

**NHS Implant Analysis Service Annual Conference
The Catalyst Building, Newcastle City Centre
25th November 2024**

Full report

Each year, around 20,000 people in the UK suffer through painful revision surgery to replace implants for joints such as hip and knee. This isn't just a burden on patients, but also on the NHS, which incurs millions of pounds in additional surgery costs and litigation fees.

Yet, once the surgery is complete, around 95% of implants are simply thrown away.

By studying retrieved joint implants, we can gain crucial information about what leads to implant failure, similar to how black box flight recorders help us understand aircraft accidents.

At this conference, we'll be sharing insights from the physical analysis of retrieved implants and discussing them together in a dynamic setting so that we can improve the safety of patients undergoing joint replacement procedures in the future.

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Welcome and introduction – Sue Waller, Clinical Nurse Specialist at North Tees and Hartlepool NHS Foundation Trust, UK¹

- The focus is on safety and prevention of harm

Session 1

Joint replacement: one of the great success stories of modern surgery: Tom Joyce, School of Engineering, Newcastle University, UK

- Before joint replacement, there was no effective treatment for joint failure and the chronic pain could lead to suicide

An overview of successful joint replacements

- Hip replacements were the operation of the 20th Century
 - The survival rate is 83% at 20 years
 - Revision rates are <5% at 10 years
- The knee replacement is now the most common joint replacement worldwide
 - There is an increase in the use of robots in surgery
 - Unicondylar (partial) knee replacement is an alternative to full knee replacement
- Ankle replacements have improved in the last 20 years
 - Infinity (Stryker) is the current market leader
 - Patient-specific instrumentation (PSI) aims to improve accuracy
 - Metatarsophalangeal joint replacements include silicone (Swanson) and synthetic cartilage (Cartiva)
- Toe joint replacements
- Shoulder joint replacements are the third most common joint replacement worldwide after knees and hips
 - The revision rate is 4% at 10 years
 - Replacements can be anatomical or reverse (reverses the ball and socket structure) – reverse joint replacements are the most common
 - There is a variety of materials and design features
- Elbow replacement is complex
 - This is the least developed replacement surgery
 - Replacements include the Stryker Latitude joint replacement
 - Increasing numbers of radial head replacements are being carried out
- Wrist replacements
 - Dominated by metal-on-metal (MoM) design (Motec)
 - The ReMotion implant is metal and polyethylene
 - There are increasing numbers of radial head replacements being carried out
- There are recent developments in finger and thumb joint replacements
 - Metacarpophalangeal (MCP) joint replacement
 - Swanson remains the market leader after 60 years

¹ Sue Waller is employed by North Tees and Hartlepool NHS Foundation Trust (NTHFT) and is contracted to work on the NHS Implant Analysis Service provided by NTH Solutions, NTHFT's subsidiary

- Proximal interphalangeal (PIP) joint
 - Silicon joints
 - More recent designs – CapFlex and Tactys
- Trapeziometacarpal (TMC) joint
 - The numbers of trapeziometacarpal (TMC) joint replacements for thumbs is increasing in the UK
 - Cemented mini-Charnley
 - Metal-on-metal
 - Dual mobility and high modularity joints, e.g. Moovis
- Disc replacements
 - Different materials are used for cervical and lumbar disc replacements
 - CoCr (cobalt-chromium), stainless steel, ceramics, polyethylene
 - There is a wide range of designs, degrees of freedom and concepts
 - Viscoelastic designs are used as natural discs are not synovial joints

What have we learnt since the ASR disaster: Tony Nargol, North Tees Hospital, Teesside, UK

The 3M Capital hip system

- In the 1990s, the 3M Capital hip system had failure rates of 19-21% at five years (four times the expected rate) – this led to a call for a National Joint Registry (NJR), launched in 2004

The ASR hip

- The ASR hip (ASR resurfacing and ASR XL total hip replacement) was launched in 2004
- In 2007, there were three reports of milky yellow fluid without infection – aseptic lymphocyte-dominant vasculitis-associated lesion (ALVAL) with hips that failed prematurely – reported at the American Association of Hip and Knee Surgery annual meeting in 2007
 - The soft tissue destruction was an adverse reaction to metal debris
- Nargol and his team used co-ordinate measuring machines (CMM) to investigate the failures
- The failures were seen in the so-called safe zone of anteversion and inclination
 - 18 failures inside the zone and 11 failures outside of the zone
- The failure rate of the ASR hips was 49% at six years in the North Tees area
 - Other centres saw similar failure rates
 - DePuy data – 37% failure at 4.5 years
 - Finland – 62% failure rate
 - National Joint Registry of Australia – 44% failure rate at 7 years
- The North Tees team met DePuy in 2007 and showed the explant analysis/mechanism of failure
 - There was no action taken – the company said that it was only an issue in the North Tees hospital

- The North Tees team met with the Medicines and Healthcare products Regulatory Agency (MHRA) in 2010:
 - Presented data showing that the high failure rate of the ASR and the Pinnacle MoM were as a result of abnormal bearing wear and abnormal female head taper wear
- ASR was recalled worldwide in August 2010 – as a result of explant analysis by David Langton and Tom Joyce

The DePuy Corail Pinnacle MoM

- Failures caused by abnormal bearing wear and abnormal female head taper wear inside the head, releasing metal debris
- The North Tees Team went to the MHRA in 2012 with blood metal ion data, explant analysis and a single hospital series of patients
- The NJR did not initially show an issue with Corail Pinnacle
 - Failure rate of 2.29% as all three types of bearings were included together, so the failures were hidden
 - After six years, separating the results out showed the outlier

The NexGen knee

- X-ray changes were seen, and explant analysis detected abnormal wear
- The NJR did not initially show an issue as it was camouflaged within many generations of NexGen products
- The LPS NexGen was recalled

The role of the National Joint Registry in joint recalls

- The NJR is published September each year, making it up to a year out of date
 - It appears to have failed to pick up the failures early – initially, the NJR was not mandatory, and only looked at primary implants, not revisions
 - NJR reporting for all cases became mandatory in 2011

