Innovations in Total Hip Replacement for Young Adult Hip Disease

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Edward M. Vasarhelyi and Steven J. MacDonald

Background

There have been significant advancements in recent years in the management of hip disease in young adults through the development of joint preserving surgery, however there still remains a key role for arthroplasty in the symptomatic management of these patients. There are challenges in the use of hip arthroplasty for young active adults with respect to balancing the demands that a young individual places on the arthroplasty given an often active lifestyle with the survival of the implant. With our current techniques and technologies, there is yet an implant that will definitively last the lifetime in a patient. There have been many innovations in implant design, bearing surfaces and techniques such as resurfacing that are currently employed in an effort to maximize patient function while theoretically extending the survivorship of the implant.

This chapter will focus on the implant options and their respective results in young adult patients. The definition of a young adult varies in the literatures as it pertains to total hip arthroplasty. The most inclusive definition is those adults undergoing surgery under the age of 60 years. This is a somewhat arbitrary watershed area in which an arthroplasty in patients younger than this age will more likely require future revision arthroplasty for aseptic causes of failure in comparison to those older than 60 years [1]. The reasons for this are felt to be the added demand that more active younger individuals place on their implants which leads to greater rates of wear and loosening [2–4] in addition to their predicted longer life expectancy.

Osteoarthritis is the most common cause of hip pathology in patients over 60 undergoing total hip arthroplasty, however the pathology in younger adults is caused by differing etiologies [5]. Hip dysplasia has been reported to account for approximately one-quarter to one-third of THA in adults younger than 40 years in the Norwegian registry, making it the most common etiology in young adults [6]. The next most common diagnosis was rheumatoid arthritis, followed by sequelae of Perthes disease and slipped capital femoral epiphysis, idiopathic osteoarthritis, post traumatic and then ankylosing spondylitis [1, 6].

Not only are the absolute numbers of total hip arthroplasties increasing each year in a trend that is expected to continue, but the proportion of total hip arthroplasty in young patients relative to the total number is projected to increase significantly over the coming decades. By some estimations, more than 50 % of primary total hip arthroplasties will be performed in patients younger than 65 years old by 2030 [7]. The fastest growing segment within this group is projected to be those in the category of 45–54 years of age, growing by a factor of nearly 6 [7].

Conventional THA

Over the past decade there have been numerous areas of innovation towards improving the function and survivorship of hip arthroplasty implants. These can broadly be divided into alternative bearing surfaces, arthroplasty coatings, stem designs and fixation technique. Prior to examining the results of more recent technologies for total hip arthroplasty, the results of conventional total hip arthroplasty in young adults should be examined [1]. There are numerous studies that report on cemented, uncemented and hybrid arthroplasty in very young adults. One of the challenges when examining the results of total hip arthroplasty in young adults is that many of the longer-term follow up studies in the literature used previous generation uncemented implants that had poor survivorship.

Dorr et al. [8] reviewed cemented total hip arthroplasty in very young adults divided into those under 30 and those over 30 years old at the time of their first arthroplasty. At 16 years,

E.M. Vasarhelyi, MD, MSc, FRCSC • S.J. MacDonald, MD, FRCSC (✉)
Division of Orthopaedic Surgery, London Health Sciences Centre, Western University, University Hospital,
339 Windermere Road, London, ON N6A 5A5, Canada
e-mail: steven.macdonald@lhsc.on.ca

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those younger than 30 years had a revision rate of 82 % for aseptic causes, while those over 30 had a revision rate of 56 %. Most failures were on the acetabular side. These results are similar to those reported by other authors who report on high rates of revision for aseptic loosening in very young adults. In a comprehensive review of the literature De Kam et al. [9] reported on the outcomes of total hip arthroplasty in young adults. Examining the 2007 annual report of the Swedish National Hip Arthroplasty Register they found that there was less than 90 % survivorship in patients under 50 years old at 10 years for both cemented and uncemented total hip arthroplasties. At 16 years there is 74.7 and 72.5 % survivorship of cemented total hip arthroplasties in males and females respectively. In contrast, there is 57.4 and 54.3 % survivorship in the same groups with uncemented total hip arthroplasties. These results must be interpreted with the caveat that specific implants are not reported; first generation uncemented implants are no longer in use and most second and third generation implants have much shorter reported follow up, and that there is a strong bias towards cemented implants in the registry.

