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Acetabular Cup Positioning during Total Hip Replacement in Osteoarthritis Secondary to Developmental Dysplasia of the Hip – a Review of the Literature

Umístění acetabulární komponenty totální náhrady kyčelního kloubu u sekundární osteoartrózy po vývojové dysplazii kyčle – přehled literatury

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SUMMARY

Various surgical treatments for osteoarthritis (OA) secondary to hip dysplasia have been reported in the literature. According to the position of the arthroplasty cup, generally they could be divided into two groups: the primary rotational center (PRC) group and the high hip center (HHC) group. Some surgeons prefer the HHC technique. Without doubt it is less demanding, but several concerns exist against the long-term stability. When restoring the PRC, since the dysplastic acetabulum is usually shallower and underdeveloped, bone grafts or other biosynthetic materials are usually needed for the ideal fixation. The source of grafts is quite wide. For example, they could be autologous (femoral head, iliac crest) or homologous (allografts), bulky or morselized. Medial wall protrusion technique, as well as other materials like oblong cup, porous titanium and tantalum augments, 3D printed implants could also be an option. Except these, reports are also divided into cemented and cementless techniques. Therefore, no technique is perfect and clinical results so far are quite variable. We think it's necessary to compare the pros and cons between each other.

Key words: hip dysplasia, total hip replacement, cup position, secondary osteoarthritis.

INTRODUCTION

Epidemiology

Developmental dysplasia of the hip (DDH) is one of the most common causes of secondary osteoarthritis (OA) in early adulthood. In some European regions the prevalence is rather high, around 0.5% among newborns and it occurs six times more in females than in males. According to national registration data, total hip replacement (THR) for secondary hip OA due to DDH is 1.8% in Sweden, 9.0% in Norway and 8.9% in Hungary among all THR (26).

Pathoanatomy

Generally, the acetabulum of DDH is shallow and has an increased acetabular angle. The femoral head is partially or fully uncovered, the rotational center is displaced laterally and cranially. The proximal part of the femur is usually with increased antetorsion. The ideal body weight pressure transferred from the acetabulum to the femoral head and neck is diminished, patients could present with coxa valga. The deformity also leads to shortened length of gluteal muscles, consequent weakness of the abduction, the iliopsoas and adductor muscles are tense, altogether eventually causes Trendelenburg type limping.

Biomechanics

Depending on the severity of the disease (dysplasia, subluxation, dislocation), DDH could differ in a wide spectrum. On one hand, the femoral head deformity and the shallow acetabulum forms a decreased articular contact area and produces an increased pressure on the joint cartilage, gradually causing early onset osteoarthritic changes. On the other hand, according to Pauwels' theory, the lateral femoral head shift or shortened femoral neck length could change the lever arm of the abductor muscle force, which finally leads to adverse effect on the hip load and the force R will be more vertical (Fig. 1a) (34).

However, Pauwels didn't take cranial shift into consideration. By graphical and mathematical studies Erceg (13) declared that both lateral and cranial shift of the femoral head contributes to the increase of force R (Fig. 1b). Therefore, in accordance with the pathophysiological process of hip dysplasia, restoration is important by placing the cup as close as possible to the primary rotational center during THR.

Classifications

Several classifications of hip dysplasia have been presented during the last decades by different authors

