Acoustic Emission Monitoring of Total Hip Arthroplasty Implants

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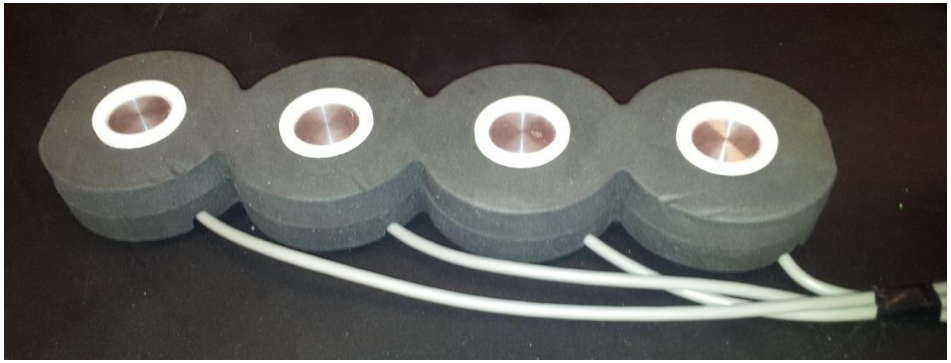

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Introduction/Research Motivation

- Total Joint Arthroplasty (TJA) surgery is one of the main treatments available to patients with advanced degenerative joint disease, such as osteoarthritis.
- With demographic ageing of the population, the incidence of TJA surgery is increasing significantly.
- Therefore, there are significant challenges to find and implement effective screening programmes for detecting early wear or failure in TJA implant materials, and clear indicators for orthopaedic surgeons to allow early diagnosis of impending failure and proper management of revision surgery.

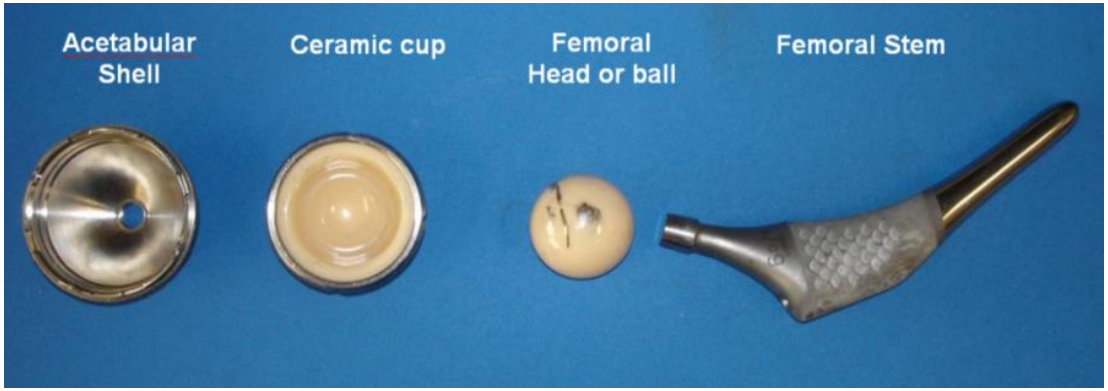
Acoustic Emissions Monitoring

- Previous research has investigated the concept of passively ‘listening’ to the ultrasonic vibrations that are emitted by a total joint replacement implant
- This device is essentially just the listening/receiving side of a standard ultrasound. Instead of transmitting sound waves into the soft tissue, the device passively listens to sounds generated by the implant
- These sounds are then correlated to patient outcomes, in-vitro implant analysis and examination of implants when patients undergo revision surgery
- A major area of interest is in the presence of ‘squeaking’ or hard-on-hard bearing surfaces.

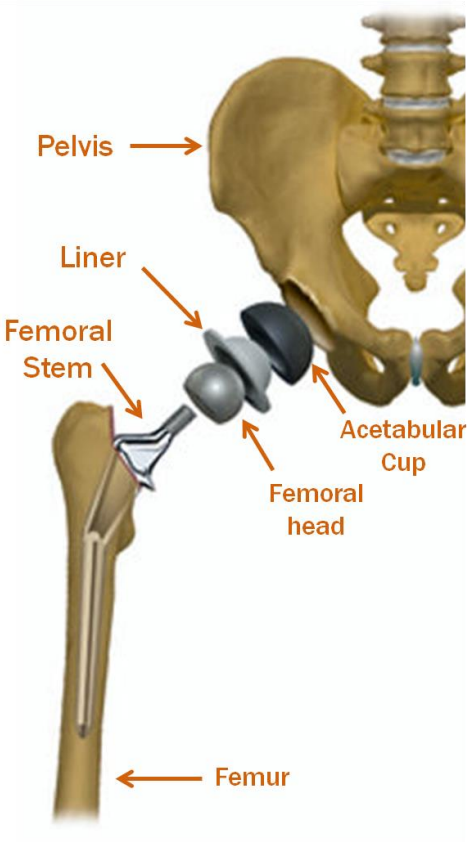
Total Hip Replacement Implants

- Implants consist of four main components:
  - The femoral stem
  - The femoral head (ball)
  - Acetabular liner (cup)
  - Acetabular shell

