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PERSPECTIVES

Revision arthroplasty: an update

D. Williams · A. Taylor · P. McLardy-Smith

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Introduction

Major joint arthroplasty is undoubtedly one of the surgical success stories of the 20th century. The number of primary and revision hip and knee replacements performed each year has increased exponentially over the last half century: 6 total hip replacements (THRs) were performed in Sweden in 1967; by 2005 there were 13,822. These increases have been sustained over the first 5 years of the new millennium: numbers are up between 6 and 21% for primary THR and up between 4 and 26% for revision hip surgery. Total knee replacement (TKR) has seen similar increases: up between 16 and 44% for primary TKR and up between 25 and 29% for revision knee surgery over the same period [1–3].

Phillip Wiles designed and implanted the first prototype hip replacements back in the 1930s. These produced initial relief of pain, but quickly loosened and failed. During the early 1950s, John Charnley introduced a Teflon hip resurfacing that wore out within 2 years. That design was superseded by a cemented stem with a metal head articulating against a Teflon socket that again produced severe osteolysis and loosening [4, 5]. Larger femoral heads in this series of patients showed higher volumetric polymer wear; therefore, smaller (22.25-mm) femoral heads were used in future designs [6]. The smaller head did, however, produce greater linear penetration into the polymer cup and was less stable.

By 1962, a high-density polyethylene cup combined with the cemented femoral stem (and the 22.25-mm femoral head) was being used with success in the elderly inactive population [7]. This design and combination of materials has formed the basis of future developments. Charnley recognised, however, that its success would largely depend on the rate and effect of polyethylene wear and cautioned against the use of hip replacement in younger patients: "In this age group we look for factors which offer a 'built-in restraint' which will continue after the operation, such as defective knees or ankles". He understood that younger patients with a higher activity level and higher consequential wear rate were a difficult group.

The McKee and Ring metal-on-metal total hip replacements were developed in parallel with the metal-on-polyethylene hip. Engineering techniques at the time produced metal-bearing surfaces that were too rough, giving rise to excessive frictional torque that led to a perceived superiority of the Charnley metal-on-plastic implant. However, by the late 1970s and early 1980s, osteolysis, associated with cement and polyethylene fragmentation (historically mis-named "cement disease") resulted in aseptic loosening of longer term implants [8]. Younger, more active patients were particularly affected and the introduction of cementless fixation did not help to solve the problem [9, 10].

Aseptic loosening, usually secondary to osteolysis, now attributed to the macrophage response to accumulated polyethylene debris within the joint, remains one of the main causes of failure of major joint arthroplasty. Deep infection and periprosthetic fracture are the other main aetiological factors. Recurrent dislocation of two or more episodes and failure of hip resurfacing secondary to femoral neck fracture or problems related to metal ions are other indications for hip revision. Symptomatic progression of arthritis in the remaining articular portion of a partial knee replacement may indicate the need for revision of a total knee replacement.

D. Williams (✉) · A. Taylor · P. McLardy-Smith
Hip and Knee Arthroplasty Team, Nuffield Orthopaedic Centre, Oxford, OX3 7LD, UK
e-mail: danhwilliams@hotmail.com

Diagnosis

Diagnosis of a failed implant requires the exclusion of other causes of pain especially if the implants appear well fixed. Start-up pain, e.g. when getting out of a chair, or pain when going up or down stairs, are the classic symptoms of a loose component. Patients presenting with pain localised to the buttock may have a loose cup and pain localised to the thigh points towards possible loosening of the stem. Infection seeded at the time of the index procedure may be secondary to delayed wound healing, persistent wound "ooze" or superficial cellulitis requiring antibiotics. "Clicking", "popping" or a sensation of the hip moving in and out of the joint may be described by patients with a history of subluxation. The number of overt hip dislocations and the position of the leg at the time of dislocation aid the planning of revision hip surgery. Instability of a total knee replacement may be symptomatic of coronal or sagittal plane imbalance secondary to poor technique at the primary operation or secondary to catastrophic polyethylene wear. Examination of gait, surgical scar, localised tenderness, active and passive range of motion, limb neurology, limb length (when considering the hip) and coronal/sagittal plane stability (when considering the knee) aids diagnosis, surgical planning and guides the post-revision surgery prognosis.