Data from advertising

- Data used in advertising isn't always backed up by science
 - An advert for the ASR claimed that 99.2% success rate was backed by NJR data – but this did not match NJR results
 - Data claimed to be from a DePuy simulator study was not correct

Explant analysis

- When sufficient numbers are tested, it provides early indication of problems

NJR – Past and Present: Simon Jameson, Consultant Hip and Knee Surgeon, University Hospitals Tees, UK

The 3M Capital Cemented Hip System

- Marketed in the UK between 1991 and 1997 as modular or monobloc, with both types available as flanged or round back, with 4688 hips supplied to 79 centres in the UK
- The data showing that 87% of Capital Hips weren't revised by February 2000 hid the poorer performance of the modular flanged version
- The UK parliament was advised of the poor performance of the Capital Hip System in January 1998, with conclusive data in February 1998 – a Hazard Notice was issued to the NHS in February 1998
- The NJR was created in 2003, as a registry could have identified the issue sooner

NJR history

- The data is improving over time
 - 2003: Created in 2003 after the 3M Capital hip system issue; initially only hip & knee replacements recorded
 - 2008 – the first feedback to clinicians became available
 - The first years showed an increase in revision rates, but the data was incomplete at this time
 - 2009 – revision rates started to fall, showing the impact of the NJR, and improvements in its dataset
 - 2010: Inclusion of ankle replacements
 - 2011: Recording became mandatory in NHS
 - 2012: Inclusion of shoulder & elbow replacements
 - 2013 – surgeon-level data was published, supporting patient choices
 - 2014 – the British Orthopaedic Association (BOA) recommended using consultant-level reports (CLR) in appraisals
 - 2016 – NJR data links with 'best practise tariff' to improve compliance, improving the completeness of the NJR dataset
 - 2017 – >97% of hip and knee implants were registered, according to NJR data quality audits
 - 2020 – the NJR Connect portal was launched, allowing users to look at their own data and Trust-level data
 - Funnel plots allow identification of outliers
 - Can look at outcomes by implant, and cost-effectiveness by surgeon
 - 2020 – the NJR was described as a leader in the field – an “exemplar registry with world-leading experience”
 - 2023: Addition of more data and more data types
 - 2024: 4 million procedures recorded

Current NJR output

- Annual Report, including separate sections on ankles, elbows and shoulders
 - Data examples – shifts in hip type and use, optimal bearing surfaces, impact of patient age and sex on revision in primary total knee replacements
- Annual Clinical Report – at trust level

- Clinical Level Reports – at individual clinician level, e.g. patients who are viable/revised/died
- Implant costs – at trust and individual level
- Stats on-line for all hospitals
- Surgeon profile – 1 & 3 yr activity, 90-day mortality

Compliance

- Compliance is good but more data is always wanted
 - In financial year 2022/2023 compared with the previous year, the number of hospitals achieving 100% compliance has increased by 20% - this may be as a result of the introduction of a three-tier award for data submission and quality
- NJR provides support for hospitals with low compliance rates

Next steps

- The 2025 annual report will include separate sections on hips and knees
- The objectives are:
 - Increase patient involvement
 - Increase the support to hospitals and surgeons
 - Support industry
 - Continuous improvement for data collection, analysis and research
 - Support value-based healthcare

Pros and cons

- Pros
 - Large dataset
 - Mandatory data input
 - Robust quality processes
 - Process for clinician feedback
 - Costs
- Cons
 - Data quality challenges
 - Outcomes/linkage with patient reported outcome measures (PROMs)
 - Lag period
 - Camouflage – results hidden by multiple versions of the same product
 - Even small changes in design can affect performance
 - Under-used by surgeons

The Southampton experience of large MoM heads on stems: Jeremy Latham, Metal Hips Research Group, Southampton, UK

History

- Early adopter of resurfacing
- 2003 – saw below par results in women – used Metasul as an alternative for salvage
 - Metal-on-metal, large bearing, durable, good stems, cemented process

- Switched stems because of changes in the company, issues with supply
- 2008 – stopped use after patients reported ‘awareness’ of the joint, greater trochanteric pain, noise from the joint
- Started investigations – saw fractures and need for huge revisions
- The issue was a significant personal and professional challenge, and the temptation was to bury it

Metal Hips Research Group

- The Ghent November 2010 meeting of 30 surgeons with combined experience of >3000 MoM hips recognised the issue
- Shared experience and expertise in identifying problems and managing the surgical challenges – started their own retrieval analysis

Patient outcomes and litigation

- Saw high failure rate, loosening of stem, erosion, fluid in the hip, dead bone in the socket and stem, issues with dead tissue – associated with increased wear at the trunnion-head interface, normal levels of wear at the articulating surfaces and evidence of corrosion on the surface of the stem leading to fractures
 - Published data in the *Journal of Bone and Joint Surgery* in 2011
- Similar cases were seen with metal on polyethylene hips – it was a design issue, not a mismatching issue
- Latham faced 10 years of litigation
 - Accused of breach of duty
 - Told he was liable under the Consumer Protection Act, which had a potential impact on his indemnity cover
 - No support from manufacturers
- The final case has now been settled
- Latham says he has learned a lot through a traumatic process
 - How to look after patients
 - The importance of obtaining consent
 - He has become more conservative – just does what works
 - He has become a better surgeon

ODEP, BC, MDR & ORP! – Keith Tucker, Chair of ODEP and the Beyond Compliance advisory group, UK

ODEP

- The Orthopaedic Data Evaluation Panel (ODEP) was set up by NICE after the 3M Capital Hip issues
- Prior to 2002 there was no obligation for manufacturers to check on the effectiveness of their joint replacements
- ODEP data is used worldwide
- Timeline
 - 2003 – hips
 - 2014 – knees