Hip Joint Implant Components



In-vivo Implant

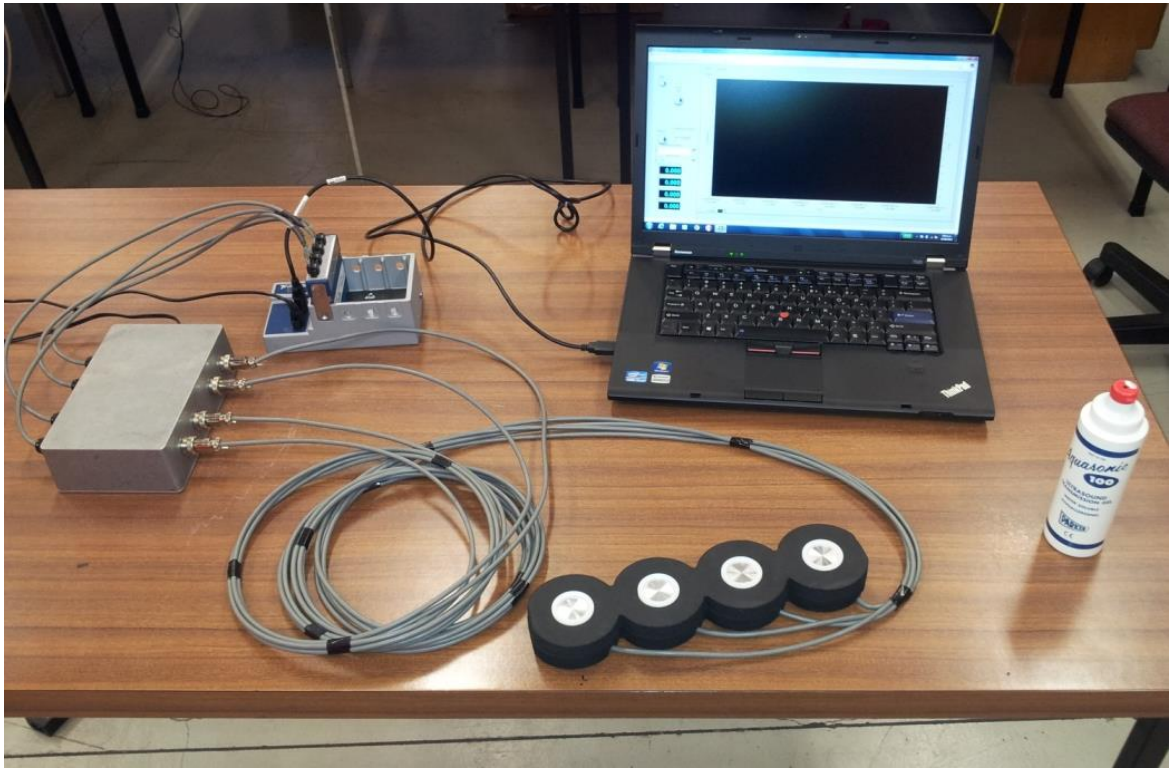


Major reasons for revision surgery

- Revision surgery is much more expensive and complicated than primary hip surgery
- Often, the root cause of pain or loss of function cannot be fully identified through x-rays
- The ultimate goal is to develop a diagnostic tool to provide additional insight for orthopaedic surgeons to manage revision surgery (surgery is paid for from a finite pool of healthcare funding)
- Reasons for revisions include:
  - Wear of the bearing surfaces
  - Biological reaction to wear debris
  - Infection
  - Loosening of the acetabular cup or femoral stem
  - Audible ‘squeaking’ of implants with hard-on-hard bearing surfaces, such as ceramic-on-ceramic
  - Loosening of the femoral head or acetabular cup on the morse tapers

Acoustic Emissions Testing Device

- A set of four ultrasonic sensors (resonant frequency 32.8kHz), placed against a patient's skin, from the greater trochanter to the mid femur.
- All four channels sampled simultaneously at 100kHz (giving 50kHz Niquist frequency)

