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Title: The clinical assessment of acoustic monitoring in revision total hip replacement
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Introduction:

Total joint replacement (TJR) surgery is the last surgical resort for people with degenerative joint disease. By the year 2030, total hip replacements (THR) in NZ will increase by 174%, largely due to the ageing population and the increased functional demands of this cohort. THR surgery is extremely successful, but these joints undergo wear and often need to be revised after 10-15 years. The more primary TJR surgeries there are, the more revision surgeries there will be, creating a significant and increasing burden to health funding agencies.

Therefore, there is a huge challenge to find and implement effective screening programmes for detecting early THR wear or failure so that orthopaedic surgeons can properly manage revision surgery. Early diagnosis of impending failure can save significant time, cost and more serious surgery. Currently THR can be monitored with serial radiographs but there are not absolutely reliable in detecting wear or a failing prosthesis.

Aim:

Our research group (involving an orthopaedic surgeon, mechanical/bio engineers and a medical student) is investigating abnormal sounds produced by THRs as a method to provide insight into implant condition and provide early detection of wear and loosening.

Method:

Implants are tested preoperatively (*in vivo,* using a custom-built sensor-device) and postoperatively (*in vitro*; lab-tested) for abnormal acoustic emissions (AE) data. Currently, 71 patients requiring a revision procedure for a failing hip replacement have been enrolled in this study plus 11 controls (people with natural, healthy hips).

In vivo testing is carried out in the weeks leading up to revision surgery, so that the AE and clinical data can be more accurately compared. At the time of writing, 38 of the enrolled patients have had their revision surgery. For this report I have focused on these 38 patients, as the most relevant and detailed clinical information is recorded just before, and during, revision surgery.

I have attempted to sort patients into groups, according to the implant failure method(s), so that the AE data can be examined, with respect to these groups, to see if any common themes emerge. I combined the pre-operative indications (the reasons for surgery) together with the operative notes, as surgery revealed many previously unforeseen abnormalities. This ‘grouping’ task has proved difficult because 20 of the 38 patients fit into 2 or more failure ‘categories’ (unsurprisingly, because implant failure is produced by a web of contributing factors, rather than one discreet problem).

Hip implants typically consist of 4 components: stem, head, liner, and cup. The stem is inserted into the shaft of the femur, and the cup into the pelvis. The head is connected to the stem via a Morse Taper and articulates with the liner. The liner and the cup form the acetabular component. The materials used are a combination of ceramic, metal and polyethylene.

Results:

The main failure methods were: loosening (18 patients), wear (19), noise (7), and fracture (4). 2 patients suffered dislocation and 1 had a chronic infection.

The acetabular component was the most common source of loosening, involved in 12 of the 18 cases. 5 stems were loose, and 1 of the 'loose' cases concerned both stem and acetabulum.

Polyethylene liners were the most common source of wear. Of the 19 'worn' implants, 14 liners were worn, 2 tapers, 1 stem, 1 involved both head and liner, and in 1 case the worn component(s) was unspecified. 11 of the worn liners were made of polyethylene (PE), 2 were ceramic, and 1 metal. 8 of the worn implants had metal heads and 4 had ceramic heads. It should be noted that this 'wear' is only what was seen via radiology and the surgeon's naked eye; microscopy would undoubtedly reveal many more cases.

Ceramic on ceramic (CoC) interfaces were most prone to squeaking. Of the 7 implants revised for noise (squeaking), 6 involved a CoC interface and 1 metal on metal (MoM). Of the 4 fractured components, 2 were stem and 2 were liner. Pain was indicated for 7 of the patients, but as it is a symptom, not a cause, of implant failure, I did not include a group for 'pain'.

For acoustic testing to be a useful diagnostic tool, the acoustic 'profile' of patients with noisy (usually squeaking) implants ('squeakers') would appear differently to patients with worn, or loose, components ('non-squeakers'). For instance, a 'squeak' can be distinguished (as a large amplitude, long duration acoustic event) from a 'click' (large amplitude, short duration). This difference *was* observed for the majority of 'squeakers' compared to 'non-squeakers.'

The 'non-squeakers' generally showed more 'high amplitude, short duration' events than the control group. This indicates that an artificial hip usually makes more noise than a natural hip. Greater implant wear was found to produce more frequent acoustic events, which may also be of increased amplitude, but further analysis is required. The most conclusive result found (so far) was that squeaking from the Morse Taper shows a markedly different response to squeaks induced by the articulating surface. Making this kind of distinction for the different failure types is key for the validation of the device.

Discussion:
The 'wear' and 'loosening' categories could be merged, as implant wear causes osteolysis (the resorption of bone) due to an autoimmune reaction to wear debris, leading to the loosening of components (where loosening was indicated, osteolysis was usually noted too). Conversely, if loosening is an advanced stage of wear, then it would be useful to keep the two groups separate, to see if the AE data can expose differences.

Many variables are involved that alter the detected frequencies and amplitudes, and need to be accounted for, such as: the force through the implant, the type of movement, surface temperatures, and the presence of lubrication. AE data from patients with well-functioning prosthetic hips is needed, to establish baseline profiles, so that deviations from the norm can be identified. The sound processing techniques are currently being revisited in an attempt to distinguish high-frequency content from background noise (*in vivo*).

I have collected hundreds of x-rays, referral letters, and clinical notes, from orthopaedic surgeons, radiologists and GP's; from both private and public databases, and the national joint registry. In addition to classifying patients according to their implant failure type, I am able to present a detailed "case study" of each patient's 'hip history.' When the AE data can be confidently interpreted, the more detailed clinical information will assist in explaining specific events and deviations.

Conclusion:

Although my work forms just a small part of an ambitious ongoing project, having the clinical and surgical information at hand will greatly assist the engineers in making comparisons and conclusions. This brings the team a step closer to the ultimate goal: the clinical validation of AE testing.