CERVICAL ARTIFICIAL DISC WEAR:
THE INFLUENCE OF SURGICAL PLACEMENT

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INTRODUCTION

Relative motion at interacting implant surfaces generates wear debris over time leading to periprosthetic osteolysis and device failure. Factors related to implant design, patient habitus and surgical approach will impact the generation of wear debris and influence the clinical longevity of artificial spinal disc devices. Further, surgeons play an important role in selecting the appropriate implant size as well as its placement within the disc space to optimize soft tissue balance and alignment.[1,2] Current wear testing standards for artificial discs do not account for the influence of anatomic structures or variations in disc placement. Dooris *et al.*[3] suggested that anterior placement of the device led to increased facet joint loads in compression and extension. These findings suggest that if the implant is placed posteriorly within the disc, the spinal stiffness will be restored and facet loads will be maintained at pre-implantation levels.

This exhibit describes the influence of neutral, anterior and posterior disc positioning on surface stresses and polymeric wear volumes using a finite element model and further seeks whether corroboration with clinical wear patterns exists.

METHODS

A finite element (FE) model of an artificial ball-on-socket cervical disc (metal-on-polymer similar to ProDisc-C (Synthes, West Chester, PA)) was created in Abaqus™ software (Dassault Systems, Providence, RI). The disc was placed in an experimentally validated ligamentous C5-C6 FE model[4] simulating appropriate surgery and subjected to sinusodial displacement conditions of flexion/extension= ±7.5°, lateral bending = ±6°, rotation= ±4° and axial loading of 50-150N as per ISO 18192 (Figures 1.a - 1.c). The C6 vertebra was completely constrained in all six degrees-of-freedom and the sliding interactions between the articulating surfaces were simulated as "hard contact" using a coefficient of friction of 0.2 at the interface. An adaptive meshing technique was utilized to compute the wear depth on the surface of the polymeric core.[5-6]

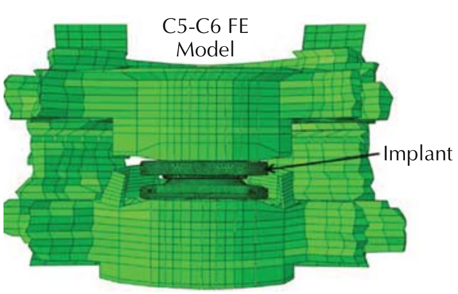


Fig 1 (a) Finite element model of the metal-on-polymer cervical disc within the functional spinal unit.

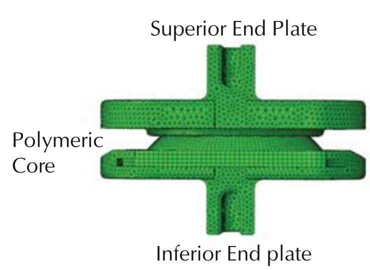


Fig 1 (b) A detailed view of the ball-on-socket design.

Wear depth was derived from Archard's wear law which is a function of contact stresses and sliding distance.

$$d = KFx$$

d = wear depth

K = wear coefficient

F = contact stress

x = relative sliding distance

The wear coefficient (K) utilized was 19.84 x 10^{-10} mm^3/N-mm derived from the work of Rawlinson et al.[5] The linear as well as volumetric wear was computed for up to 5 million cycles. To study the influence of position of the device, these models were further modified by moving the device 0.5 mm in anterior and posterior directions from the neutral position and the positional wear data compared.

