Developing Ceramic Hip Replacements for Young, Active Patients

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Introduction and Objectives

Osteoarthritis affects 8.5M people in the UK[1], causing disabling pain. Function is restored by hip replacement.

Results are typically excellent, but the NHS still spends over £50M per year revising failed hip replacements[2,3].

Outcomes are good in males and older patients, but worse in young, active females, who may experience sensitivity to metal ions from wear debris. Ceramic materials are highly durable and bioinert, and could eliminate these concerns.

A thin-walled, bone conserving ceramic hip replacement was proposed. This research concerns its development, and verification of its strength and predicted biomechanical performance.

Figure 1: Metal Hip Resurfacing Implant

Methods 1: Biomechanical Modelling

- A ceramic hip replacement system was developed in an iterative modelling process, using intact and implanted bone Finite Element (FE) Analysis models, with geometry and materials derived from medical CT-Scans.
- Algorithms were developed to predict bone fracture and density adaptation over time[4], incorporating:
  - A Range of Loads and Surgical Positions
  - Comparison of proposed implant geometries to a metal control (Fig. 1, ADEPT®, MatOrtho Ltd).

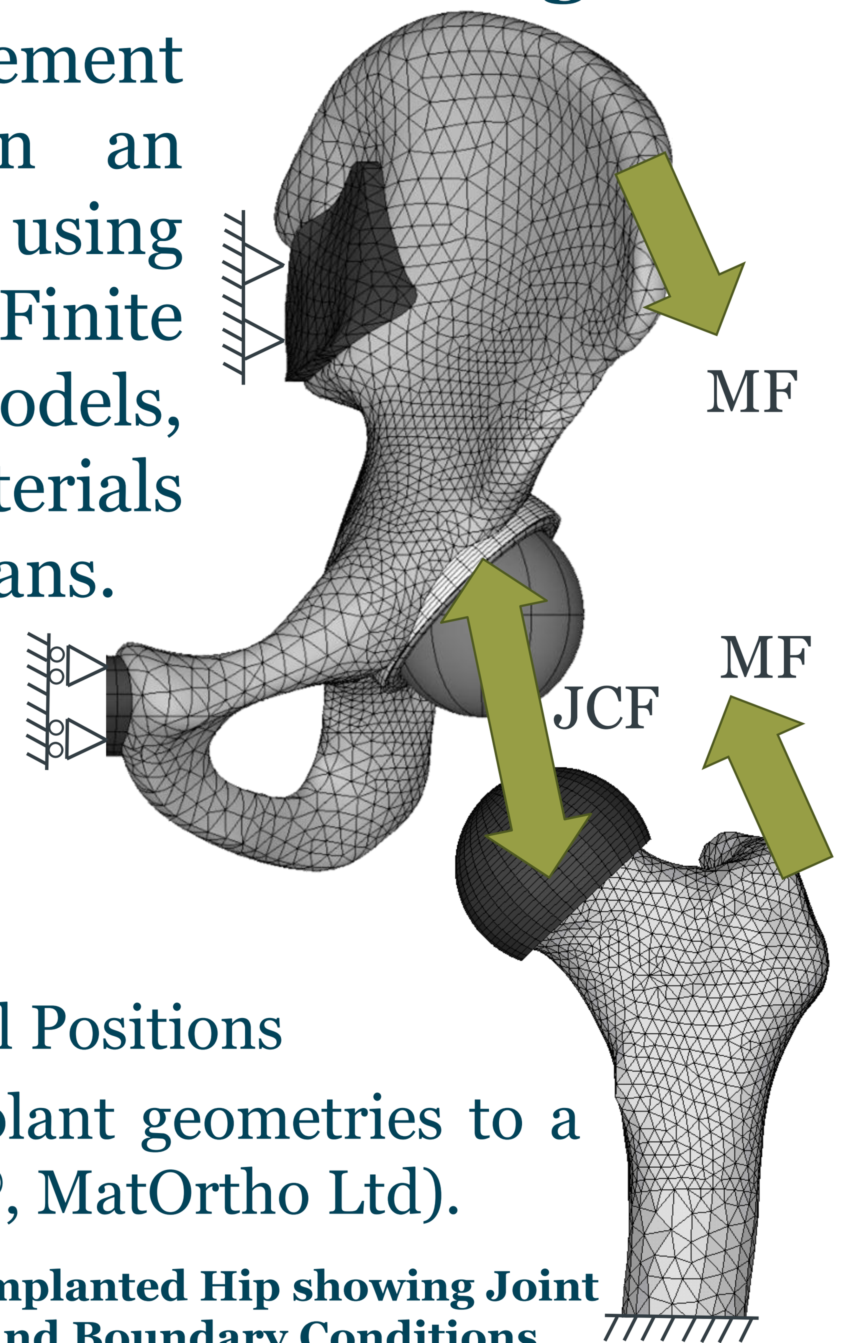
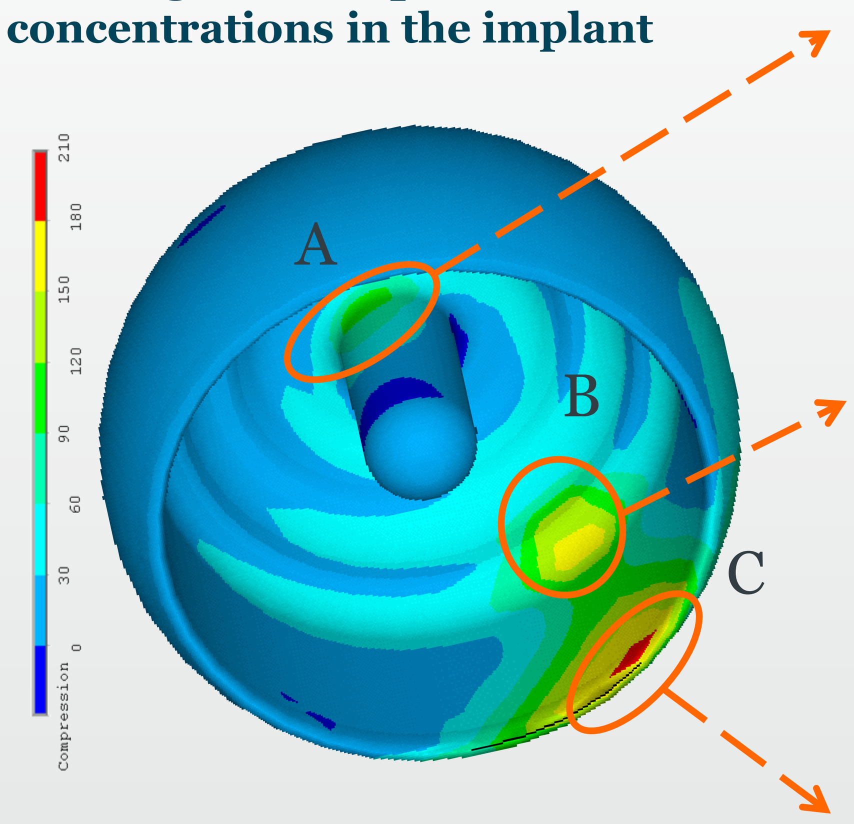


