节置换术后。
different for resurfacing and for conventional hip replacements. We used a model that has an advantage over clinical models, which include numerous confounding variables (e.g. soft tissue attachments), and still reflects component and anatomic restrictions on range of motion.

Materials and methods

We studied 3 contemporary hip resurfacing arthroplasty systems and 5 conventional hip arthroplasty systems representing widely implanted, historic, and current systems: A Wright Conserve Plus, Depuy ASR, Birmingham Hip Resurface, Charnley flat back, Mckee-Farrar metal-on-metal, SROM metal-on-polyethylene, SROM metal-on-metal, and Prodigy metal-on-metal. An intact, native hip model was also included (Table 1).

Validated adult composite femur and pelvic models (Cristofolini et al. 1996) (size Adult/Large) were used to create the in vitro hip model; they were of uniform size throughout the study. All components were implanted with standard operative technique by a single surgeon using concentric acetabular reaming, oscillating saws, cylindrical femoral head reamers, and burrs.

The acetabular components were press-fitted into the pelvis with molding clay if necessary. For reasons of reproducibility, the component was placed with an orientation parallel to a plane created by 3 points along the acetabular rim. The result was an abduction angle of 45 degrees (± 2 degrees) determined by goniometry.

The femoral components were placed according to each manufacturer’s recommended technique, again using molding clay. For stemmed implants, the femoral neck was cut with an oscillating saw, the canal broached and prepared for 0 or 20 degrees of anteversion with restoration of offset, and the center of the head maintained at the level of the tip of the greater trochanter (Figure 2). Care was taken to ensure coaxial alignment of stem and femoral shaft. For resurfacing components, cylindrical reamers and burr were used to resect only the bone that would be replaced by the resurfacing component with particular attention paid to center of neck stem position, avoidance of femoral neck notching.

Table 1. Component specifications

| Component                  | Head Diameter | Length | Cup Outer Diameter | Bearing |
|----------------------------|---------------|--------|--------------------|---------|
| Charnley flatback          | 22            | Nonmodular | 44      | PE      |
| McKee-Farrar               | 46            | Nonmodular | N/A     | M       |
| SROM 16-11-150 stem length | 28            | 0      | 54      | M       |
| SROM 16-11-150 stem length | 32            | 0      | 52      | PE      |
| Prodigy 12 mm LRG          | 36            | 8.5    | 54      | M       |
| Birmingham Hip Resurface   | 50            | N/A    | 56      | M       |
| Conserve Plus              | 50            | N/A    | 56      | M       |
| Depuy ASR                  | 46            | N/A    | 52      | M       |
| Native hip                 | N/A           | N/A    | N/A    | N/A     |

* Bearing. PE – polyethylene; M – metal
b Depuy, Warsaw, IN
c Smith and Nephew, Memphis TN
d Wright Medical Technology, Arlington, TN
e Pacific Research Laboratories Inc.
and recreation of concentric and flush transition from the metal surface to the femoral neck.

Implanted hip models were then mounted inside a 3-dimensional compass that has been used in previous publications, with a measurement accuracy of one degree (Amstutz et al. 1975, Chandler et al. 1982) (Figure 3). This compass allowed controlled, selective motions of the hip, specifically rotations in the sagittal, coronal, and axial planes. The compass also allowed femoral and pelvic adjustments to establish a single, concentric point of rotation. The implanted hips were then moved in 10 different motions, with the range and point of impingement recorded. Stemmed femoral systems were tested at both 0 degrees and 20 degrees of anteversion.

In order to minimize variation due to anatomical differences, composite model femurs and pelvises were used rather than cadaver specimens. These models provide almost identical geometry from one specimen to the next, representing typical/average cadaveric anatomy and mechanical properties. One pelvis was used for all acetabular components, whereas a fresh femur was used for each type of femoral component implantation.

