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Mini-symposium: The Hip

(ii) The Role of Imaging in Follow-up of Newly Introduced Implants

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1 Abstract

A wide variety of orthopaedic implants are in clinical use and many new devices are brought to the market each year. The vast majority of these devices have no published clinical data. The concept of phased introduction has been developed. The use of radiostereometry and cross-sectional imaging in the follow-up and phased introduction of new orthopaedic implants is discussed.

1 Keywords

RSA, implant assessment, follow-up, cross-sectional imaging

1 Introduction

The mainstay of orthopaedic treatment for end-stage joint disease, particularly for the hip and the knee, remains joint replacement. To service this need a considerable number of joint replacement implants have been developed and new devices are being introduced on an ongoing basis. Some of these new devices are incremental changes to existing designs and others embrace either new designs, concepts or materials. Whilst regulation has increased and pre-clinical testing has become obligatory, the majority of implants in use have very little published clinical data available. By definition new devices will have no track record. The National Joint Registry for England and Wales recorded that 123 brands of acetabular cups, 13 brands of resurfacing implants and 146 brands of femoral stems were used in 2010(1). Of these devices, for 42% of the brands of acetabular cup and 47% of the brands of femoral stem no data had been submitted to the Orthopaedic Data Evaluation Panel (ODEP). The aim of this article is describe and discuss the use of various imaging modalities in

the staged introduction and continued assessment of orthopaedic implants. The article focuses on the use of radiology and cross-sectional imaging for hip and knee implants, illustrated by examples of the use of these techniques. The discussion of robust assessment methodologies and staged release is particularly topical given the recent media attention on implants. The use of inappropriate materials in breast implants(2) has revealed weaknesses in the regulation process and the early failure of metal-on-metal hip replacements demonstrate the need for continued assessment of implants(3).

1 Key Failure Modes

Amongst the most authoritative sources of information on failure modes of orthopaedic implants are the Swedish Hip and Knee Registries. The single largest reason for revision remains aseptic loosening, accounting for more than half of all hip revisions(4) and over a quarter of all total knee replacement revisions(5). Aseptic loosening reflects a failure of the fixation of the implant. Given the relationship between aseptic loosening and wear debris(6), methods that can measure implant motion relative to the host bone and that can measure wear *in vivo* are useful for the assessment of new designs and materials. The most established technology for such measurements is radiostereometry or RSA. Adverse events can be considered as another class of failure, this article will focus on tissue response and the use of cross-sectional imaging to aid in the diagnosis of this failure type. These failure modes are summarised in Figure 1, together with their associated imaging modalities.

1 RSA

RSA for assessing orthopaedic implants originated from the work of Goran Selvik and Lars Ingvar Hansson in Sweden(7, 8). The basis of the technique is the use of two xray sources to simultaneously image the object(s) of interest(9). If the locations of the xray sources and the image planes (xray plates) are all known, the principles of photogrammetry can be used to reconstruct the three-dimensional (3D) information regarding the object(s) of interest. For example, RSA imaging of a hip prosthesis implanted in a femur (Figure 2) will allow the 3D position of the prosthesis to be reconstructed. Early systems used easily identifiable markers (spherical tantalum beads) attached to the prosthesis components; later model-based systems removed the need to modify components. The 3D location of a prosthesis becomes more useful if its position relative to the host bone is known, for this purpose small tantalum beads are also inserted into the bone at the time of surgery. Thus the 3D location of the prosthesis relative to the axis system defined by the beads, and thus relative to the bone, can be established. Taking serial measurements at different time intervals thereby allows the migration of the implant relative to the bone to be calculated. RSA measurements are highly accurate, typically accurate to at least 0.1 mm.

The reason why migration is of interest is that continued early migration has been shown to be indicative of failure. The very high accuracy of measurement means that adequately powered studies can be performed using relatively small cohorts, thereby exposing only small numbers of subjects to new designs/materials. The landmark work in this area was performed by Ryd *et al*(10) and Karrholm *et al*(11). Ryd *et al* demonstrated that the early migration pattern of total knee replacement tibial components were predictive of whether revision for mechanical loosening would be required. Most of the study cohort demonstrated movement of approximately 1 mm in the first year and then a much slower rate of movement. Those that continued to migrate after the first year

went on to require revision. Karrholm *et al* studied the Lubinus SP I (Waldemar Link GmbH, Hamburg, Germany) femoral component. Those stems that migrated more than 1.2 mm per year had a greater than 50% risk of revision by 7 years.