Figure 2: Femur and Pelvis FE Models of Implanted Hip showing Joint Contact (JCF) and Muscle Forces (MF) and Boundary Conditions

Methods 2: Structural Verification

- No existing ISO/BS standards were applicable to this implant concept, so a set of tests were developed[5].
- In the proposed ceramic head component, three main tensile stress concentrations were predicted, across the range of analysed physiological loads and positions:

Figure 3 (Below): *in-vivo* FE Analysis showing 1st Principal (tensile) stress concentrations in the implant



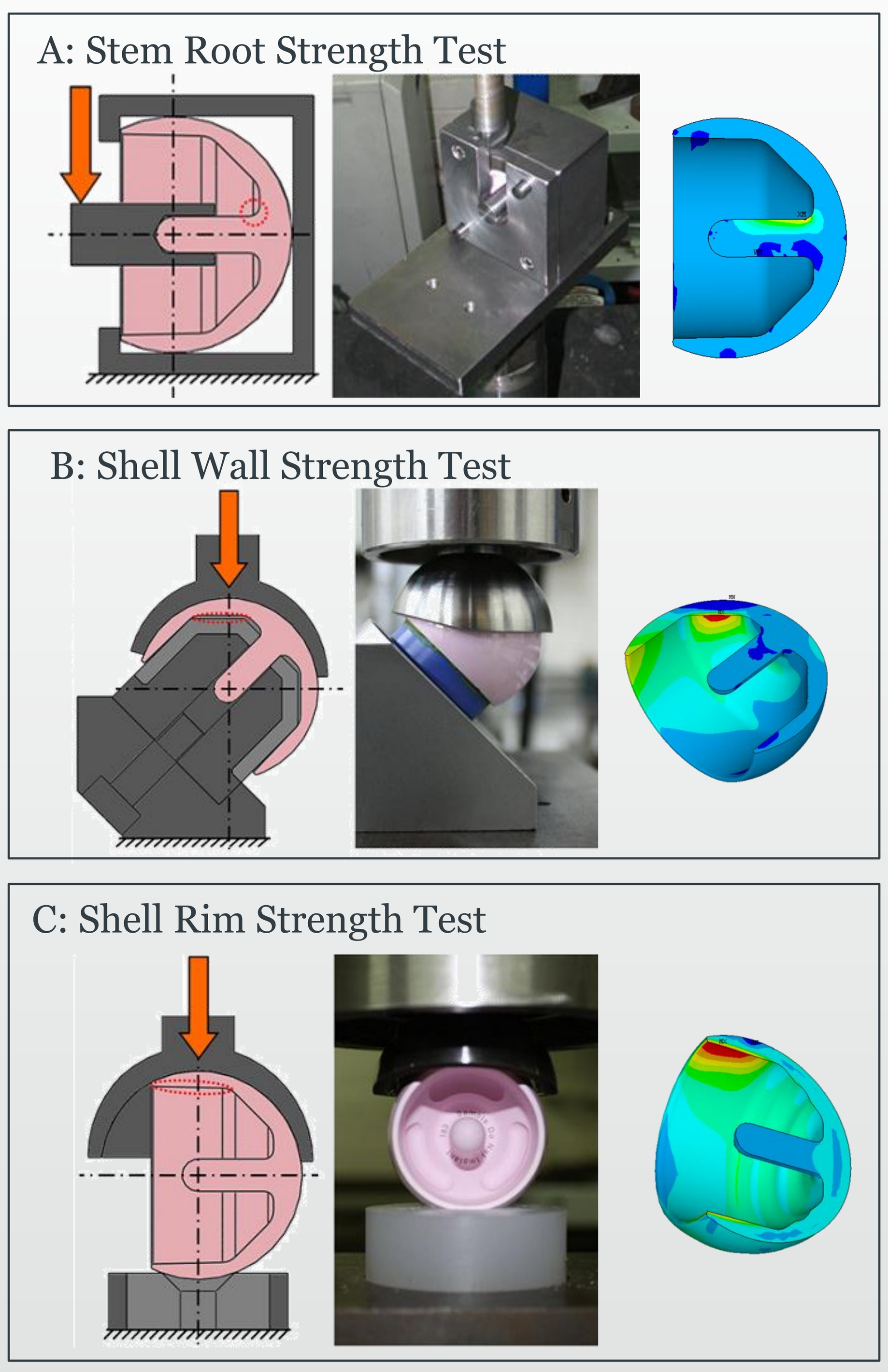


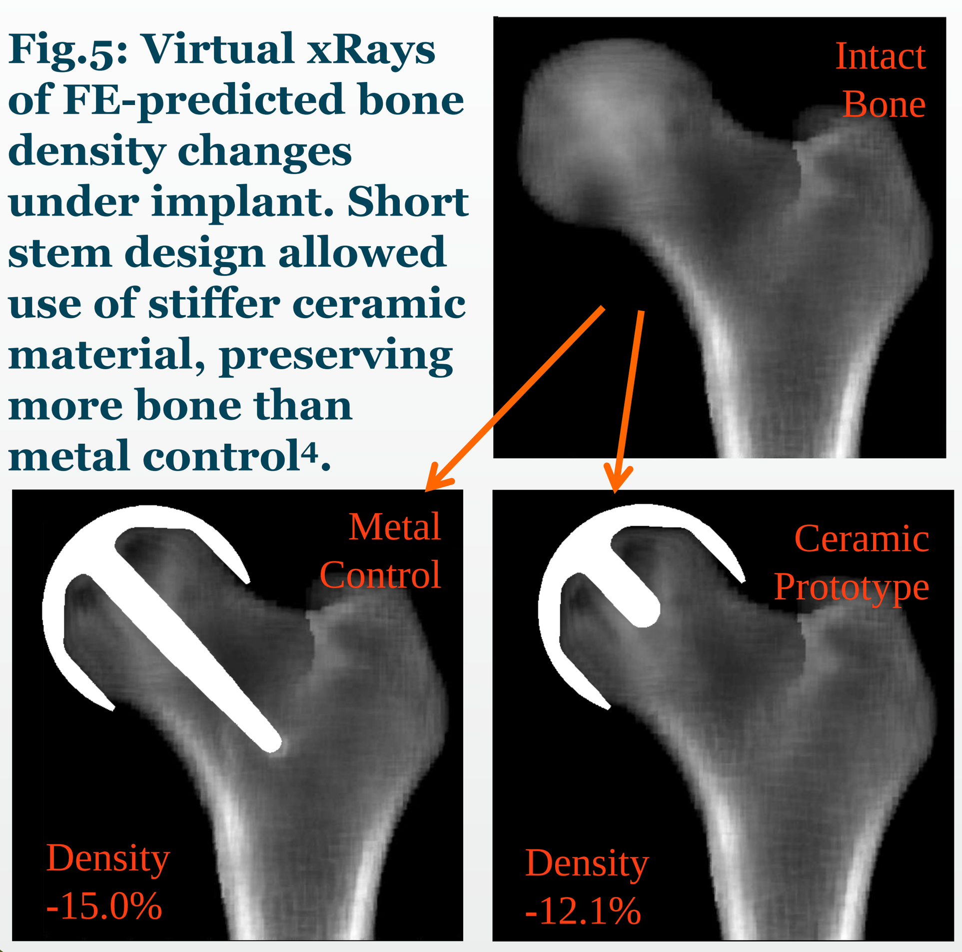
Figure 4 (Right): Development of three physical tests to reproduce these stress concentrations *in-vitro*

- For quantitative model evaluation, flexural strength testing was conducted to characterise the Weibull distributed strength of the ceramic material.
- Physical tests were run on extreme sizes of the implants, under fatigue loading and to static failure.

Summary of Results

- All prototypes survived the equivalent of 10^7 jogging cycles and exceeded the strength of the metal control.