- 2015 – Netherlands joined
- 2017 – shoulders
- 2017 – uni-condylar knees
- 2023 – elbows
- 2022 – spines: cervical discs
- 2023 – wrists
- 2024 – 1st carpo-metacarpal joints
- ODEP is set up to award benchmarks, based on agreed standards
 - Manufacturers collect and submit data to gain benchmarks and support the continuing use of their product
 - Implants have to progress through the benchmarks otherwise they lose their benchmark
- The submission forms and options are tailored to an individual joint
 - The number represents the years of use and the letter (A*, A, B) the strength of the evidence
 - The data includes the revision rate and why revisions have been made, for example
 - Infection
 - Aseptic loosening
 - Dislocation
 - Implant failure
 - Periprosthetic #
 - Other
- ODEP ratings are based on brands and product codes to reduce camouflage
 - Manufacturers must declare all product codes within a brand

Beyond Compliance

- NJR did not pick up ASR or MoM quickly, because of poor compliance, therefore ODEP did not react adequately
 - The issues with the implants were picked up by word on the street, the MHRA, Belfast (Dave Beverland) and explant studies, especially Newcastle and Stanmore
 - The CE Mark failed to prevent ASR or MoM
- The BOA and MHRA decided that closer monitoring of total joint replacements was needed
 - Creation of the MHRA MoM committee
 - Action from the British Hip Society (BHS)
- MHRA asked ODEP to assess and monitor new devices
- ODEP created Beyond Compliance – a service to support the safe and stepwise introduction of new or modified implantable medical devices – was established in 2012 following the problems of metal-on-metal hip replacements and the ASR implants, and is linked to ODEP and NJR
 - It is voluntary, it links with NJR, and it is independent, with no conflict of interest
- Beyond Compliance carries out risk assessments, automatically collects data from the NJR and reviews the data
 - Carries out six monthly reviews with manufacturers
 - Holds surgeon user group meetings

- Too often, manufacturers want to blame the surgeons or statisticians say that numbers are too small
 - Beyond Compliance's policy is that if the data looks worrying, it should be chased up
 - Beyond Compliance contacts the surgeons to find out what is happening before more patients are harmed
- Beyond Compliance wants to assess all explants in an independent explant retrieval centre
 - The explant committee has encouraged this since 2012
 - The committee includes all stakeholders: industry, MHRA, all retrieval centres, NEC
 - Manufacturers routinely give written agreement that they will ensure this will happen
 - It was agreed that all implants would be included (pristine and damaged)
 - Uptake has been poor – there is room for improvement, and it is good to have the Implant Analysis Service involved

Camouflage

Camouflage occurs when the results of a less used variant of a type or brand of implant are amalgamated with the rest of that type or brand, to the extent that the overall results of this type or brand fail to demonstrate the results of the lesser used variant, which has been 'camouflaged'.

An example is where a poorly performing variant of an implant, with a high revision rate, is camouflaged within a larger brand 'family' that overall performs satisfactorily within an implant registry.

- The issues with the large head metal-on-metal implants were not picked up by ODEP or NJR
 - The NJR hierarchy had silos for cemented femoral stems, uncemented femoral stems, cemented cups and uncemented cups, and did not separate bearing surfaces
 - ODEP evaluated cemented, uncemented, hybrid and resurfacing hips
 - Analysis of the data showed that the stemmed metal-on-metal were doing badly – the variants were camouflaged
- With NexGen, the 'standard' implant had low levels of revisions, but a combination of variants (Option Tibia, high flex knee) led to high levels of revisions
- Manufacturers blamed surgeons and cementing techniques

Medical Device Regulation (MDR)

- Introduced in 2017 but gestation has been slow
- For new devices:
 - Under the MDR, "Equivalents" and "predicates" are rarely accepted, clinical investigations are needed for new devices, and notified bodies refer the data to the EU panel
- For legacy devices:
 - Clinical investigations are required regularly
 - PROMs are required

- One unintended consequence is that 20% of implants have been taken off the market – this is particularly an issue for ‘boutique’ implants, where the cost implication is high
- ODEP wants to collect essentially the same data for new and legacy products

Outcome registries programme (ORP)

- The Cumberledge report is behind a lot of the changes
- Recommendations:
 - Any implant in a patient should be in a registry
 - There should be independent monitoring of new devices
 - Monitoring should be clinically focused

One Bad Apple? My experience with the NexGen – Chris Jack, consultant trauma and orthopaedic surgeon, University Hospital Southampton, UK

- When Jack started as a consultant in 2013, he was told to use the NexGen PS implant and resurface the patella
 - Saw a lot of revisions, but no impact from patient or surgeon factors – the only impact was the day of the week (results were better on a Tuesday)
 - 87% of the revisions were from aseptic loosening of the tibia
- First case in see in in 2015
 - Initially happy, but started to have a problem at one year
 - At 18 months – looked like infection on X ray
 - In 2017 – loose tibial tray at surgery, with massive osteolysis and no infection – analysis showed double the expected wear of the PE insert
- Issues with loose tibial trays in two other patients, colleagues also reported issues, but Zimmer Biomet reps said that there was no issue
- Patients continued to report pain after being happy initially
- Analysis in 2019 showed no difference in cement, tibial slope, gender or resurfacing of the patella
- Stopped using NexGen as much as possible, while still being reassured by the company
- The joint was recalled in 2022
 - There were 288 different combinations camouflaging the issue– turned out to be the Option Tibia had much higher revision rates (lower cost, uncoated option)
 - Better results on a Tuesday – used the pre-coated Option Tibia
- Received a letter from the NJR in 2023 stating that his revision rate was higher than expected – told to develop an action plan to address this
 - NJR did not have the facility to look at revision rates per implant
 - 13.8% with Option implant
 - 0.38% with all other primary total knee replacements
- The NJR noted an issue with the NexGen knee in 2015 (level one outlier) – if it had been withdrawn then, there could have been different outcomes for patients and surgeons