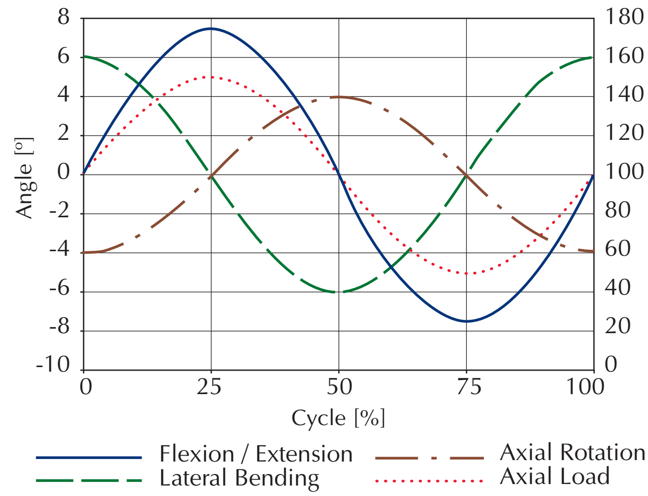


Fig 1 (c) *Phasing of the displacement and axial load curves for wear simulations per ISO 18192. The lateral bending is shifted 90-degrees to the flexion/extension axis, while the axial rotation and lateral bending are 180-degrees out-of-phase. The axial load (N) is in-phase with the flexion/extension motion.*

RESULTS

Lift-off/separation was observed at the device interface for all cases during extension and lateral bending (Figure 2.a). An increase in Von Mises stresses was observed (Figure 2.b) for both the anterior and posterior placement test cases in comparison to the neutral position. These stress images give an indication of the areas where polymer damage is likely to occur.