It was later shown by Alfaro *et al*(12), that for polished cemented femoral stems a small amount of distal migration was not indicative of failure, but probably beneficial. This study highlighted the importance of rotational stability of femoral stems, and also the importance of performing true 3D measurements. A key parameter indicative of rotational stability was the migration of the head in the posterior direction, or posterior head migration (PHM). The findings showed the difference between the Exeter (Stryker, Newbury, UK) and the Charnley Elite stems (DePuy, Leeds, UK). The Exeter with its double taper tended to migrate distally, causing it to engage further into the cement mantle. This was thought to have the effect of re-enforcing the cement/bone interface and enhancing the rotational stability of the stem. The Charnley Elite had subtle design differences to its predecessor, and was more cylindrical. There was a greater amount of PHM and less distal migration for the Charnley Elite stem. A subset of the Charnley stems exhibited very high values of PHM, with a mean value of 2.8 mm/year compared to 0.26 mm/year for the Exeter stem. It was suggested that this may be indicative of a higher risk of failure, which was controversial at the time.

A follow-up study set out to test whether the earlier predictions were borne out. Hauptfleisch *et al*(13) performed a clinical review of all Charnley Elite stems implanted at the centre where the original Alfaro *et al* study had been performed. Hauptfleisch *et al* reviewed all patients and found that the revision rate was 17% (95% CI: 10 to 24) at 9 years. They also evaluated radiological signs of loosening, and taking the endpoint as either failure or radiologically loose, the failure rate was 33% (95% CI: 19 to 47) at 9 years. Importantly, all the cases from the original RSA study with high PHM were all revised for loosening.

1 Wear Studies with RSA

RSA technology is also well suited to estimating the amount of *in vivo* wear, particularly for total hip replacement (THR) implants. It must be borne in mind that RSA cannot actually measure true wear. What the method is able to do is to measure the motion over time of one component relative to another. In the case of a THR using a metal-on-polyethylene bearing, the *penetration* over time of the femoral head into the polyethylene can be measured if there are radio-opaque markers in the polyethylene or there is a metal backing to the socket. If the socket is made from titanium alloy, the silhouette of the head can be detected within that of the socket. The penetration will be a combination of wear and creep deformation of the polyethylene. This method was used to examine the wear associated with high failure rates due to osteolysis by von Schewelov *et al*(14) to determine the levels of wear rate associated with osteolysis; these authors concluded a wear rate exceeding 0.2 mm/year is prognostic of failure.

Some of most significant recent advances in hip replacement technology have been the development of cross-linked polyethylenes. The early work was performed using laboratory tests(15). It is always important to ensure that laboratory findings are applicable to the clinical situation, and RSA is ideally suited to performing *in vivo* wear assessments.

The effects of different polyethylene sterilisation techniques and types of polyethylene were investigated by Digas(16). The RSA measurements demonstrated that cups sterilised in ethylene

oxide had twice the penetration rate of those that had been gamma sterilised. A powerful bilateral study methodology was used to examine the effects of polyethylene type, 32 patients received a cross-linked polyethylene cup on one side and a standard polyethylene cup on the contra-lateral side. Digas reported that highly cross-linked polyethylene cups showed less penetration after the first year than conventional polyethylene.

Glyn-Jones *et al*(17) performed a double blind randomised control trial (RCT) to examine the differences in wear between standard polyethylene and Longevity (Zimmer, Warsaw, IN, USA) highly cross-linked polyethylene. As RSA was being used a relatively small cohort was needed, 54 patients were randomised to receive either a standard liner (n=26) or a Longevity liner (n=26), with no other difference between the groups in terms of THR components. Measurements were made within a week post-operatively, and at 6 months, 1, 2 and 3 years. The penetration data demonstrated a bimodal pattern (Figure 3). The early (less than 1 year) penetration was relatively rapid, followed by slower penetration. These authors suggested that creep effects dominated the early phase and, whilst creep probably continued, wear dominated the later phase. There were no differences in creep behaviour between the two types of polyethylene. Fitting lines to the data at 1 year and later allowed the wear rate to be calculated, the standard polyethylene wear was 0.07 mm/year compared to 0.03 mm/year for the cross-linked polyethylene ($p<0.01$). This study's findings have important implications for design of studies aiming to compare polyethylene wear; at least three measurement points are needed after the creep domination phase has ended.