- 32 avoidable revisions
 - The numbers of revisions will grow as patients present (“I don’t want to make a fuss”)
- His revision rate would have been 1.4%
- The issues don’t always show up on bone scans – the NJR’s suggestion is if the X ray is okay, it should be left alone
 - If the joint is painful, then osteolysis is occurring and the joint is loose
- The NJR needs to share concerns earlier and inform surgeons about issues with implants
- The NJR needs better data
- Surgeons don’t like admitting that they are wrong, so data is published in smaller journals
- Remember the patients – they just want to get on with their lives

Session 1 discussion

- The NJR won’t prevent problem implants coming onto the market, but it will reduce their impact
- The issues with the 3M Capital hip were picked up in 1999 but not in high enough numbers to be persuasive
- Companies can put similar products onto the market – the equivalence rationale is now much tighter
- The EU/UK Medical Device Regulations (MDR) is putting a greater scrutiny on compatibility
- The NJR needs to be able to have sets of data with and without specific implants to show how devices are used at specific institutions
- Changes in devices can be large or subtle – for example sterilisation differences to the polyethylene in a joint – but these mean that the joint is not the same as the original one
 - This should require a notification to the notified body
 - Can’t mitigate risk altogether but under the MDR there is a lot more scrutiny

Session 2

Explant analysis of spinal rods from children with scoliosis – Tom Joyce, Professor of Orthopaedic Engineering, School of Engineering, Newcastle University, UK

- In November 2012, the House of Commons Science & Technology Committee recommended that “explanted joints should be analysed, and subsequent data generated should be reported to the NJR and published”

The MAGEC spinal growing rod

- Allows a scoliotic child’s spine to be straightened and to grow
 - Activated remotely without the need of an operation

- Recommended by NICE in the UK in 2014
- Explant analysis of over 200 rods
 - Rigid extending bars that skew sideways, causing wearing of the internal surface of the outer casing, and the extending bar
 - Skew compresses the seal on one side, allowing body fluids in and titanium debris out
 - Other issues include O-ring seal damage, destroyed bearings, corrosion of Cu based insert, broken locking pin
- Risk is unclear, but is fed into a risk-benefit analysis, and reports shared with supplying surgeons, NHS England, the manufacturer and MHRA
 - Working together contributes to patient safety
- MHRA investigations led to suspension of the CE mark in 2020 and withdrawal in the UK

Revised version: MAGEC X

- Explant analysis of the new version – 21 explanted rods
 - Metallosis in 73% of cases
 - New sealing mechanism (separate end cap) is not working
 - 24% end cap separation
- There has been no NICE recommendation for MAGEC since 2020

Explant Analysis: How and Why – David Langton, Founder & Chief Scientific Officer, ExplantLab, Newcastle, UK

How and why

- The aim – to understand how much material is worn away, and the rate and location of the wear
- Uses visual analysis and surface profilometry
 - Location and amount of wear
 - Roughness compared with surface as manufactured
- Wear can also be assessed by testing blood levels
- Explant analysis can inform implant development
- It's not about blame

The impact

- 40% of a major orthopaedic manufacturer's bearing diameters did not meet specifications
- Patients react to metal debris – reducing wear reduces the risk of immune response
- >300,000 patients affected globally
- The NJR is good, but it has its limitations – it took until 2024 to publish NexGen data

Carrying out explant analysis – ExplantLab

- In the House of Commons Science & Technology Committee Report of Session 2012-13, the UK Government recognised the value of routine explant analysis but did not consider the costs and logistics made it feasible

- ExplantLab worked to reduce labour costs and increase the number of explants that could be analysed
 - Started with hip joints
 - Used AI and machine learning to be able to analyse knee joints
 - Looked at observer reproducibility
 - Validated approaches

Funding sources

- British Orthopaedic Association (BOA)
- Carrying out medicolegal consultations for patients
- FDA
- Arthroplasty for Arthritis
- Private investment
- UK government
- Implant Analysis Service

A Revision Surgeon's Lifetime Experience of Implant Retrieval: Why it is Important – Richard Beaver, consultant surgeon, Royal Perth Hospital, Perth, Western Australia

- Established a retrieval lab to benefit his practice
- Has seen implants come and go – the good, the bad and the bizarre
 - Can only identify failings if the implants are collected and analysed
- Registries help both surgeons and manufacturers
- Analysis can show why implants fail
 - But can be influenced by manufacturers and by levels of training
- Retrieval labs don't always see the implants that have functioned well
- Who should carry out an analysis?
 - Surgeons don't have the skills
 - Manufacturers may be biased
 - Regulators are underfunded
 - The best solution is an independent lab
- Analysis should be carried out by independent labs with independent funding, using standardised equipment
- This is complementary to implant registries

Case study

- Carried out a trial for a new short stem implant – a modification to an existing (and good) implant
- Three of 55 patients had pain after one year
- At revision – well-fixed implants but soft tissue pseudotumours
 - Reaction to corrosion where the head met the stem

Insights from a government administered retrieval unit – Moreica Pabbruwe, Assistant Professor, CITRA – Bioengineering Health Technology Management Unit, East Metropolitan Health Service, Perth, Western Australia

- The Centre for Implant Technology and Retrieval Analysis (CITRA) – an independent service - develops patient-specific devices, carries out product testing and implant retrieval analysis
- Implant retrieval analysis includes orthopaedic devices, breast implants, trauma nails, plates and IVCs
- Implant failures are multifactorial:
 - Implant factors – materials, geometry, wear, corrosion, fixation
 - Patient factors – physical activity, BMI, gender, age, allergies, infection
 - Surgical factors – positioning of the implant (alignment and inclination), bone preparation, patient/implant selection
- Implant retrieval analysis goals:
 - Identify potential failure modes
 - Determine if a medical device present harm to patients
 - Assess the severity of failure
 - Identify optimal or successful design criteria for future implants
- Implant retrieval analysis disadvantages:
 - Lack of appropriate comparative controls (well-functioning devices)
 - Small number – need to collect more
 - Bias, if influenced by industry
 - Lack of agreement/standardisation between labs on analytical techniques
- Implant retrieval analysis advantages:
 - Realistic and complex biocompatibility model
 - Subject to more environmental factors
 - Inclusion of patient-specific factors that could impact implant performance:
 - Biomateriogenomics: the study on how genes affect the outcome of biomaterials – medical devices