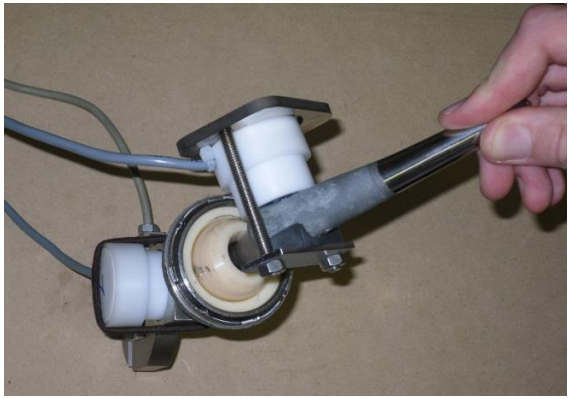


In-vivo Patient Testing

- Patients undergo a range of exercises, such as stand-from-sit, climbing stairs and walking
- Recruitment involves patients scheduled for revision surgery and patients with implant issues (such as squeaking or loosening)
- Patients that proceed to revision surgery are consented to have their retrieved implants examined and tested in-vitro
- Subsequent in-vitro testing can provide insight into the mechanism of observed signals in-vivo
- Results are analysed to observe both frequency and time domain characteristics
- Performed at Burwood COBRA Unit:
- Control patients, N = 20 (natural hips)
  Revision patients, N = 68 (artificial hips)
- (Ethics approval URA/10/11/075)