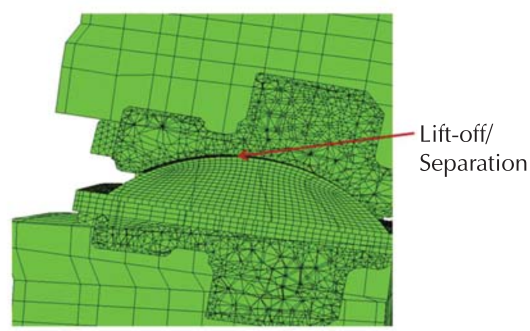


Fig 2 (a) *Lift-off/separation at the implant interface.*

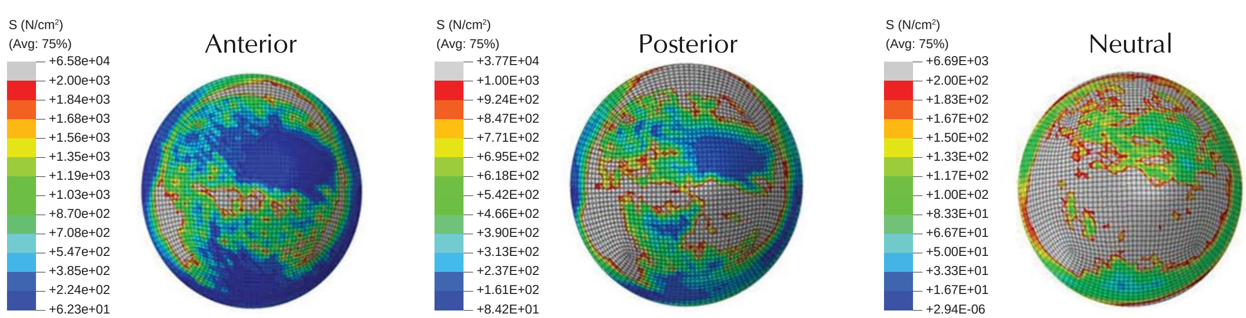
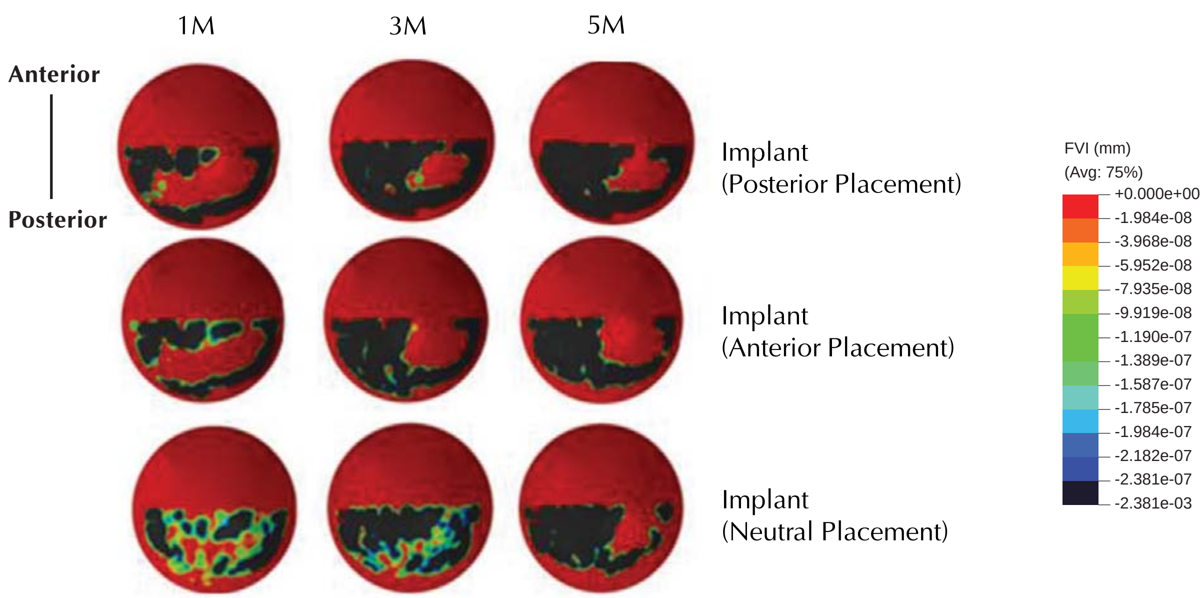
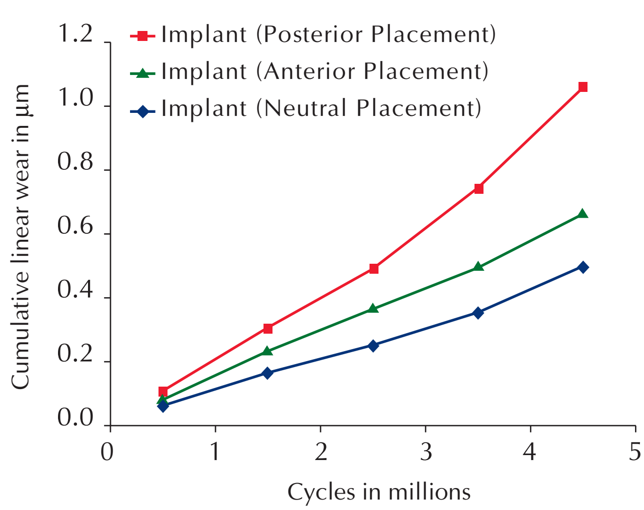


Fig 2 (b) *Von Mises stress contours for the test cases, grey/red denotes maximum, blue denotes minimum. It should be noted that stress scales are different.*