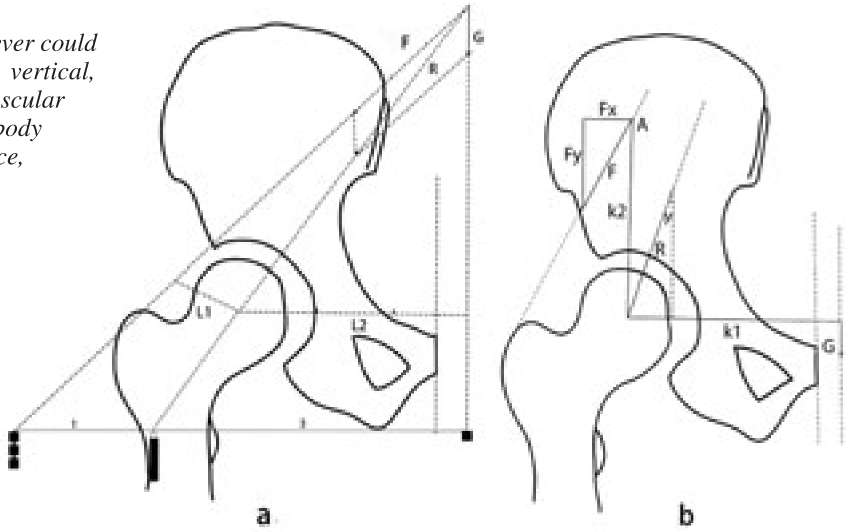


Fig. 1a. Pauwels' theory, shortening of L1 lever could cause total hip load R increase and more vertical, R the resultant compressive force, F the muscular force, G body weight, L2 the lever arm of body weight, L1 the lever arm of the muscular force, L2=3×L1.
Fig. 1b. Marinko's theory, total hip load R=G×k1/k2×sin γ, the shorter lever k2 (cranial shift) the larger hip load, γ force R inclination (16º), R the resultant compressive force, F the muscular force, G body weight, A the proximal attachment of pelvitrochanteric musculature, k1 the lever arm of body weight, k2 vertical lever the force of abductors is conveyed.

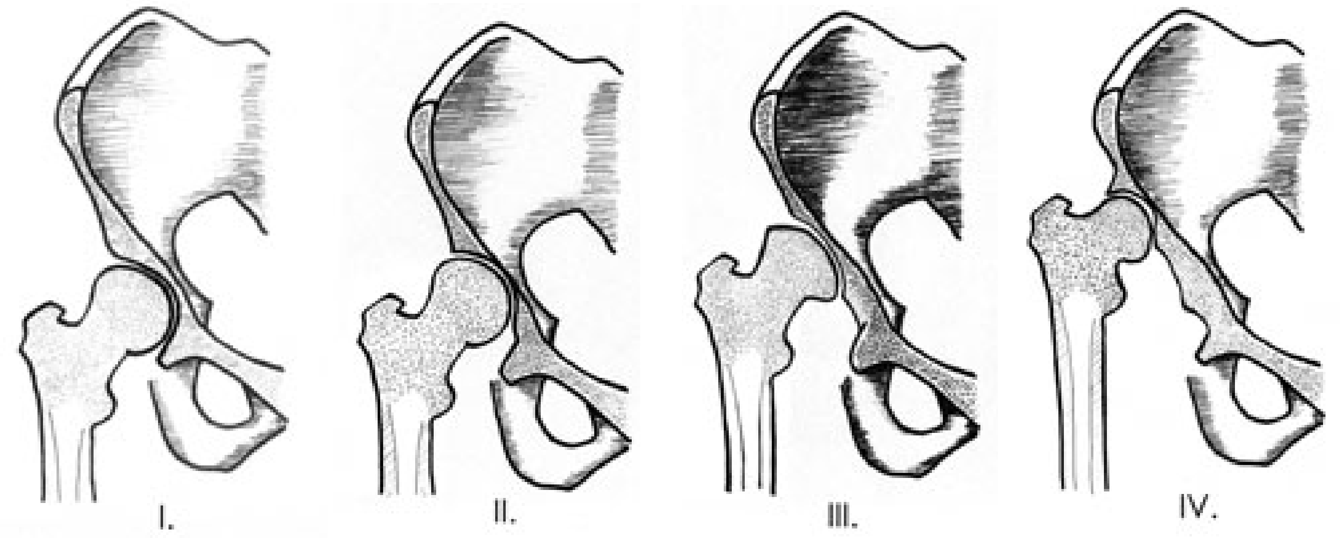


Fig. 2. Crowe's classification I <50% subluxation, II 50%-75% subluxation, III 75%-100% subluxation, IV >100% subluxation.

(Crowe (7), Hartofilakidis (17), Eftekhar (12), Mendes (27), Kerboul (25)) focusing on the severity of the acetabular deformity.

Among them Crowe's (Fig. 2) and Hartofilakidis' classifications (Fig. 3) showed the best inter- and intraobserver reliability and have been widely used. However, classification only by using a-p radiographs may not provide enough information for surgeons to plan the operation. As the severity of the deformity varies in a wide range, the classifications are not able to determine the size of the uncovered part of the femoral head accurately for every case. For precise surgical planning, further X-ray and CT scans are necessary for the most difficult cases. CT-based 3D printing could also be a useful tool.