1 Cross-sectional Imaging

The recent experience with metal-on-metal implants demonstrate that new designs often introduce new failure modes. It is instructive to note that an RSA study(18) of Birmingham Hip Resurfacing found it to have very low migration and concluded that it probably would not suffer from mechanical loosening. RSA studies can demonstrate that fixation is adequate, but does not necessarily give an insight into all failure modes. The early failures of hip resurfacing were mostly due to neck fracture(19, 20), which is thought to be due to disruption to the femoral head blood supply during the approach(21). A more serious complication emerged with the reporting of pseudotumours after metal-on-metal hip resurfacing by Pandit *et al*(22). There was a considerable delay in identifying this problem due to the reliance upon xray investigation for symptomatic patients; and this provides a useful lesson in dealing with unexpected clinical complications with new implants. Xray investigations did not reveal the presence of the soft tissue reactions (Figure 4) around the implant. The experience with pseudotumours clearly points to the need for using cross-sectional imaging as an adjunct to xrays. The pseudotumours were found to be reliably detected using ultra-sound(23, 24) (Figure 5). The main problem with ultrasound is the reliance on skilled and experienced interpretation of the images(24). Toms *et al*(25) developed metal artefact reduction sequences (MARS) for MRI scanning of metal-on-metal hip replacements. The MARS MRI technique now allows routine imaging of patients with metal implants and MRI can reveal the presence of pseudotumour (Figure 6).

1 Discussion

The current regulatory framework for orthopaedic implants requires rigorous and standardised pre-clinical tests before implants can be introduced to the market. However, it is clear from the history of orthopaedic devices that small design changes or the use of new materials can have unexpected

negative consequences. For example, introducing a matt finish on the Exeter stem led to dramatic increase in revision(26). The introduction of Boneloc (Biomet, Warsaw, IN, USA) cement was intended to reduce the problems of high polymerisation temperatures(27), but during clinical use of this cement significantly higher early failures were observed for hip stems(28). Phased introduction has been proposed as a method of reducing the consequences of unforeseen complications, and imaging techniques have a clear role in clinical trials forming part of such an introduction scheme.

Radiostereometry or RSA, due to its high accuracy, has a particularly valuable role. Relatively small cohorts are needed for trials because of the high accuracy achievable with RSA. Nelissen *et al* (29) have recently demonstrated that knee implants tested using RSA have between 22% to 35% fewer revisions at five years compared to non-RSA tested knee implants. There is a clear role for using RSA to assess the effectiveness of materials and designs at improving wear resistance. The usage of RSA for phased introduction requires well designed studies, and perhaps one method is to compare new devices against the current gold standard.

RSA studies cannot, however, give insight to every failure mode. Johan Karrholm recently stated "RSA can tell you what is bad, but cannot necessarily tell you what is good". For well known failure modes with established patterns of migration, RSA clearly has a strong predictive value. However, if a failure mode is not associated with a repeatable migration pattern, then RSA studies would probably not be able to predict it. It should be borne in mind that the results obtained with RSA measurements are reflective of the whole process of joint replacement not just the implant being assessed. Operative technique, patient selection and rehabilitation may all play a role in the migration patterns of implants and RSA studies should be designed to reduce bias.

It is important to consider RSA studies as forming part of a comprehensive clinical assessment for new devices. The experience of metal-on-metal hip replacement has demonstrated that a true comprehensive approach is needed when confronted with unforeseen complications. This experience has demonstrated the value of cross-sectional imaging, which previously had not been considered as part of a routine follow-up for an orthopaedic implant. However, the very nature of an unexpected complication means that it may not be detected until a device is in widespread use, and most likely the future holds more examples of failures due to unforeseen consequences of the introduction of new implants.

1 Conclusion

Imaging has a number of important roles in the clinical follow-up of newly introduced implants. RSA in particular is an important measurement tool for performing comparative trials of designs and new materials, and is now being recommended as part of the phased introduction of new implants(30, 31). The recent experience with pseudotumours associated with metal-on-metal hip replacement has shown the importance of using cross-sectional imaging to investigate symptomatic patients, particularly in the early adoption phase of new implants. Future developments need to focus on improving the resolution and accuracy of RSA; whilst RSA can detect penetration rate differences between standard and highly cross-linked polyethylene, it probably cannot measure the differences between two different types of cross-linked polyethylene. A major overhead with cross-sectional imaging is the reporting of the images. More automated methods may play a role in allowing more detailed clinical follow-up in a cost-effective manner.