Case study: Modular neck stem

- Crevice corrosion and fretting greater at the neck-stem junction than at the head-neck junction
 - ALVAL caused by corrosion, not wear particles
 - Outcome – industry abandoned modular stems

Case study: Head-neck junction

- Analysis of four decades of retrieved femoral stems and heads to evaluate how implant composition/design affected fretting corrosion and determine the optimal modular components in the hip
 - Investigate if factors such as gender, age, level of activity and time in service contributes to fretting corrosion in these devices
 - Corrosion increases with time of implantation
 - There is greater corrosion in head than in stem tapers

- Stem alloy – stem corrosion is worse in TMZF stems ($p < 0.001$) than in TiAlV stems; stem corrosion is less in HAp coated-TiAlV uncemented stems ($p < 0.001$) than in TiAlV cemented stems
- Stem taper length – longer stem taper resulted in less head and stem corrosion due to greater stability
- Bearing surface – stem corrosion is less in CoP bearings ($p < 0.001$) than in MoM bearing
- Stem taper length – longer stem taper resulted in less head and stem corrosion due to greater stability
- The ideal combination for a modular hip is a titanium alloy (TiAlV) uncemented stem paired with a ceramic on polyethylene bearing

Case study: Patient and implant factors that impact performance of total knee arthroplasty

- Aim: Analyse demographic, clinical and implant factors of retrieved knee systems to determine their success and failure
 - Patient, clinical and implant factors were statistically analysed using survival analysis, Kaplan Meier Method and Cox proportional hazard models.
- Conclusions
 - Activity level and weight affect survivorship of primary retrieved knees
 - Uncemented knees have lower hazard for failure than cement/hybrid retrieved knees
 - Lower rates of failure for mobile bearings post 4-5 years' time *in situ*
 - Retrieved mobile bearings appears to be more forgiving in obese patients
 - Higher expected hazard for failure for PS knees than CR knees
 - Collectively, the results may guide in preoperative matching of TKAs to specific patient groups and in the development of TKA systems

Case study: A review of ultra-high-molecular-weight polyethylene (UHMWPE) for knee prostheses

- Elements for success or failure: polymer specification, manufacturing method, design and patient demographics
 - Different manufacturing techniques and treatments change the wear properties of the polymer
 - Retrieved devices – assessed patient demographics, wear assessment, extent of oxidation
- Each manufacturer uses different techniques – retrieval analysis needs to focus on polymer specification, manufacturing method, design, patient demographics, context with registry/retrieval data

Case study: Quantification of polyethylene wear in fixed bearing unicompartmental knee arthroplasty

- Explant analysis of contemporary UKRs
 - Looked at wear patterns
 - AI aids finding of deepest wear point on each bearing surface
 - Wear differs according to materials, patient sex (likely to be because of differences in weight and activity levels)

- Robot-assisted surgery allows precise positioning of components

Benefits of retrieval analysis

- Identifying design, materials and manufacturing issues of devices early, possibly before local registry data show poor performance.
- Cost savings
 - Each revision surgery avoided saves \$75,000
 - For a single device identified by CITRA (MoM hip implants), the estimated cost saving to WA Health was approx. \$8.8 million
- Patient safety
 - Identify patient cohorts susceptible to early failure (e.g. Triathlon and Legion knees)

Secrets of success

- Retrieval service as part of a larger bioengineering service
- Is a partnership between engineers and surgeons, working with surgeons but not directed by surgeons
 - Allows the service to be independent and provide services hospital-wide
 - Involving surgeons from training creates a culture
- Provides a service to all Western Australian hospitals
- Service started in the 60s – would be difficult to establish a similar service under current budget constraint in Australia
- Staying lean but mean: two engineers and two technicians working on retrieval analysis

Collaborations

- With surgeons on studies that are clinically relevant
- With universities, training engineers as bioengineers and working on projects such as additive manufacturing
- With other retrieval centres, pooling data clinically relevant studies and using different testing techniques
- With Australian registry and regulators, investigating devices with higher than expected revision rates

The future

- Hope to become a national service, not just Western Australia

Session 3

The NHS Implant Analysis Service – Sue Waller, Clinical Nurse Specialist at North Tees and Hartlepool NHS Foundation Trust, UK² & David Langton, Founder & Chief Scientific Officer, ExplantLab, Newcastle, UK

Setting up the IAS

- Started from a bright idea, went on to a lot of meetings and a very long DPIA (Data Protection Impact Assessment) and a GDPR (General Data Protection Regulation) Process, and took about two years
- The aim was to keep it independent and reduce bias
- Put out to tender twice in 2021 and 2023 – now work with ExplantLab, which has provided the expertise, knowledge and facilities
- Used by trusts across England

Why is it important?

- Reports offer learning and discussion opportunities for surgeons
- Trend analysis with an early warning system can improve patient outcomes
- If implants are thrown away it's hard to make a difference for the future

How it works

- The process:
 - Liaison between IAS and hospital
 - Staff are trained
 - IAS provides approved containers and consent forms
 - Explants are removed, shipped from hospital to lab and decontaminated
 - Analysis is carried out
 - Report emailed to surgeon
 - All explants are stored for five years
 - High volume screening service (£199) or full detailed report service (£495)

IAS: Data Handling – David Langton, Founder & Chief Scientific Officer, ExplantLab, Newcastle, UK

- Patient information is important for context

Patient consent for data/explant access

- Consent is needed so that data can be shared for scientific education (for example publications and presentations), to help manufacturers, and for regulators
- Consent is not obtained for disposal

² Sue Waller is employed by North Tees and Hartlepool NHS Foundation Trust (NTHFT) and is contracted to work on the NHS Implant Analysis Service provided by NTH Solutions, NTHFT's subsidiary