Cup placement options

Bone coverage of the acetabular cup is one of the most important factors during the surgery of OA secondary to DDH. Most authors suggest that host bone coverage should be at least 70% to provide sufficient primary stability, otherwise bone grafting is needed (24). Also, we should keep in mind that nowadays cup loosening is the most frequent cause of revision, even for cases without hip dysplasia. A few decades ago an alternative technique was in use: cement augmentation of the acetabular roof reinforced with previously inserted screws (41). Since we know that this technique is foredoomed to failure, it is no more an ideal choice. During THR in case of secondary OA caused by DDH, a well-positioned acetabular cup determines the long-term results after the operation. We should be aware that when applying acetabular grafting, surgeons are divided into two groups: those using cemented cup and those using mainly uncemented one. Generally, according to the cup positioning they can also be divided into two groups: placing the cup into the PRC or out of it. The second group includes HHC, protrusion socket technique and other different techniques. In this paper, we aim to present all in detail.

MATERIAL AND METHODS

We collected the main options proposed by the literature. Interpretation of the data is difficult, and con-

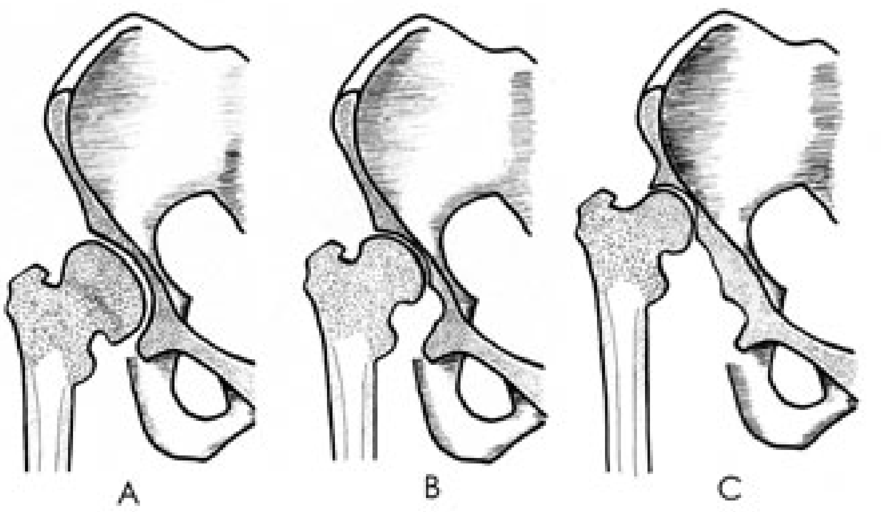


Fig. 3. Hartofilakidis classification
A dysplasia;
B low dislocation;
C high dislocation.

The primary rotational center of the hip joint can be calculated with mathematical and geometrical methods, so the positioning of the cup can be well planned preoperatively. Even for complicated Crowe III–IV type of dysplasia, PRC is still considered by most authors as the best cup position because both the HHC and lateral cup placement (LCP) techniques have higher complication rate.

clusion should be drawn with caution as most studies included different types of dysplasia, different surgical techniques and evaluation systems, different length of follow-up time and so on.

According to the Cochrane handbook of systematic review, we went through the database of PubMed and EMBASE from January 1973 to December 2016. All studies related with total hip arthroplasty for dysplasia published in English were identified through electronic and manual search. The following keywords were used for searching: total hip arthroplasty, THA, total hip replacement, hip prosthesis, hip dysplasia. Articles without detailed surgical technique or follow-up data, review studies, animal research and case reports were excluded. During the search 312 publications were identified, all of them are clinical studies. Studies included from 18 to 128 patients with mean follow-up from 1 to 20 years. According to the journal's requirements, we were limited not to go beyond the 50 most relevant publications. We divided all studies into variant groups according to the acetabular cup position, as well as the surgical techniques as follows:

1 PLACING THE CUP INTO THE PRIMARY ROTATIONAL CENTER (PRC)

Numerous arguments exist in favour of placing the cup into the PRC. The advantages of the technique include: (a) The rotational axis of the two hips will be parallel to the ground, the gait will be more harmonic and the load on the lumbar spine will decrease (if only one side is affected or in bilateral cases after the operation of both sides). (b) The Trendelenburg limping may disappear by increasing the tension of the gluteus medius and minimus. (c) Primary acetabulum often has the largest bone mass in the pelvis towards certain directions, which could provide more bone stock for the cup in dysplastic hips.

However, the main characteristic of DDH is the relative lack of bone on the superolateral aspect of the acetabulum. To be able to place the cup into the PRC, it may have certain difficulties and complications, and for many cases bone grafting technique should be applied.

Acetabular roof reconstruction is generally suggested when the uncovered part of acetabular cup exceeds 20%. Schuller (37) showed that the lateral part of the acetabular roof is important for load transfer. A loaded bone graft in this location could reduce stress on the cement-bone interface. However, for cementless cups the advised amount of coverage of the socket by the graft has not reached agreement so far, the safe percentage ranges from 30% to 50% for some authors (22, 38).