The range of motion of the intact femur within the acetabulum was first measured without any implant. Then, ranges of motion in each plane (10 separate motions) for each of the combinations of femoral and acetabular components were conducted. With each of the 10 motions, each measurement was repeated twice by the same observer.

Statistics
For each of the 10 motions (hyperextension, abduction, adduction, internal rotation, etc.), mean and standard error of the 2 measurements (in degrees of rotation) were plotted and compared using a separate Student’s t-test for each comparison. For illustrative purposes, motions that corresponded to the same plane were added to equal the arc of motion in that plane (e.g. the degree of internal rotation was added to the degree of external rotation to equal the arc of motion in the axial plane). Impingement profiles of components were recorded as 2 groups: neck impingement (component or native) and non-neck impingement (typically greater trochanter on pelvis and lesser trochanter on pubic ring).

Results
Mean and standard error of each range of motion are depicted graphically for zero degrees of femoral anteversion, separately for those in full extension (Figure 4) and for those in 90 degrees of pelvic flexion (Figure 5). The results are similarly depicted for 20 degrees of femoral anteversion, separately for those in full extension (Figure 6) and for those in 90 degrees of pelvic flexion (Figure 7). In general, compared to conventional hip replacements, resurfacing arthroplasties showed less range of motion. Specifically, of the 20 movements evaluated (10 with zero femoral anteversion, and 10 with 20 degrees of femoral anteversion), conventional
hip replacements had greater range of motion in 12 movements, while resurfacing implants exhibited greater range of motion in 2 movements (Table 2).

Average ranges of motion corresponding to each of the sagittal, coronal, and axial planes were then calculated by combining averages of hyperextension and full flexion, abduction and adduction, and internal and external rotation (Table 3). Resurfacing arthroplasty showed arcs of motion in the sagittal, coronal, and axial planes of 135, 78, and 115 degrees. Conventional hip arthroplasty with 0 degrees of femoral anteversion showed average arcs of motion of 174, 87, and 150 degrees. Conventional hip arthroplasty with 20 degrees of femoral anteversion showed average arcs of motion of 158, 90, and 147 degrees (Figures 8 and 9).

The impingement profile of resurfacing arthroplasty showed cup-on-neck impingement in 29/30 motions. Conventional hip arthroplasty had a more varied profile with 20/50 motions causing
neck-on-cup impingement for the 0-degrees antverted group and 21/50 motions for the 20-degrees antverted group. The native hip showed neck impingement in 12/20 of movements.

**Discussion**

We found that overall, in situ hip resurfacing arthroplasty exhibits less range of motion than conventional hip arthroplasty. While not every individual motion showed this difference, the model showed that conventional hips had statistically significantly more range of motion in 12 of the 20 movements evaluated, while resurfacing exhibited increased range in only 2 movements. These data coincide with the computer model of Dr Doherty et al. from Dr. Phil Noble’s group (Houston, Texas; personal communication), which suggests resurfacing range of motion is
Table 2. Mean (SE) for each range of motion (in degrees), comparing conventional hip replacements to resurfacing implants

| N     | Coventional | Resurfacing | Difference * | p-value |
|-------|-------------|-------------|--------------|---------|
| 0° femoral anteversion |             |             |              |         |
| Full extension |             |             |              |         |
| Hyperextension | 2 | 69 (3) | 33 (6) | 36 | <0.01 |
| Abduction | 2 | 50 (3) | 30 (4) | 20 | <0.01 |
| Adduction | 2 | 36 (3) | 48 (2) | -11 | 0.02 |
| Internal rotation | 2 | 86 (3) | 93 (4) | -7 | 0.2 |
| Externl rotation | 2 | 60 (3) | 22 (6) | 38 | <0.01 |
| Full flexion | 2 | 105 (3) | 102 (2) | 4 | 0.4 |
| 90° pelvic flexion |             |             |              |         |
| 10° abd., full flexion | 2 | 63 (17) | 15 (1) | 48 | 0.03 |
| Adduction | 2 | 14 (3) | 21 (5) | -7 | 0.2 |
| Internal rotation | 2 | 15 (3) | 7 (2) | 8 | 0.05 |
| Externl rotation | 2 | 89 (5) | 81 (4) | 8 | 0.3 |