Assessment of implants is now also moving to a functional level and there is role for imaging here too. Imaging methodologies have been used as research tools to obtain objective functional data, for example performing dynamic tracking of joint motion with MRI(32) or assessing the differences in the kinematic function of knee replacements(33). These have not yet translated into routine clinical use. Further development of these tools will allow implant assessment to be undertaken on an objective functional performance basis.

Figure Captions:

Figure 1: Failure modes and the associated imaging modalities for assessment.

Figure 2: Typical RSA measurement arrangement.

Figure 3: Penetration data for standard (UHMWPE) and Longevity highly cross-linked (HXLPE) polyethylene against time. Blue shaded area shows creep dominated early phase.

Figure 4: Xray of a patient with bilateral pseudotumours.

Figure 5: Ultrasound imaging of resurfacing hip patient with a pseudotumour.

Figure 6: MARS MRI scan of patient with large pseudotumour.

References

1. National Joint Registry for England and Wales 8th Annual Report. 2011.
2. Smith R, Lunt N, Hanefeld J. The implications of PIP are more than just cosmetic. *Lancet*. 2012 Mar 31;379(9822):1180-1.
3. Smith AJ, Dieppe P, Vernon K, Porter M, Blom AW. Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. *Lancet*. 2012 Mar 31;379(9822):1199-204.
4. Garellick G, Kärrholm J, Rogmark C, Herberts P. Swedish Hip Arthroplasty Register, Annual Report 2010. <http://jrorthoguse>. 2010.
5. Sundberg M, Lidgren L, W-Dhal A, Robertson O. Annual Report 2011 The Swedish Knee Arthroplasty Register. 2011.
6. Orishimo KF, Claus AM, Sychterz CJ, Engh CA. Relationship between polyethylene wear and osteolysis in hips with a second-generation porous-coated cementless cup after seven years of follow-up. *J Bone Joint Surg Am*. 2003 Jun;85-A(6):1095-9.