Radiography of the hip ideally includes an antero-posterior (AP) pelvis, a centred AP and a lateral radiograph of the involved hip of sufficient length. Forty-five-degree Judet views provide assessment of the integrity of the anterior and posterior columns [11] that support acetabular reconstruction. It may sometimes be necessary to image the extent of bone loss with computerised tomographic (CT) imaging. Angiography may occasionally be indicated if there is concern that the iliac vessels may be damaged during implant removal. If the vessels lie between the implant and the bone, then a retroperitoneal approach is favoured. An adequate picture of both the distal extent and the distribution of the femoral cement mantle guides the direction of osteotomes, chisels and other cement removal instruments at the time of revision surgery. A good quality lateral is particularly useful. Plain radiography of the knee should include an AP and lateral view of the involved knee demonstrating the complete prosthesis, including any cement, together with full long leg views if there is significant limb deformity. All films should be scrutinised for evidence of loosening, infection (periosteal reaction), bone loss (which is usually underestimated) or significant deformity. CT or magnetic resonance imaging (MRI) can demonstrate cement that does not contain radio-opaque dye and provide a more accurate picture of bone loss [12].

Definite loosening of cemented components exists if there is evidence of component migration, e.g. subsidence of the femoral stem or fracture of the cement mantle; probable loosening exists if there is evidence of a continuous radiolucent line at the bone–cement interface; and possible loosening if there is evidence of a radiolucent line of 50–99% at the bone–cement interface [13, 14]. Cementless components are unstable if there is evidence of component migration, with subsidence or varus/valgus tilting, or if there is endosteal scalloping around the intramedullary stems; fibrous/stable if there is evidence of reactive lines present in the area of the component's porous coating that are non-progressive and show no evidence of component migration; and osseointegrated if there is an absence of reactive lines in the area of any porous coating or there is presence of spot welds of endosteal new bone contacting the porous surface. For descriptive purposes the acetabular component is divided into three DeLee–Charnley "zones" and the femoral component into seven Gruen "zones" (both numbered from superolateral) on the AP radiograph and seven "zones" on the lateral film [15, 16].

There are many classification systems that describe the extent of bone loss around failing components. The ideal classification system should accurately describe the pattern of bone loss from pre-operative images and point towards the most appropriate reconstruction option. It should be reproducible between observers and between repeated observations and allow comparison of different techniques within the published literature [17]. Taking femoral defects around a failed hip implant as an example, the three most common classification systems in current use are:

1. The AAOS classification (D'Antonio et al.) which is descriptive, but less useful for selecting reconstructive options [18, 19]
2. The Mallory classification, which is more simple to use, but does not address more critical determinants of femoral reconstruction [19]
3. The Paprosky classification, which is based on bypassing the compromised proximal femur and is arguably the most useful (Table 1) [20, 21]

Assessment of inter- and intra-observer reliability using any of these classification systems reveals only mild to moderate agreement and often in clinical practice accurate classification of bone loss is finalised at operation. Furthermore, this limited reliability makes comparison of results from different centres difficult [22].

Treatment

The aims of revision surgery are to extract the failed prosthesis with minimal damage, implant new components to provide long-term stable fixation and manage bone loss by augmenting deficient bone stock. These aims are

Table 1 The Paprosky classification [20, 21]

Type	Description
I	Minimal loss of metaphyseal cancellous bone with an intact diaphysis
II	Extensive loss of metaphyseal cancellous bone with a completely intact diaphysis
IIIA	Metaphysis is severely damaged and non-supportive; a minimum of 4 cm of intact cortical bone is present in the femoral isthmus
IIIB	Metaphysis is severely damaged and non-supportive; less than 4 cm of intact cortical bone present in the femoral isthmus
IV	Extensive metaphyseal and diaphyseal damage in conjunction with a widened femoral canal (ectasia)

achieved by utilising the original incision where possible, debriding abnormal or infected tissue and removing failed implants together with any associated cement. Exposure of the knee may necessitate a 'rectus snip" or quadriceps turndown (the repair of which would not be evident on post-operative radiographs) or a tibial tubercle osteotomy, which would require screw fixation and introduces the possibility of non-union [23]. A bony femoral window or, specific to the hip, an extended trochanteric osteotomy is occasionally required to remove all foreign material [23–25]. The stem of the revision component should bypass any osteotomy by a length equal to two diaphyseal diameters. Osteotomy non-union may compromise the final result. Underlying bone must be cleared of any adherent fibrous membrane before reconstruction can proceed. Reconstruction of deficient bone stock and implantation of new components then proceeds as a single-stage or two-stage procedure (if infection present).