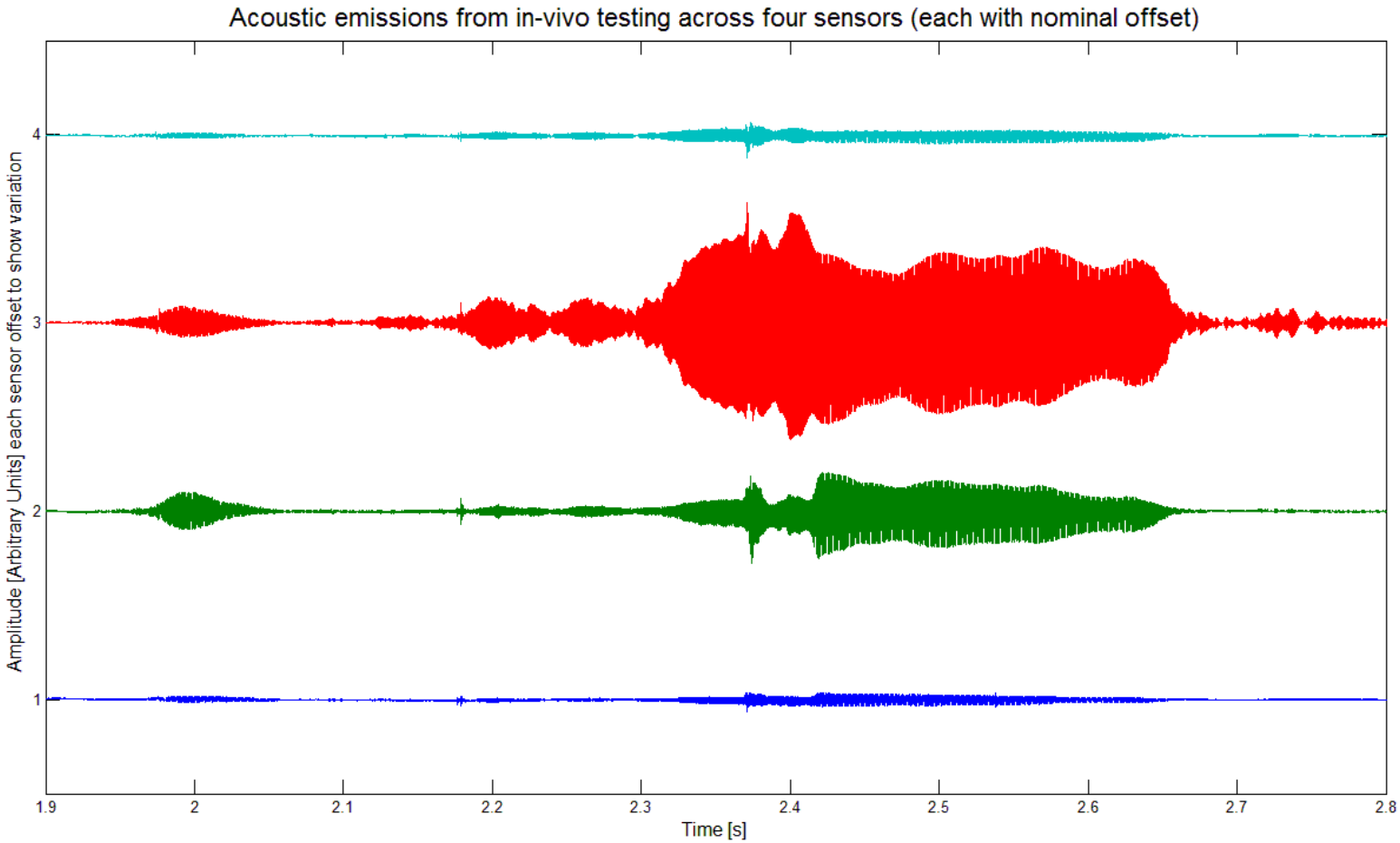
In-vitro Implant Testing

- In-vitro testing undertaken with both manual manipulation and robot-manipulation
- Robot manipulation is more repeatable, but vibration-isolation is required to avoid signal contamination with robot-induced vibrations
- Sensors mounted to both femoral stem and acetabular shell
- Different motions undertaken to represent flexion, rotation and impingement
- Comparisons drawn to the observed signal content of the corresponding in-vivo motion



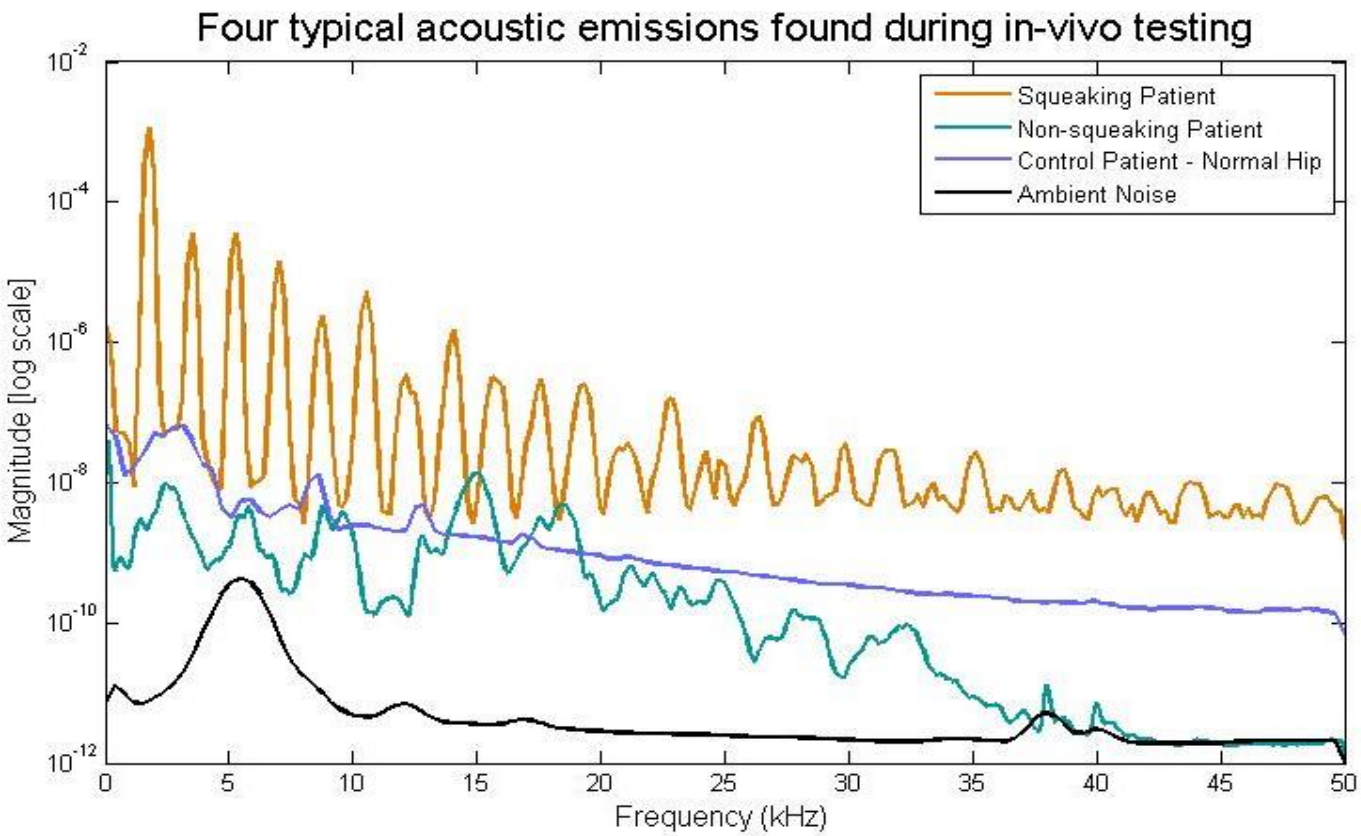
Results

- Typical time-domain response of a total hip replacement implant with audible squeaking.
- Four sensor provide some indication of the source location.