Table 3. Summed motion arcs. Values are mean degree

| Arc               | Summed motion arc |
|-------------------|--------------------|
|                  | Conventional | Resurfacing |
| 0° femoral anteversion |             |             |
| Sagittal          | 174         | 135         |
| Coronal           | 87          | 78          |
| Axial             | 150         | 115         |
| 20° femoral anteversion |             |             |
| Sagittal          | 158         | 135         |
| Coronal           | 90          | 78          |
| Axial             | 147         | 115         |

reduced in all 3 planes of motion.

Perhaps just as important, the impingement profiles of hip resurfacing were essentially all neck-on-cup impingement, whereas conventional hip arthroplasty had a more heterogenous profile.

We feel that the excellent range of motion of the native, intact hip used in our study is somewhat of an artifact and should only be used for contextual purposes when evaluating implanted hips. This artifact arose from the fact that the native diameters of the femoral head and acetabulum are less congruent than that of the instrumented hip, yielding less constraint and allowing slight subluxation, which enhanced range of motion.

The in vitro model we used has been used previously (Amstutz et al. 1975, Chandler et al. 1982). Recently, an in vitro model using only component geometry constraints was used to investigate hip stability (Bader et al. 2004). The model we used has the same advantage of simplicity, devoid of the numerous confounding variables found in clinical, in vivo, or cadaveric models. It does, however, retain anatomic skeletal constraints as well as component geometry constraints.

Our study has several shortcomings that are readily apparent. Most importantly, this was an in vitro study, and therefore could not incorporate the complex nature of an in vivo implanted hip. Furthermore, human hips move in concert with the lumbar spine and pelvic mobility (Perron et al. 2000, Watelain et al. 2001, Vogt et al. 2003), thus potentially compensating for impingement profiles of hip arthroplasty.
Another shortcoming is that the variations in anatomy or other characteristics among patients were not included. Rather, the model was constructed using standardized composite femurs and pelvises. A new composite model femur was used for each implant design, and each setup was measured twice. Consequently, the statistical analysis is based on variance in outcome due to measurement error rather than differences between patients. Such a model offers the ability to more easily detect differences in range of motion due to differences in implant design; however, this comes at the cost of making it difficult to generalize the results to patients without reference to additional clinical evidence. On the other hand, patient studies of hip range of motion typically suffer from large variations due to many confounding variables such as differences not only in anatomy but also in soft tissue characteristics, age, underlying disease, and many others, and therefore require large numbers of subjects before statistically significant differences can be detected.

Finally, our study was subject to technical confounding variables such as implantation technique. While this is unavoidable to some extent with this type of model, we sought to minimize internal variables by using several simple parameters: implanting the acetabular component in the plane of the pelvic rim, minimizing potentially biased techniques, implanting the femoral component to restore offset, maintaining the center of femoral head at the level of the tip of the greater trochanter, and ensuring a smooth transition from resurfacing head to femoral neck. We note that at the time of surgery, acetabular components may be “ideally” oriented to minimize impingement. For the purposes of this study, one reproducible position was based on the acetabular brim to avoid confounding variables.

Historically, hip resurfacing has underperformed relative to conventional total hip arthroplasty, largely due to aseptic loosening. Our findings suggest that component loosening may be caused by—or be at least partially attributable to—a relatively smaller arc of motion and a predominance of neck-on-cup impingement. This is particularly concerning given that a large proportion of the patient population undergoing hip resurfacing are younger and more active, thus potentially exacerbating the impingement profile of these devices.

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BCB: in vitro model implantation, experiment design, and writing of manuscript. SNS: experiment design and literature research. EE: editing of manuscript, experimental design, and literature research.

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