Hip reconstruction

Acetabular reconstruction utilises either a cemented or an uncemented socket. The bony surface is often sclerotic following removal of failed components, cement and interface membrane. A balance must be struck when reaming this sclerotic bone between fully revealing a healthy bleeding surface and conserving bone stock. Cemented revision components generally require bone graft to improve the quality of fixation at the cement–bone interface as all cancellous bone will have mostly been lost. Mesh can be screwed to existing bone to convert a small segmental defect into a cavitatory defect that allows impaction of morcelised bone graft to recreate bone stock. Structural allograft or trabecular metal wedges can be implanted to reconstruct larger defects.

Cemented, all polyethylene acetabular components have reasonable longevity with impaction grafting of small acetabular defects. Larger defects rely on the press fit or "pinch grip" of an uncemented socket supplemented with multiple screws. The most reliable quadrant for screw placement is the weight-bearing zone posterior to the vertical plane (through the anterior superior iliac spine) bisecting the acetabulum. The porous external surface of the cup is coated with hydroxyapatite that encourages bony ongrowth and ingrowth to achieve a long-term biological fixation. More expensive trabecular metal sockets— the outer surface of which resembles the fine microscopic structure of cancellous bone—can be used in cases of very large bone loss (and are covered in more detail later). Initial fixation and long-term biological fixation are thought to be more stable. Good results can also be achieved by cementing a liner into the acetabular shell when the shell remains well fixed. Pelvic discontinuity, where bone loss has progressed to separate the superior and inferior parts of the pelvis, is an uncommon but difficult management problem that may require supplemental plate fixation or acetabular cage support [26, 27].

Femoral reconstruction utilises either a cemented or an uncemented stem. Cement in cement revision of the femur is appropriate where the cause of the revision is not on the femoral side and the cement—bone interface remains pristine. Bonding of the new cement to the old mantle is good and allows implantation of a smaller sized cemented stem. Specific cemented revision stems have recently come to market for this purpose and the technique has good reported medium-term results [28–30]. When the old cement mantle has failed and requires removal, cemented revision, without supplemental graft, has produced disappointing long-term results: the shear strength of the new cement–bone interface is up to 80% weaker than in primary THR [31]. Revision with impaction of morcelised bone graft is required to improve the quality of the new cement–bone interface and has, in some hands, good proven 10-year results [32–34]. Femoral cortical deficiencies require either reconstruction or must be bypassed by a stem that relies on distal fixation. Where possible, wire is carefully tensioned around a "tube" of mesh to reconstruct the proximal femur, thus again converting a segmental into a cavitatory defect. This allows impaction of autogenous or allogenic morcelised bone graft to augment bone stock. This approach fills very wide or unusually shaped proximal femora, but often requires large amounts of allogenic bone graft. There are reported high rates of implant subsidence (possibly related to inadequate density of initial graft packing) and high rates of peri-prosthetic fracture, which have not been fully resolved by the use of longer stems [35].

Reconstruction with a large proximal femoral allograft can be used successfully [36], but integration of a large piece of allogenic bone can be unreliable, donated bone is expensive and supply is limited. If reconstruction of the proximal femur is not possible the defect can be bypassed by an uncemented femoral component that relies on distal fixation [37]. Titanium uncemented stems have a modulus of elasticity or stiffness that is most similar to bone and are considered "bone friendly". Design requires either metaphyseal or diaphyseal fixation, which relies either on directly filling the femoral canal (requiring precise reaming) or on a three-point fixation within the femoral canal. There is a significant risk of cortical perforation or femoral fracture while reaming the deficient cortex. Implantation of uncemented implants is often quicker and more straightforward than impaction grafting and modular stems can ensure the correct stable placement of the femoral head. The modular nature of some stems, however, introduces another mechanical interface, which can potentially fail.

In the presence of massive bone loss a large proximal femoral replacing prosthesis can be used [38, 39]. These "megaprostheses", or tumour prostheses, are more suitable in elderly sedentary patients. Abductor mechanism failure and a high rate of dislocation are the main disadvantages.