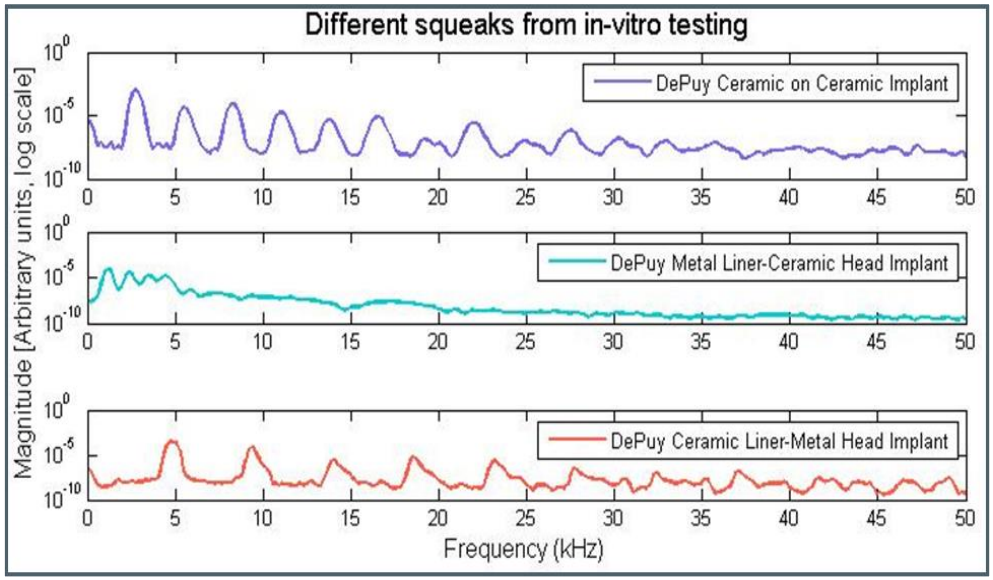
Results

- Comparison between patient with implant squeaking, non-squeaking patient with an artificial hip implant and control patient with a natural, healthy hip joint



Results

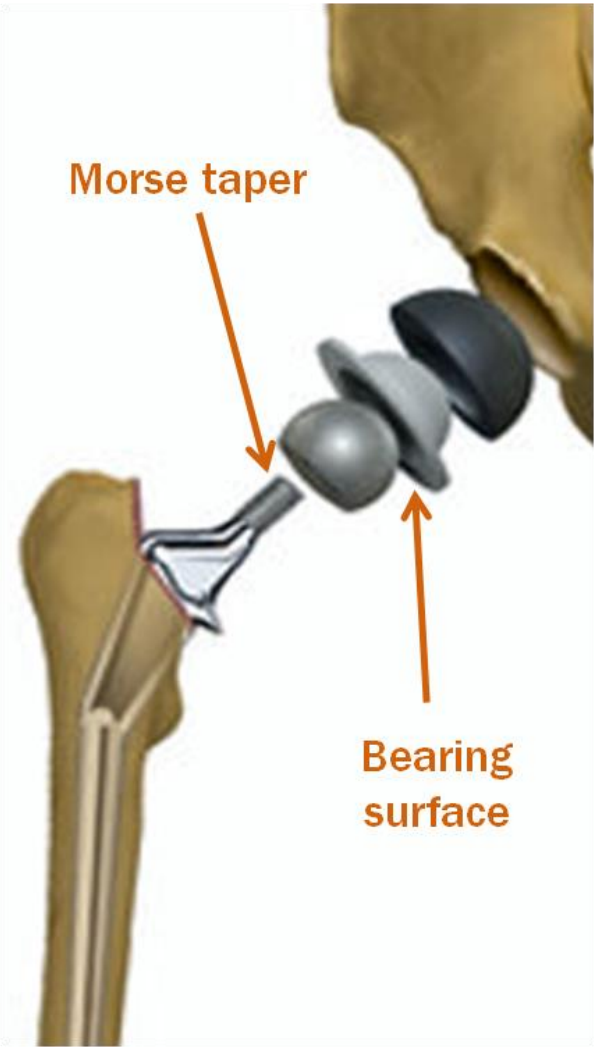
- Squeaking of ceramic-on-ceramic implants has received significant research attention. Different implant designs have been observed to make different frequency emissions