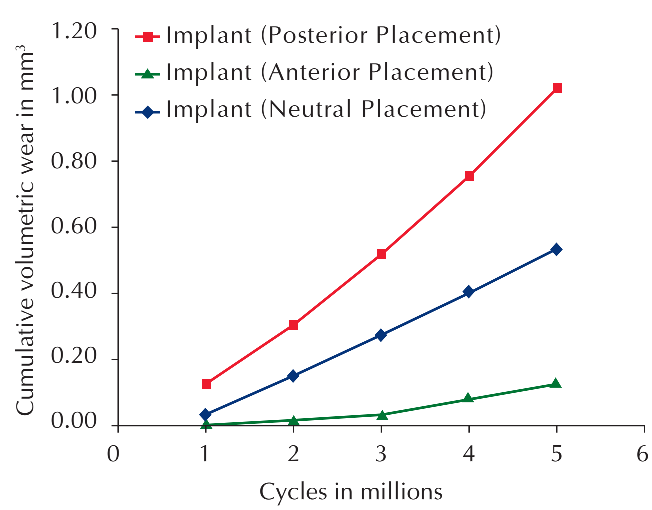
The footprint of the surface stress distribution also influences the wear contours. The linear wear patterns for the implanted cervical disc cases were lopsided posteriorly, irrespective of their placement (Figure 3.a). The maximum linear wear was computed for the posterior test case while the minimum wear was observed for the neutral case (Figure 3.b). On posterior positioning of the implant, the linear wear depth increased 2.65 times in comparison to the neutral position at the end of 5 million cycles. The posterior case also reported a maximum cumulative volumetric wear of 1.14 mm^3 compared to the neutral value of 0.6 mm^3 (Figure 3.c) after 5 million cycles.



(a)



(b)



(c)

Fig 3 (a) Linear wear contours observed during various positions, black denotes maximum, red denotes minimum (M = million). (b) Cumulative linear wear in µm for up to 5 million cycles. (c) Volumetric wear in mm^3.

DISCUSSION

Though the anterior positioning led to increased peak stresses, posterior positioning led to uniformly distributed high stresses. As wear is a function of not only the stresses but also the sliding distance, which was lesser in the case of anterior placement, the overall effect led to increased wear during posterior positioning.

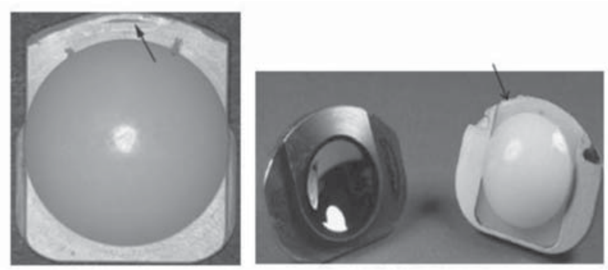


Fig 4 Incidence of burnishing and plastic deformation of the polymeric core after retrieval for a ProDisc-L device.[8]

Incorrect positioning of the cervical disc replacement can lead to impingement, causing a torque at the bone-device interface, increased wear and risk of dislocation.[7] This has been reported by Choma *et al.*, where the device was retrieved due to malpositioning, which showed evidence of impingement wear.[8] Figure 4 represents a case of non-uniform wear distribution in an *in vivo* setting. And though burnishing is reported anteriorly, this study is based on a single implant. Clinical retrieval data for cervical disc replacements is essential for understanding *in vivo* wear patterns. Further, as the average length of implantation for retrievals is 1.0±0.2 years, long term clinical data is needed to reach a conclusive judgment.

It was determined in this current study that anterior positioning produces a decreased range of motion for all directions evaluated, especially extension. Additionally, it has been reported that microseparation in THA is detrimental and this cannot be ruled out at the disc interface *in vivo*. A recent study[9] demonstrated that lift-off is more common with larger radii implants which contributes to articulating surface damage and excessive wear.

CONCLUSION

As clinical experience with newer implants grows in pace with iterative design modifications, it becomes increasingly important to understand the mechanics and long-term wear behavior of the implants *in vivo*. The maximum wear, both linear and volumetric, resulting from posterior positioning is attributed to a combined effect of the stresses and sliding distances at the interacting implant surfaces. As anterior positioning led to decreased motion, while posterior placement caused higher wear, this finding strongly suggests that precise device placement to match the instantaneous axis of rotation (neutral placement) is requisite for achieving optimal clinical outcome. Comparison with retrievals supports this finding and also indicates that total disc arthroplasty represents a constant surgical learning curve involving soft tissue balancing as well as precise placement of the implant.

This study demonstrates that artificial cervical disc replacement wear is dependent on stress and sliding distance which are influenced by device placement.

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