The Biomechanics of Balloon Kyphoplasty

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The Biomechanics of Balloon Kyphoplasty

SUMMARY
Treating fractures of the spine is a major challenge for the medical community both within Ireland and internationally with an estimated 1.4 million fractures per annum worldwide [Johnell 2006]. Treatment options for these fractures have evolved from simple bed rest through to modern minimally invasive cementation techniques. Balloon Kyphoplasty is one such minimally invasive treatment that uses an inflatable bone tamp to restore the height of collapsed vertebrae, followed by cement injection to stabilise the structure (Figure 1).

Figure 1

An Irish study [Lenehan 2009] of ~1,000 admissions during a 5-year period found traumatic spinal injuries needed on average 46 days of hospital admission along with life-long monitoring in cases of spinal cord injury. Costs for life-long treatment of a 25-year old with spinal cord injury has been estimated at €2.9 million [NSCISC 2012].

A recent clinical study [Kim 2012] of 175 patients drew attention to the significance of the bone-cement interface region following Kyphoplasty. The current work hypothesised that mechanical loading at the bone-cement interface is altered by the changing load angle induced by vertebral height loss.

METHODS
A validated finite element model [Tyndyk 2007] of a human thoracolumbar spine was segmented into a single L1 vertebral body and modified to replicate bilateral Balloon Kyphoplasty (Figure 2). Cement was modeled using prolate spheroids surrounded by an interface region divided into anterior, middle and posterior sections. Interface thickness was calculated using a previously developed mathematical model with a bone volume fraction of 0.3 and 50% bone compaction [Purcell 2012, 2013]. An 800N [Tyndyk 2005] load was applied at angles of 0° and 20° [Aquarius 2011] to represent the loading conditions during rehabilitation after the Kyphoplasty procedure.

Figure 2

RESULTS
Results indicate that increased Kyphotic loading causes a shift in stress distribution to the posterior parts of the interface region by up to 34-44% (Figure 3). The anterior and middle sections of the interface experienced changes in average Von Mises stress of less than 11%. Maximum Von Mises stresses were not strongly influenced by the altered loading angle and increased by up to 7% in the posterior section of the interface region.

Figure 3

DISCUSSION & FUTURE WORK
The results show that height loss induced load changes initiate a shift in stress distribution to the posterior parts of the interface region. Further investigation of the stress states found significant compressive stresses are imposed on the posterior parts of the interface region due to the transmission of shear loads through the pedicles caused by Kyphosis. This demonstrates that height loss and interface loading are strongly interdependent and can contribute to sustaining a cycle of increased interfacial stresses leading to further vertebral collapse.

Applying these findings in the context of Kyphoplasty, where poor cement interdigitation is prevalent [Kruger 2012], indicates an increased likelihood of sliding at the contact points between the bone and cement. It has been shown [Zhao 2012] that localized deformation at bone-cement contact sites constitute a significant proportion of the deformation seen in the interface region. The increased loading in the posterior parts of the interface carries additional significance in a clinical context since the cement bolus in this region often contains an imprint from the cannula used by the surgeon and can act as a site for crack formation.

Investigations into alternative surgical devices and techniques is ongoing to address shortcomings in the present treatment strategies. These investigations have highlighted multiple opportunities for product innovations with the potential to improve patient outcomes and reduce costs for healthcare providers.

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"Our vision is to provide excellent biomedical research with an emphasis on improving human health and quality of life by applying engineering principles to medical problems that will ultimately lead to innovative applications in clinical practice."

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