	DePuy Ceramic on Ceramic Implant	DePuy Metal Liner/Ceramic Head	DePuy Ceramic Liner/Metal Head
Number of Samples	13	11	10
Mean Fundamental Frequency (kHz)	2.734	1.154	4.043
Standard Deviation	0.700	0.059	0.568

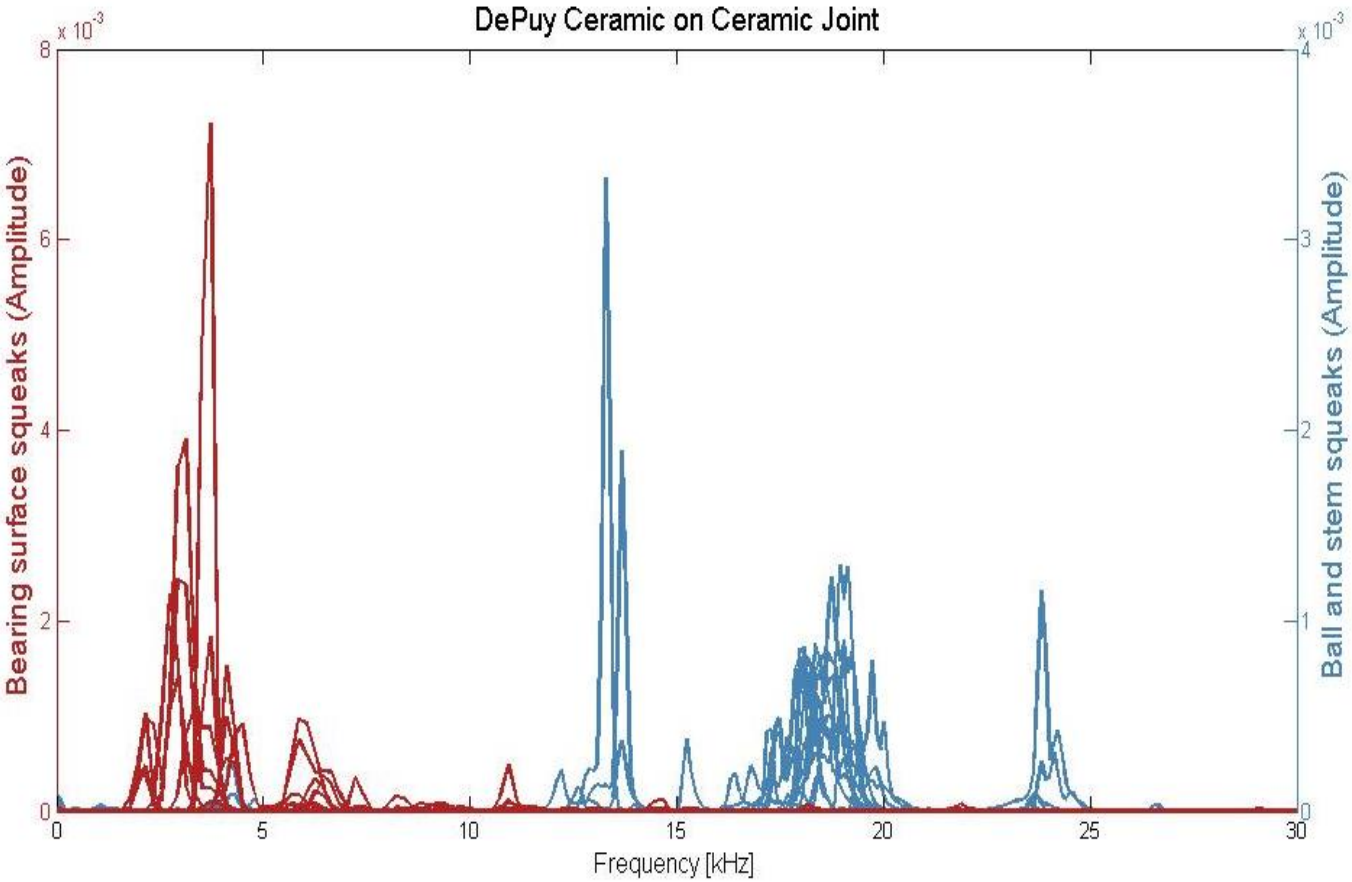
Results

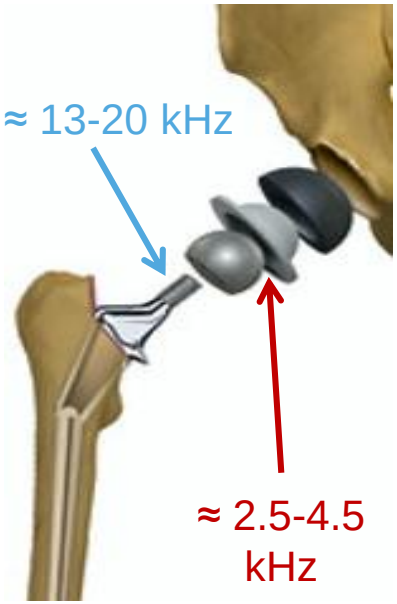
- Squeaking is generally considered to originate at the primary bearing surface.
- Morse-taper squeaking has been considered and is seen to produce signals with a distinctly different frequency signature
- Every joint tested to date showed this clear difference in fundamental frequency for squeaks from the two surfaces