Single report vs routine analysis

- Routine analysis provides valuable data
- Measuring old devices is useful for comparison with new ones
- Mass analysis – the more you look, the more you learn

Costs

- Costs can be an issue – but many hospitals already spend a lot on surgical robots
- Clinical waste disposal can be costly
- Failing devices cost the NHS a lot

The power is in the data

- Routine collection is important, but it may need punitive measures
- Publishing data on individual cases is slow and inefficient, and reviewers can be conflicted
- Ideal publication is a six- or 12-month aggregated report
- One-off device reviews are less cost-effective than larger numbers
- Ideally, data sets should combine explant data, NJR data, in vivo data (imaging, blood results), genetics

What is needed

- Money for improved analytical technology
- Support to make the IAS a global service for all devices, not just orthopaedics
- A multidisciplinary advisory board
 - Surgeons, including with NJR and regulatory experience
 - Bioengineers
 - Data analysts
 - Ethicists
 - Patient representatives

Explant analysis and our MDTs – Raghu Sidaginamale, Consultant Trauma and Orthopaedic Surgeon, Hip & Knee arthroplasty, North Tees and Hartlepool NHS Foundation Trust, UK

- Focus on essential aspects of explant analysis and the role of Multidisciplinary Teams (MDTs)

Hip case study: CoC – abnormally low diametrical clearance

- Reason for revision as listed by the surgeon: Aseptic loosening of socket and adverse soft tissue reaction to particulate debris
 - Implant in place for 10 years
 - Clearance abnormally low, leading to friction and instability
 - Fluid ingress and asymmetric metal transfer on the ceramic liner
 - Metal debris released from the posterior surface of the shell

Hip case study: Aseptic loosening of femoral stem (n = 6)

- Extensive changes to stems, reduction in surface roughness

Hip case study: CoP – abnormally low diametrical clearance

- Reason for revision as listed by the surgeon: loose stem – aseptic
 - Implant in place for 5 years
 - Negative clearance – may have resulted from the PE liner or internal surface out of tolerance of the acetabular shell being manufactured – head too large for the cup
 - Increased friction at the bearing surfaces may have contributed to femoral instability
- The median wear rate of components overall was higher than expected

Knee case study: Unusual delamination and oxidation of the PE bearing surface

- Reason for revision as listed by the surgeon: Aseptic femoral loosening and delamination of polyethylene
 - Implant in place for 6.5 years
 - High and asymmetric volumetric loss from bearing and backside surfaces – error in alignment during the manufacturing process, resulting in instability of the polyethylene surface

Knee case study: fracture from minimal force

- Revised total knee replacement >10 years before – revised in 2020
- 2024 – developed pain with loosening, implant taper disconnected after a fall, aseptic
- Reason for revision as listed by the surgeon: Disconnection of body from stem taper
 - Gross damage to modular junction of femoral components
 - Fall caused fracture from minimal force; failure was over a period of time

Shoulder case study: Instability, dislocation/subluxation

- Reason for revision as listed by the surgeon: Instability, dislocation/subluxation
 - Implant in place for 7 years
 - Abrasive changes to the bearing surface

The role of IAS and MDTs

- The NHS Implant Analysis Service and its robust, validated methodologies, with the collaborative efforts of MDTs, play a vital role in improving orthopaedic care
- Integrating advanced analysis techniques and diverse expert perspectives will ensure that explant evaluation remains at the forefront of orthopaedic advancements
- This will benefit patients through more durable and effective joint replacement solutions
- Every private and NHS centre should get involved in IAS
- Every explant should be routinely analysed – whether a success or a failure
 - Large numbers are needed
 - Successful implants show what is ‘normal’
- Sharing full clinical details supports interpretation of the explant results

Evidence of time dependent degradation of polypropylene surgical mesh explanted – Nicholas Farr, School of Chemical, Materials and Biological Engineering, University of Sheffield, UK

- In a sheep study, vaginal mesh was implanted and harvested
 - Developed method to prepare materials, including digesting tissues
 - Analysed tissue + mesh and then mesh alone
 - Observed mesh degrading – cracks and crazes in mesh, formation of particles, changes in stiffness
 - Seen after 60 days, increased after 180 days
 - The only group publishing in this area
- Evolving research techniques can provide insights into biomaterial characterisation
- For analysis of retrieved implants, need to decide:
 - What analysis should be undertaken of the retrieved implant
 - How the analysis of the retrieved implant can be judged on the expected implant characteristics
 - How hazard analysis techniques can be used to provide a focus for pre-clinical deployment biomaterial characterisation

Session 4

Explant Analysis, AI and Genetics – David Langton, Founder & Chief Scientific Officer, ExplantLab, Newcastle, UK

- Arthritis is a large and growing problem
 - The demand for hip and knee replacements is forecast to double as the population ages and obesity levels rise – more surgery means more revisions required
- Several thousand different designs of joint replacements have been available for UK surgeons over the last 15 years
- Levels of chronic pain following joint replacement remain at approximately 10-20%
- Immune responses limit the long term survival of joint replacements
 - Reducing wear could reduce immune responses, therefore increasing the lifespan
 - Understanding of the immunogenetic response is relatively poor

Developing and predicting ALVAL

- Some patients develop delayed-type allergies – the same material debris can provoke different immune responses in different patients
 - Known as ALVAL – a T cell inflammatory response
- Knee surgeons do not routinely request examination of tissues to look for ALVAL
 - Loose abnormally wearing components are associated with pathological processes that cause pain and mimic infection
 - Greater incidence of ALVAL in failed TKRs than expected