Knee reconstruction

The choice of implant is dictated by the extent of bone and soft tissue destruction following the removal of failed implants. There is a spectrum of implants available from posterior cruciate ligament (PCL) sparing resurfacing implants to "mega-", tumour- or bone-replacing prostheses.

The level of built-in constraint required in revision knee prostheses depends upon whether the posterior cruciate and collateral ligaments are preserved. PCL sparing/preserving resurfacing components can be used if removal of failed implants results in a knee that compares favourably to a primary TKR with intact ligaments. If the PCL is compromised or there is a fixed coronal plane or flexion deformity the PCL is substituted by a cam and post, the design of which controls sagittal plane kinematics. This subtly changes the projected shadow of the femoral implant on the AP radiograph. The height and width of the post on the polyethylene insert can be increased to provide increased varus/valgus stability. If the collateral ligaments are compromised a hinged prosthesis is chosen to further improve coronal plane stability. Inevitably, this puts greater strain upon the hinge itself and produces increased shear stress at the implant interface with the bone. A rotating hinge allows movement in the axial plane between the polyethylene and the tibial surface, decreasing these stresses, but producing a secondary surface for the generation of wear debris. Modular femoral and tibial stems are added to the resurfacing implants in this scenario to increase the area of fixation, spreading load and decreasing stresses at the implant–bone interface.

Femoral or tibial stems of varying lengths may also be added if there are significant uncontained bone defects. Generally, a contained bony defect with an intact cortical rim or an uncontained defect of less than 5 mm can be filled with cement upon implantation. Contained defects greater than 5 mm with an intact cortical rim can be treated with morcelised impaction grafting in a similar manner to the hip. Uncontained defects require shaping to accommodate metal wedges that are added to the implant. Larger defects may require bulk allograft. The addition of a femoral or tibial stem provides additional stability and protects supplemented defects, minimising the risk of long-term implant subsidence [40].

Distal femoral or proximal tibial replacing hinged "megaprostheses" are utilised if there is massive bone loss and these function well in low-demand patients.

The future

Incremental improvements in implant engineering, design and material science continue to promise improvements in the fixation of implants to bone, which will hopefully lead to improvements in the longevity of both primary and revision implants. For example, new porous "bone friendly" titanium (Ti) and tantalum (Ta) implants were introduced in the late 1990s. Tantalum is a very hard, dense, ductile, easily fabricated transition metal with a good biocompatibility and safety record. Vapour deposition of commercially pure elemental tantalum onto a polymer foam skeleton creates a trabecular metallic (TM) configuration of high porosity with physical and mechanical properties similar to bone, i.e. a low stiffness (3 GPa), but a yield and ultimate strength that are ten times greater than those of subchondral bone [41–44]. Early clinical and radiological results are encouraging [41, 45–48], but time will tell if the additional cost of these new materials leads to sufficient additional clinical benefit.

The debate regarding the optimal bearing surface also continues to evolve. Pathological processes that disrupt the implant–bone interface are minimised by reducing wear of the bearing surface or moving parts. As previously discussed, osteolysis was noted to be a significant problem in the late 1970s and early 1980s in longer term implants. Attention has thus, over the last decade or so, turned to so-called hard-on-hard bearing surfaces. A proportion of the original McKee and Ring metal-on-metal cobalt chrome hips were found to be long-lasting and retained their mirror-like articulating finish [49]. These successful implants had achieved an exacting, highly polar bearing geometry at

manufacture that can now, with modern engineering techniques, be consistently reproduced. Similar tolerances can also nowadays be achieved with ceramic-on-ceramic implants. In vitro wear tests reveal 10 to 100 times lower rates than traditional polyethylene and medium term results are promising [50–58]. There are, however, potential down sides: a 2% risk of "squeaking" and a small but serious risk of implant fracture with the ceramic hip; plus, a small but serious risk of problems related to high metal ions with the metal-on-metal hip that has only recently revealed itself [59–62].

These concerns, taken together with the improved wear characteristics of new "ultra-highly crosslinked" polyethylene and new vitamin-impregnated polyethylenes, have led to the pendulum swinging back in favour of an improved traditional metal-on-polyethylene bearing surface. Improved polyethylene may also allow larger bearing surface diameters to be employed, resulting in greater stability than that afforded by Charnley's original small-diameter, low-friction arthroplasty. As ever though, the long-term clinical and radiological results of these new materials are eagerly awaited.

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