Uncemented arthroplasty in young patients, which is performed in more than 90 % of cases in North America have comparable results [9]. None of the current literature satisfy the NICE criteria of 90 % survivorship at 10 years [10]. One of the most comprehensive looks at uncemented reconstructions was that of McAuley et al. [11]. In their series of 561 hip replacements over 15 years with all-cause revision as an endpoint found a survivorship of 60 % in patients under 50 years old. In the very young patients (those under 40 years old at time of primary arthroplasty), the 15-year survivorship was 54 %.

When considering the components of the reconstruction in isolation, there is a large volume of research in the literature examining cemented versus uncemented fixation for acetabular components. There is support in these works for both forms of fixation. In comparison to previous generation cementless implants, there is superior survivorship with cemented implants [12]. More recent designs however are suggestive of superior results with uncemented components [13]. Uncemented components in particular trend towards improved osteolysis and acetabular migration. That said, in a comprehensive review of the literature, Pakvis et al. [12] found that when only examining randomized controlled trials comparing cemented and uncemented fixation there were no statistically significant differences between groups with respect to osteolysis, migration and cup survival. All of these results however were based on short- to medium-term follow up. It is in non-RCT trials that the literature supports improved results for the uncemented components [14–17].

When specifically examining acetabular components in young patients there are some studies suggestive of superior results with uncemented acetabular components. Based on the results from the Finnish arthroplasty register, Eskelinen et al. [18] found that in patients younger than 55 years old, there were some clear differences between cemented and uncemented acetabular components. When considering revision for aseptic loosening, there was a three-fold increase in revision for cemented cups. If endpoint is defined as all-cause revision the two groups were nearly equal with a 10-year survivorship of 94–93 % for cemented and uncemented respectively. The most common of the uncemented revisions were for liner exchange. Current press-fit acetabular components appear to be resistant to loosening, however continue to have failures as a result of polyethylene wear and failure of the locking mechanisms between the liner and shell [19]. These results show that although the revision rate is not insignificant, for most people a liner exchange would be far preferable to an acetabular revision for aseptic loosening.

The femoral components in young adults are a more reliable component of the reconstruction. There is are very good reported results in the literature for both modes of fixation in young adults. Kim et al. [20] in their study of 219 patients randomized to either uncemented or cemented femoral components showed 96 and 97 % 20-year survivorship respectively, in patients younger than 50 years old. Numerous studies in the literature point to similar success rates with femoral aseptic revision at long-term follow-up for both methods of fixation [19, 21–24].

Overall, when considering conventional total hip arthroplasty in young patients, the short- and medium-term data show very good survivorship and clinical outcomes. There are, generally speaking, excellent outcomes with conventional femoral components. Unfortunately applicable long-term data in patients with uncemented acetabular components is somewhat more sparse, but point to high rates of revision once in the second decade of implant use. This is especially true of the very young patients. Some caution however must be taken when interpreting these numbers, given that they represent outcomes with older generation implants. There is a marked difference in outcomes between older and young patients, which has driven many of the attempts at innovating the reconstruction and dictates resource allocation when using alternative bearing surfaces and implants that often have significant cost increases over conventional implants [25]. The remainder of the chapter will focus on recent innovations in total hip arthroplasty, unfortunately however, very little in the literature at this point can actually answer the question as to whether the implant changes improve long term survivorship and function of the hip reconstruction.

Stem Design

Even though the primary mode of failure is on the acetabular side, femoral survivorship is not 100 %. Particularly for young patients, there continues to be efforts directed at bone preservation through techniques such as hip resurfacing and short femoral stems. The short stems are also often advocated to be used with alternative approaches to the hip such as the anterior approach, which typically presents challenges in accessing the femur [26]. There is no evidence to suggest that these stems reduce intraoperative complication of fracture [27]. Theoretically the shorter stems may reduce stress-shielding through loading the proximal femur and avoid the potential challenges of a metaphyseal-diaphyseal mismatch [28], although again there is no definitive evidence for this or clinical correlation to outcome improvements.

Implant Coatings

The use of coatings on implants have been purported to improve bony ingrowth, and by extension, improve survivorship of implants. The evidence in the literature is somewhat sparse in this regard, in part owing to the relatively short timeline since the introduction of coatings such as hydroxyapatite. Hydroxyapatite has been extensively used in modern uncemented implants, however a volume of recent literature does not show superiority to hydroxyapatite coated stems in comparison to uncoated stems at 10 year follow up. Lazarinis et al. [29] compared Bi-Metric (Biomet) hydroxyapatite and uncoated stems from the Swedish registry. They found no differences in 10-year survival with either implant. Both had a 98 % survivorship. These trends have been also reported in two meta-analyses that did not find any differences in revision rates in coated or uncoated uncemented femoral stems [30, 31].