- 30+% of failed TKRs show ALVAL signs, with the ALVAL grade correlating with pain levels
- Cobalt chrome alloy is used in over 70% of arthroplasties
 - Elevated blood CoCr concentrations in TKRs – but little has been published
 - Some patients are ALVAL-resistant, despite high levels of metal debris and high levels of cobalt in the blood
 - Some develop ALVAL despite low levels of metal debris and low levels of cobalt in the blood
- Metal debris release in knee arthroplasty is not recognised as a significant clinical issue
 - Believed that there is no metal exposure from knee implants – but wear is seen on explant analysis and in simulator studies
- Certain patient characteristics promote the development of ALVAL, whereas some patients are relatively resistant to developing the condition
- Characteristics associated with ALVAL development in patients with low-wearing prostheses
 - Female
 - Increasing age
 - Debris from the taper more than the bearing
 - Presence of certain HLA alleles
 - On chromosome 6, encode MHC structures
 - Determine autoimmune and hypersensitivity diseases
 - Certain HLA alleles are protective
- Machine learning algorithm trained with data from 70% of patients – patient factors, prosthetic factors, disease factors
 - Validated with patient and prosthetic data from the remaining 30% of patients, compared with disease data
- 15% of patients of European descent have significantly increased reactivity to CoCr
 - 15% of patients who receive CoCr implants as part of knee replacements have chronic pain
- Alternatives are provided for hip replacements but disregarded for knee replacements
 - Hip surgeons routinely test blood levels on pain, but knee surgeons don't

ArthroGenex Study

- 2000 patients – UK, US, Australia
- NexGen LPS knee – aseptic loosening of the option stemmed tibial tray
 - Femur remained fixed; titanium tray showed wear
 - Increased levels of titanium ions in all revision cases
 - Genetic links to pain with elevated Ti levels; not the CoCr risk alleles

Explant analysis

- Can help us to:
 - Understand disease processes better
 - Develop diagnostic tests
 - Improve understanding of diseases outside of orthopaedics (e.g. allergies)

Session 5

Manufacturers Q&A

Question: Is there value in autopsy analysis?

- 1) Retrieving implants at autopsy seems logical
 - o Retrieval should be independent
- 2) Need as much information as possible
 - a. Not everyone will want to focus on the issues
- 3) Would allow us to see the successful implants
 - a. Personal opinion
 - b. It's a difficult question – the challenge is getting the right people involved – need R&D input to feel into development
- 4) Should be mandatory – carry an implant donor card, like a kidney donor card
 - a. Personal and company opinion – will reduce mistakes
 - b. Not all companies will agree – driven by money and by investors
- 5) Needs multidisciplinary input
 - a. Personal opinion

Question: With up to 40% of retrievals being out of spec, is there a QA problem?

- 1) Out of spec issues should be picked up in internal and external audits
- 2) Not sure that this figure is for all companies or just a few
- 3) Ours are all tested as they leave
- 4) We do our best – where does the data come from? It can't be as bad as you think – there is a lot to engineering. I don't think we get it wrong that often
- 5) Not to my knowledge in my company

Question: Are issues a regulatory thing or should they be picked up by the QMS?

- 1) QMS is important, but there should also be internal auditing – these should work together
- 2) New implants should be analysed as well as explants
- 3) Should be picked up by the auditors
- 4) It depends on the auditors – they are generally looking at the system
- 5) Picked up by the QMS

Question: Should implant analysis be part of post-market clinical follow up? Or made a legal requirement?

Yes – but who would manage it and fund it?

Audience comment

I spent 10 years looking at manufacturing problems – I've seen things on production lines that people don't want to tell anyone senior about. I have seen FDA reports where UK things have been noted as wrong but not reported to the MHRA. These issues can be hidden.

Some are retested to get them off the production line. Some companies are not even measuring. It does happen.

Question: Should implant analysis be internal or external?

- 1) External and independent
- 2) Both internal and external
- 3) External – internal analysis may not be standardised. I don't want to work for a company that is brushing things under the carpet
- 4) Has to be external – but it can be hard for external people to understand everything involved. The ultimate would be companies always doing it right. Big corporate decisions don't always make sense.
- 5) Would want retrieval labs to be consistent and audited

Question: There is no guidance for allergies

- 1) This is a developing area
- 2) We need to get organisations to acknowledge hypersensitivity
- 3) Instructions for use (IFU) may just talk about 'allergy' as a blanket comment
- 4) It's hard to change an IFU. I'm concerned that we are taking allergies too far
- 5) Surgeons should check – so we need to alert the surgeons

Session 6

Revision TKR and its Associated Costs – Jacky Ping Hei Cheng, Trauma and Orthopaedics Surgeon, University Hospital Southampton NHS Foundation Trust, UK

- There is a financial hit associated with revision total knee replacements
 - Revision surgeries are more costly than primary procedures
- Based on implant cost, operative time recorded, length of stay, bed cost per day and operating theatre cost per day, the average cost per patient is £15,638
 - Additional costs include GP and outpatient visits, investigations, diagnostic procedures and therapy, as well as psychological and economic impacts
 - Overall costs could be as much as £30,000

Explant analysis in the private sector – Debbie Dobbs, Executive Director, Circle Health Group, UK

- The independent sector is not yet involved in explant analysis, as it does not usually do revision surgery
- Allergy blood tests could predict the risk of revisions – the costs for tests will be handled differently for self-pay patients, insured patients and NHS patients
- Surgeons in the independent sector may push back against pre-op and post-op testing for a variety of reasons
 - Scaremongering
 - Impact on business

- Lack of scientific basis
- However, it could be seen as a business opportunity
- The independent sector needs to:
 - Consider the risks and benefits of getting on board with new research
 - Look at the opportunities that can be offered to patients depending on payor type
 - See what the commercial or financial slant is
 - Encourage support/dispel myths
 - Does this conflict with income generation?
 - Consider whether to get involved or leave it to the NHS
 - Decide whether to wait until the research is proven