- The design was predicted to increase supporting bone strength and preserved bone density vs. control[4,7]:

Fig.5: Virtual xRays of FE-predicted bone density changes under implant. Short stem design allowed use of stiffer ceramic material, preserving more bone than metal control[4].



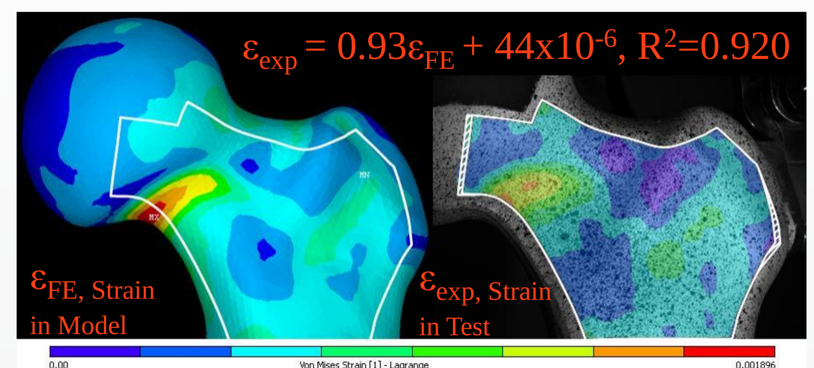


Fig.6: Models Validated Experimentally with Digital Image Correlation Strains[6]

Fig. 7: Resulting DeltaSurf® and DeltaMotion® Implant Designs (DePuy Intl).

Conclusions and Impact

A ceramic hip replacement system was developed, and verified in a purpose-built evaluation programme.

Results were adopted by SME sponsors Finsbury Orthopaedics Ltd. leading to CE-Marking of DeltaSurf® and DeltaMotion® products.

DeltaMotion is now in clinical use with over 9700 implantations globally, performing well after 2 years[8].

The methodologies are now being applied to dental implantology and lower limb amputee biomechanics.

References

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Acknowledgements

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