There are several authors that have found inferior results of hydroxapatite coating compared to uncoated porous implants, especially for acetabular components in young patients [32]. Lazarinis et al. [33] found that patients, particularly those under 50 years old with hydroxyapatite coated acetabular cups had a higher risk of failure caused by aseptic loosening. Implant survival is predicated on minimizing osteolysis, cup loosening and polyethylene liner wear [33]. It has been postulated that the wear particles from the hydroxyapatite coating facilitates the wear rates [34, 35].

Tantalum implants are another of the more contemporary hip implants currently in use. There is no long-term data on the survivorship beyond the first decade [36]. There are numerous properties of this metal theoretically making it an ideal component to use. Tantalum has high porosity, low modulus of elasticity and high frictional coefficient making it conducive to achieve bony ingrowth and have a favourable load-share profile [37]. It also has a monoblock acetabular design with the polyethylene liner. It is more commonly used in revision arthroplasty, but there is a growing body of evidence in support of its use in the setting of primary total hip arthroplasty as well. To date, the series do not focus on young patients specifically, but have survivorship reported as high as 100 % at 10 years [38]. Mid-term results as well show no cases of revision for aseptic loosening in primary total hips [36, 37, 39, 40]. Tantalum has many tribological properties that make the implant appealing to use. There is however no convincing evidence in the literature to adopt its widespread use in young patients at this time, particularly in the context of the significant cost increases over conventional implants.

Bearing Surfaces

A great deal of research has gone into developing bearing surfaces for total hip arthroplasty. The initial bearing couple introduced by Sir John Charnley was a Teflon coated acetabulum that had poor results caused by early loosening. Over the next several years he developed an articulation couple of ultra high molecular weight polyethylene acetabular articulation with a 22 mm stainless steel femoral head [41]. This formed the basis of today's conventional total hip replacement. Today this combination is satisfactory for older adults, but given the rates of osteolysis and wear debris that is seen with longer-term follow up in younger patients work has been done on improving the wear characteristics and longevity of polyethylene [42].

Polyethylene in recent history has been modified through changes in sterilization technique, storage and degree of cross-linking [25, 43, 44]. Over the past 20 years, various permutations of handling polyethylene were trialed and lessons were learnt that have resulted in current techniques. Sterilization was initially carried out with gamma irradiation in air, however this resulted in entrapped free radicals that during exposure to air during both storage and in vivo resulted in oxidation of the polyethylene. The effect of this was decreased fatigue strength, toughness and wear resistance [44]. Sterilization is currently performed in either a vacuum or nitrogen gas to minimize free radical production. Modern irradiation techniques are used to cause cross-linking of polyethylene. This creates cross-linking, which improves wear characteristics but must be balanced against free radical production. The amount of radiation varies among manufacturers, generally most irradiate between 5 and 10 Mrads as it has been shown that there is no significant improvements in wear rate with doses greater than 10 Mrads [45]. Alternatively, polyethylene can be sterilized without radiation using gas plasma or ethylene oxide which serves to minimize free radicals, but does not confer the wear resistance achieved with highly cross-linked polyethylene [46]. In addition to reducing the amount of irradiation, the production of free radicals are reduced through annealing or melting following radiation. Annealing preserves the mechanical properties of irradiated polyethylene, but does not control free radical production as well as melting which eliminates free radicals but causes a conversion of polyethylene to its amorphous form from it crystalline form [47].

To address these material issues, techniques such as repeated irradiation, consisting of a series of three low-dose radiation with intervening annealing to achieve more extensive cross-linking and eliminate free radial production. This has been demonstrated in laboratory studies to improve wear resistance over both conventional as well as first-generation highly cross-linked poly [48]. Unfortunately, these implants, although used extensively in young adults, do not have any medium or long-term clinical studies showing their effectiveness. These results are inferred from laboratory wear data. The last of the common areas to improve polyethylene is the use of Vitamin E to reduce free radical production. In addition to the free radical reduction, simulator testing has found this to confer additional fatigue resistance for the polyethylene [49]. There are no clinical studies reporting on this technique however.