- This information could be used to identify which mode of squeaking a patient is displaying, which will in turn dictate the surgeon's choice of revision procedure
- The main limitation of this method is the extreme attenuation of high-frequency signals in the soft tissue, which makes it difficult to pick up the relevant frequencies



Results

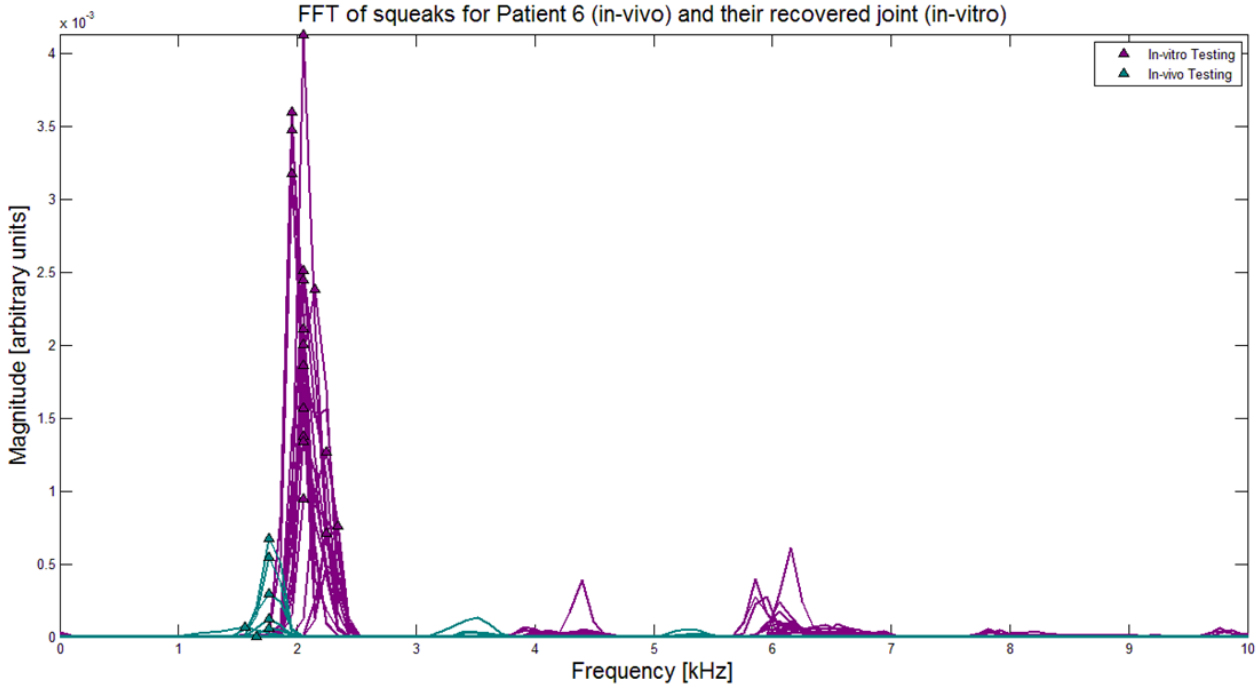
- Squeaking at the primary bearing surface produces frequency content on the range of 3-5kHz, while movement at the morse taper produces frequency content on the range of 18-24kHz.