Session 7

Implant failure: My story – Sharon Craddock, patient

- Primary total knee replacement with NexGen in both knees 2017/2018
 - After first knee replacement – wasn't ready for the pain, the bend wasn't good
 - Similar in the left knee but knew what to expect
 - Grateful for two new knees, but was still in pain and on inflammatory drugs
 - Had stomach and haemoglobin issues and had to come off anti-inflammatories
- Revision total knee replacement in both knees 2021
 - First revision in 2021 – left knee – delayed by Covid
 - Had to reduce working hours, became anxious about crowds
 - Anxious about the revision outcome
 - Needed IV iron and repair to femur
 - Second revision in 2023
 - Had allergic adverse reaction to glue and dressings, and a skin infection
- Impacts
 - No day without pain
 - Affected holiday of a lifetime to Australia
 - Had to make changes at home, change car
 - Can't do long walks any more – even gardening is hard
 - Ongoing pain – now potentially unrevisable
 - Now have hip pain
 - Has affected freedom and self-confidence
 - Had a lot of time off work
 - Was told 'enjoy what you can now'

The MHRA perspective on implant retrieval analysis and its role in patient safety – Rebecca Owens, Medicines & Healthcare products Regulatory Agency, UK

- The MHRA is the UK regulator of medicines, medical devices and blood components, responsible for safety, quality and efficacy
- One of the key elements of the medical device regulations is post-market surveillance
 - Monitoring the performance of a medical device after gaining the CE/UKCA mark
 - Identifies design and usage problems from real-world evidence
 - Ensures long-term safety

Post-market surveillance – Manufacturer’s responsibilities

- Have systematic processes in place to review experience in post-production phase, investigate complaints and identify trends/signals
- Have systems in place to identify non-compliance and opportunities for improvements, make corrective and preventive actions
- Actively update clinical evaluation with post-market surveillance data
- Carry out continuous risk management to ensure that benefits outweigh risks
- Report adverse incidents to MHRA
- Report field safety corrective actions to MHRA, issue field safety notices to users

Post-market surveillance – MHRA’s responsibilities

- Similar to manufacturer’s responsibilities
- Signal detection
 - Adverse incident reports, real-world data, engagement, risk prioritisation
- Assessment
 - Review of all data sources, engagement, expert advice, benefit-risk evaluation assessment
- Communication
 - National Patient Safety Alerts, Devices Safety Information (DSI), engagement, expert advice
- Impact assessment and signal detection
 - Engagement, adverse incident reports, real world data, lessons learned

Implant retrieval analysis reports as a signal

- Questions to answer:
 - Does it fit the reportability of the criteria?
 - Do we understand the clinical and patient factors?
 - How will it be embedded into PMS procedures?
 - Can the manufacturer still complete an independent investigation?
 - Is engagement with stakeholders optimal?
 - Is there an escalation procedure for concerns?
 - Can pre-publication early notifications be shared?
 - How can it be linked to registries?
 - Will there be guidelines on how to interpret the data?

- Manufacturers have a responsibility to report issues to the MHRA
- The details in reports need standardization and guidance

Signal assessment and benefit risk evaluation

- Explant analysis could fill a gap in root cause analysis and help towards corrective action by answering these questions:
 - Why did the device fail?
 - Can any trends in failure be identified?
 - Is there a fundamental design issue?
- It can be used to gain additional information and strengthen a signal of concern alongside other data sources
- It is the manufacturers responsibility to establish the root cause

Retrieval analysis and post-market surveillance

- Linking to the NJR would provide a better view of issues
- The MHRA can only take action when it is notified of issues
- To be important for post-market surveillance, retrieval analysis needs:
 - A national reach
 - Maximum engagement with stakeholders including manufacturers
 - Early notification for signals
 - Linked clinical data and minimum agreed data sets
 - Integration into robust manufacturer PMS systems
- It has:
 - The ability to enable better RCA assessments
 - The potential to assist with identification of issues sooner
 - The ability to gain a better understanding of how different devices perform relative to one another, including brands and variants
 - A current use in supporting signal assessment
 - The capability to improve both current and future patient outcomes
 - The ability to increase patient safety

Legal Implications of Explant Analysis - Catherine Slattery and Natalie Truman, Associate Solicitors, IrwinMitchell, UK

Legal test for product liability

- The Consumer Protection Act 1987 states that a product is 'defective' if the safety of the product is 'not such as persons generally are entitled to expect.'
- Derived from EU law
- Post-Pinnacle, it looks at the individual patient rather than statistical data
- The claim must be within 10 years of the product leaving the factory/going into circulation, even if the implant is on the shelf for some time before use
 - The timeline cannot be extended

Investigation of claims

- Information required includes:
 - Medical records/radiology from the hospital and GP
 - History from claimant – background and personal impact

- Independent expert evidence
- Explant analysis – including clinical evidence and trauma
- Disclosure from manufacturer – rarely provided voluntarily; may need court intervention
- Testing evidence in conference with Counsel

How can explant analysis affect a legal claim?

- Provide evidence as to why the implant failed
- Show mechanism of failure
- Provide evidence of design or manufacturing defect
- Correlate with clinical evidence to link explant analysis and outcome

Excluding other factors for product failure

- Patient and surgical factors need to be considered, as manufacturers may argue that surgeons with high revision rates are outliers, or that patients have a propensity to certain outcomes
- Infection needs to be excluded
- The focus from a legal perspective is on the individual patient's outcome and why their product failed

Use of explant analysis in practice – Pinnacle MoM group litigation

- Complex expert evidence may have made it harder to identify a manufacturing or design defect
- The Court decided that the propensity to shed metal debris was not a defect, even where some patients might suffer an adverse immunological reaction or require early revision surgery
- The claimants relied heavily on statistics arguing that that the cumulative revision rate for the prosthesis at 10 years post-implantation was materially higher than comparators, but the court accepted DuPuy's argument that statistics were unreliable
 - NJR did not record data on activity, which can impact hip implant survival
 - The NJR data included a number of outlying surgeons
 - The NJR data was incomplete and included little long-term data
 - The NJR data conflated a number of variants (camouflage)
 - MHRA guidance following the withdrawal of a different type of MoM prosthesis resulted in enhanced surveillance, increasing the number of revisions
 - Media reporting had an impact on revision rates
- Reliance on epidemiological data requires caution
 - Can identify trends, but cannot prove causation
 - Needs expert analysis
- Identifying a unique mechanism of failure through explant analysis can help to avoid this problem, and may be more attractive to the courts