The current literature on highly cross-linked polyethylene suggests that there are short-term advantages with respect to wear in comparison to traditional polyethylene, however no long-term studies have been conducted yet to confirm whether these translate into long-term benefits [36]. As has been shown with other technologies, in vitro modeling and wear, do not necessarily translate into clinically significant in vivo benefits. That being said, highly cross-linked polyethylene has now been in widespread clinical use globally for over a decade and very clearly there is a significant reduction of wear. At 10 years, on plain radiographs, polyethylene wear and osteolysis can not be seen, which is a significant change from previous generations of polyethylene at the same clinical followup interval.

Ceramic-on-polyethylene has been proposed as a bearing couple to reduce polyethylene wear over metal-on-polyethylene owing to the decreased surface roughness in comparison to metal. Original ceramic heads were made of zirconia but have since been recalled as a result of very high early failure rates attributable to its thermal instability that made it susceptible to phase transformation and subsequent cracking which resulted in third body wear [50]. Second and third generation ceramics that are a composite of zirconia and alumina have a lower propensity to fracture and in laboratory studies as well as mid-term clinical studies show favourable results. The potential advantages over a metal-on-polyethylene articulation are its hardness, scratch resistance, lower coefficient of friction, improved lubrication and superior wear resistance [51, 52]. Alumina ceramic heads on cross-linked polyethylene have been shown to have a 50 % lower wear rate in in-vitro studies [53] and small mid-term studies have reported survivorship of 95 % at 10 years [54]. In a prospective randomized comparison of ceramic-on-polyethylene with ceramic-on-ceramic mid-term results showed increased wear in the ceramic-on-polyethylene group, but no clinical differences between the groups [55].

The hard bearing surfaces consist of metal-on-metal, ceramic-on-ceramic and more recently, ceramic-on-metal. Each has their respective relative advantages and disadvantages, both realized and theoretical. Metal-on-metal bearing surfaces have the longest history of alternative bearing surfaces. There were several design attempts early in the development of total hip arthroplasty that were abandoned secondary to manufacturing shortcomings. It wasn't until the late 1980s that the second generation metal-on-metal bearings attained widespread use.

Metal-on-metal implants are an appealing bearing couple in young adults from several standpoints. The ability to use a large head diameter is a potentially significant advantage of this bearing couple. Large femoral heads increases stability, range of motion, and decreases impingement and rates of dislocation [56, 57]. There is evidence indicating that larger head diameters reduce already low volumetric wear in total hips through fluid film lubrication and the ability to self-polish which minimizes particle debris [58, 59].

Metal-on-metal bearings however have recently begun to fall out of favour with many surgeons for several reasons – recalled implants, local soft tissue reactions, hypersensitivities and concerns regarding effects of metal ions. While the volumetric wear is very low, the number of particles owing to their small size is greater than those seen in metal-on-polyethylene total hips. It is speculated that wear is increased in hips with less than optimal acetabular orientation, namely in cups that are aligned with too much inclination, and to a lesser extent, anteversion [60]. It has been demonstrated that hips with acetabular cup inclination greater than 50° are associated with increased blood ion levels [61, 62]. There have been reports of pseudotumour and aseptic lymphocytic vasculitis associated lesions (ALVAL) associated with metal-on-metal bearings. The etiology of this is unclear at this time. There have been theories such as a Type IV delayed hypersensitivity reaction, however these have not been reliably demonstrated [63, 64]. The true incidence of pseudotumour has not been accurately documented, however, it is estimated to be as high as 1 % incidence within 5 years [64].

Ceramic bearing surfaces, as previously outlined, have many properties that make them desirable implants to use. They should have prolonged longevity as a bearing owing to their inertness, low roughness, lubrication, low friction, high wetability and high wear resistance [65, 66]. These make it a preferred bearing surface in young patients, including women of child-bearing years, in whom concerns regarding metal ion level preclude its use.

There are however some concerns with ceramic bearings. The risk of fracture, although improved, is still estimated to be around 1 in 5,000 [67]. This is true of both the acetabular liner, which can sustain rim chipping on insertion, and the ball. There is conflicting information in the literature regarding revision of fractured ceramic components. Fractures result in intra-articular ceramic fragments as well as damage to the trunion placing the revision head at increased risk of re-fracture [67, 68]. For these reasons, revision following ceramic fracture is a challenge. Some authors recommend a thorough irrigation and debridement followed by conversion to a metal-on-polyethylene articulation, while authors advocate the use of another ceramic-on-ceramic bearing to minimize the chance of accelerated polyethylene wear from microscopic ceramic debris.