7. Selvik G, Alberius P, Aronson AS. A roentgen stereophotogrammetric system. Construction, calibration and technical accuracy. *Acta Radiol Diagn (Stockh)*. 1983;24(4):343-52.
8. Selvik G. Roentgen stereophotogrammetry. A method for the study of the kinematics of the skeletal system. *Acta Orthop Scand Suppl*. 1989;232:1-51.
9. Karrholm J, Gill RH, Valstar ER. The history and future of radiostereometric analysis. *Clin Orthop Relat Res*. 2006 Jul;448:10-21.
10. Ryd L, Albrektsson BE, Carlsson L, Dansgard F, Herberts P, Lindstrand A, et al. Roentgen stereophotogrammetric analysis as a predictor of mechanical loosening of knee prostheses. *J Bone Joint Surg Br*. 1995 May;77(3):377-83.
11. Karrholm J, Borssen B, Lowenhielm G, Snorrason F. Does early micromotion of femoral stem prostheses matter? 4-7-year stereoradiographic follow-up of 84 cemented prostheses. *J Bone Joint Surg Br*. 1994 Nov;76(6):912-7.
12. Alfaro-Adrian J, Gill HS, Murray DW. Should total hip arthroplasty femoral components be designed to subside? A radiostereometric analysis study of the Charnley Elite and Exeter stems. *J Arthroplasty*. 2001 Aug;16(5):598-606.
13. Hauptfleisch J, Glyn-Jones S, Beard DJ, Gill HS, Murray DW. The premature failure of the Charnley Elite-Plus stem: a confirmation of RSA predictions. *J Bone Joint Surg Br*. 2006 Feb;88(2):179-83.
14. von Schewelov T, Sanzen L, Onsten I, Carlsson A. Catastrophic failure of an uncemented acetabular component due to high wear and osteolysis: an analysis of 154 omnifit prostheses with mean 6-year follow-up. *Acta Orthop Scand*. 2004 Jun;75(3):283-94.
15. Oonishi H, Kuno M, Tsuji E, Fujisawa A. The optimum dose of gamma radiation-heavy doses to low wear polyethylene in total hip prostheses. *J Mater Sci Mater Med*. 1997 Jan;8(1):11-8.
16. Digas G. New polymer materials in total hip arthroplasty. Evaluation with radiostereometry, bone densitometry, radiography and clinical parameters. *Acta Orthop Suppl*. 2005 Feb;76(315):3-82.
17. Glyn-Jones S, Isaac S, Hauptfleisch J, McLardy-Smith P, Murray DW, Gill HS. Does highly cross-linked polyethylene wear less than conventional polyethylene in total hip arthroplasty? A double-blind, randomized, and controlled trial using roentgen stereophotogrammetric analysis. *J Arthroplasty*. 2008 Apr;23(3):337-43.
18. Glyn-Jones S, Gill HS, McLardy-Smith P, Murray DW. Roentgen stereophotogrammetric analysis of the Birmingham hip resurfacing arthroplasty. A two-year study. *J Bone Joint Surg Br*. 2004 Mar;86(2):172-6.
19. Shimmin AJ, Back D. Femoral neck fractures following Birmingham hip resurfacing: a national review of 50 cases. *J Bone Joint Surg Br*. 2005 Apr;87(4):463-4.
20. Steffen RT, Pandit HP, Palan J, Beard DJ, Gundle R, McLardy-Smith P, et al. The five-year results of the Birmingham Hip Resurfacing arthroplasty: AN INDEPENDENT SERIES. *J Bone Joint Surg Br*. 2008 Apr;90(4):436-41.
21. Steffen RT, Smith SR, Urban JP, McLardy-Smith P, Beard DJ, Gill HS, et al. The effect of hip resurfacing on oxygen concentration in the femoral head. *J Bone Joint Surg Br*. 2005 Nov;87(11):1468-74.
22. Pandit H, Glyn-Jones S, McLardy-Smith P, Gundle R, Whitwell D, Gibbons CL, et al. Pseudotumours associated with metal-on-metal hip resurfacings. *J Bone Joint Surg Br*. 2008 Jul;90(7):847-51.
23. Kwon YM, Ostlere SJ, McLardy-Smith P, Athanasou NA, Gill HS, Murray DW. "Asymptomatic" Pseudotumors After Metal-on-Metal Hip Resurfacing Arthroplasty Prevalence and Metal Ion Study. *J Arthroplasty*. 2011 Jun;26(4):511-8.
24. Chen Z, Pandit H, Taylor A, Gill H, Murray D, Ostlere S. Metal-on-metal hip resurfacings--a radiological perspective. *Eur Radiol*. 2011 Mar;21(3):485-91.
25. Toms AP, Marshall TJ, Cahir J, Darrah C, Nolan J, Donnell ST, et al. MRI of early symptomatic metal-on-metal total hip arthroplasty: a retrospective review of radiological findings in 20 hips. *Clin Radiol*. 2008 Jan;63(1):49-58.

26. Rockborn P, Olsson SS. Loosening and bone resorption in exeter hip arthroplasties. Review at a minimum of five years. *J Bone Joint Surg Br.* 1993 Nov;75(6):865-8.
27. Nimb L, Sturup J, Jensen JS. Improved cortical histology after cementation with a new MMA-DMA-IBMA bone cement: an animal study. *J Biomed Mater Res.* 1993 May;27(5):565-74.
28. Abdel-Kader KF, Allcock S, Walker DI, Chaudhry SB. Boneloc bone-cement: experience in hip arthroplasty during a 3-year period. *J Arthroplasty.* 2001 Oct;16(7):811-9.
29. Nelissen RG, Pijls BG, Karrholm J, Malchau H, Nieuwenhuijse MJ, Valstar ER. RSA and registries: the quest for phased introduction of new implants. *J Bone Joint Surg Am.* 2011 Dec 21;93 Suppl 3:62-5.
30. Valstar ER, Gill HS. Radiostereometric analysis in orthopaedic surgery. *Clin Orthop Relat Res.* 2006;448:2.
31. Valstar ER, Gill R, Ryd L, Flivik G, Borlin N, Karrholm J. Guidelines for standardization of radiostereometry (RSA) of implants. *Acta Orthop.* 2005 Aug;76(4):563-72.
32. Fellows RA, Hill NA, Gill HS, MacIntyre NJ, Harrison MM, Ellis RE, et al. Magnetic resonance imaging for in vivo assessment of three-dimensional patellar tracking. *J Biomech.* 2005 Aug;38(8):1643-52.
33. Rees JL, Beard DJ, Price AJ, Gill HS, McLardy-Smith P, Dodd CA, et al. Real in vivo kinematic differences between mobile-bearing and fixed-bearing total knee arthroplasties. *Clin Orthop Relat Res.* 2005 Mar(432):204-9.