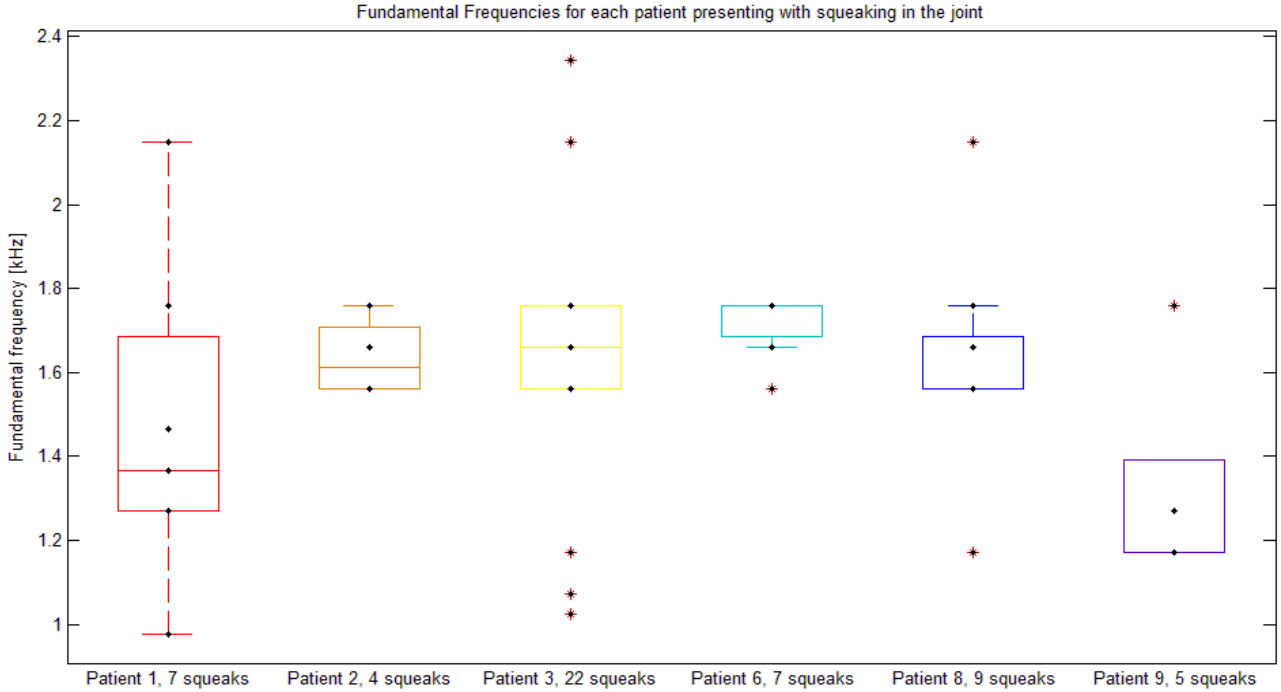
Results – Comparative Testing

- Patients tested in clinical trials (in-vivo) that have since undergone revision surgery have had their retrieved (and sterilized) implants tested
- Comparative testing allows us to gain insight into the differences in behaviour for the same joint when both in-vivo and in-vitro
- The fundamental frequencies of the squeaks were lower for in-vivo testing which is in line with past work into attenuation characteristics of soft tissue



Results – Comparative Testing

- Every squeaking patient displayed a different median fundamental frequency of observed squeaks
- This could be a result of many factors, including:
  - Different implant type
  - Different levels of loading and attenuation
  - Different wear patterns and fatigue



Ongoing Research

- Ongoing research is continuing with both in-vivo patient testing and in-vitro implant testing
- Twelve patients so far have been tested in-vivo and then undergone revision surgery
  - These have been ceramic-on-ceramic implants, metal on metal and metal in plastic
  - In-vitro testing on the retrieved implants shows key links in the signals in-vitro and in-vivo
- A range of implants and different bearing combinations are being tested.
- In-vivo patient testing is focusing on revision patients, where their clinical outcome will be known and their retrieved implants will be available.
- Correlation between these recordings is being examined to develop a diagnostic tool for orthopaedic surgeons to manage revision surgery

Conclusion

- Key frequency signatures between the in-vivo and in-vitro testing
- Development of a large bank of experimental test data
- Ongoing in-vivo and in-vitro measurements are validating this model
- Direct comparison of in-vivo and in-vitro tests using the exact same implant increases confidence in the validity of comparative results.

Acknowledgement

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Conclusion

- Thank you for your time.....

  Any Questions?