The properties of a ceramic-on-ceramic articulation limit options that are available with other bearing coupling. There are no offset options for the liner and given the brittleness of ceramic, thicker liners are required, resulting in a smaller head size. Stripe wear is another consideration which can result from either impingement or edge-loading [69]. The incidence of a squeaking ceramic-on-ceramic hip has been reported to range from 0.5 to 7 % [45]. There are numerous theories regarding the source of squeaking, but no clearly accepted explanation. Some series have shown it to be more common in younger, heavier and taller patients [45]. Although some authors have linked squeaking with component malpositioning, others have shown there to be no relationship between positioning and the incidence of squeaking [70, 71]. A squeaking hip should be monitored, but when otherwise asymptomatic, does not warrant revision surgery.

Hip Resurfacing

Hip resurfacing arthroplasty is a technique that has been used historically, abandoned and reintroduced in the past decade. It is advocated to be a procedure for younger patients requiring a hip arthroplasty in whom it is desirable to preserve bone stock in anticipation of possible revision surgery in the future. It is indicated in young, generally male, patients with hip osteoarthritis. Careful patient selection is important in achieving satisfactory results; the lowest risk of failure is in those patients who are male less than 55 years old with no proximal femoral deformity and of normal weight [72, 73]. The Australian Registry indicates higher mid-term revision rates in cups less than 50 mm and patients older than 65 years old [74]. Failures in this category are likely related to poor bone quality, reduced coverage arc and possible increased metal hypersensitivity [75]. Given the femoral fixation, resurfacing arthroplasty is generally contraindicated in pathology that causes proximal femoral deformity or affecting bone stock. Such examples include avascular necrosis, prior fracture, proximal femoral hardware, large bone cysts, prior slipped capital femoral epiphysis and Legg-Calve-Perthes disease [76–78]. Hip resurfacing arthroplasty is more technically demanding than total hip arthroplasty and may benefit from computer assisted or individualized templating techniques [79, 80].

Clinical outcomes in prospective, randomized trials showed no differences between resurfacing arthroplasty and large head total hip arthroplasty in young adults [81, 82]. The Australian registry data indicates a higher mid-term revision rate in resurfacing arthroplasty of 7.2 % in comparison to 5.4 % for total hip arthroplasty at 9 years [74]. Early failures are most commonly femoral neck fracture [83]. A meta-analysis has also shown higher early rates of failure of 2.6 % at 3.9 years in comparison to 1.3 % of cementless total hip arthroplasty [84]. Similar to total hip arthroplasty, acetabular alignment, and inclination in particular, has been shown to be an important predictor of implant function. As inclination, or abduction angle, is increased to greater than 50–55° there is a significant correlation to increased circulating cobalt and chromium serum levels. It is speculated that this is owing to the greater risk of edge loading [85].

At the present time there are no long-term studies comparing hip resurfacing arthroplasty to total hip arthroplasty in young patients. Registry data indicates a higher reoperation rate in those patients with a resurfacing arthroplasty at mid-term results. There are no clear differences with respect to post-operative function and patient satisfaction in appropriately matched groups. That said, in some young, male patients, resurfacing arthroplasty can be a viable option provided the patient and surgeon have a clear understanding of the differences of the implants and that measures are taken to ensure accurate component placement as resurfacing arthroplasty appears to be more sensitive to malalignment than total hip arthroplasty.

Summary

Total hip arthroplasty is being performed with increasing frequency in all age groups, especially young adults in particular. These are challenging patients as there is generally higher expectation about the level of functioning of the arthroplasty. There is also a differing distribution of etiology necessitating the arthroplasty. These factors in combination place significant demands on the implant. Although total hip arthroplasty is one of the most successful surgeries that is performed across all disciplines, the results in young adults demonstrate some shortcomings with the procedure still. There are many innovations that are brought to market on relatively short lifecycles that make long-term conclusions regarding survivorship challenging. Those studies that do provide long-term data have the caveat that the reported implants are often no longer available for use as primary implants. This creates challenges for the surgeon, and in some instances the patient, to decide on the most appropriate implant for a given patient. Based on the current evidence in the literature, there is no definitive answer regarding the best implant to use. Ultimately, the surgeon must decide based on familiarity and comfort with a given implant and technique in combination with a detailed discussion of the pros and cons with the patient regarding implant types, in particular bearing surfaces. Caution must be exercised when interpreting industry marketing and laboratory data. Although it can be suggestive of improved wear and implant survivorship, with the current state of technology, the differences in implants are often subtle, and would require large, long-term survivorship studies to establish advantages of an implant over another, which is not currently available in today's literature.

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