1.1 Autologous femoral head bone graft

Merle d'Aubigné (28) firstly reported acetabular roof reconstruction for dysplastic hip joints using a Judet prosthesis and massive autologous bone grafts in 1952. Later this technique was improved in both primary and revision THA and was described as the golden standard to achieve superolateral bone coverage. The advantage of the technique is placing the cup into the PRC and the autologous bulk bone graft could provide extra bone stock during a further revision surgery. But it must be stated that since Harris' method (36) (Fig. 4) the bone grafting technique has changed a lot and in fact based on its modifications there is a relatively wide range of surgical manners for reconstruction of the acetabular roof.

The results of using bulk bone autograft in cemented and cementless THA remains controversial.

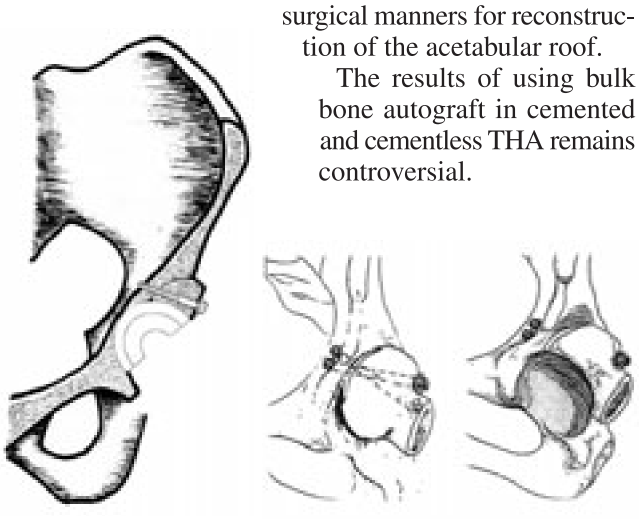


Fig. 4. Harris' original bulk femoral head bone autograft technique.

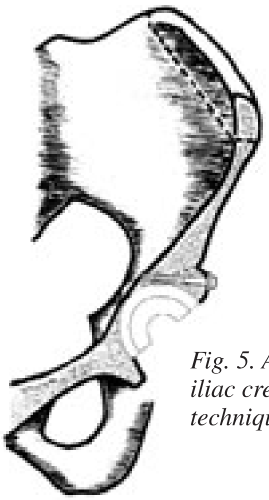


Fig. 5. Autologous iliac crest bone graft technique.

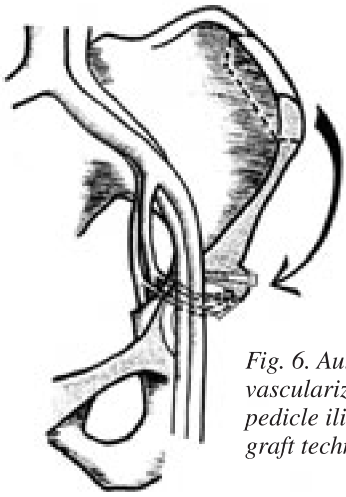


Fig. 6. Autologous vascularized pedicle iliac crest graft technique.

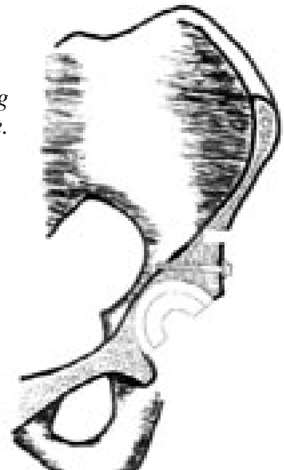


Fig. 7. Iliac sliding graft technique.

1.1.1 Cemented technique

Most studies reported that the early-to-midterm (around 3 to 6 years) results are promising, the mechanical loosening or failure rates were only 0%-5% (8), but long-term results are variable. Busch (5) reviewed 74 hips (patients' average age was 45 years) who underwent THA combined with autologous bulk bone graft (femoral head wedge was taken and fixed with two cancellous screws with its sclerotic concave side toward the defect as an inlay graft before reaming) with an average 10.4 years' follow-up. The survivorship for all-cause was 98%, all grafts incorporated and no additional radiographic loosening. Mulroy (30) applied an autogenous femoral-head graft to the acetabulum during THA for compensation of marked osseous deficiency in 46 hips of OA secondary to DDH. After an average of 11.8 years' follow-up, the total incidence of loosening was 46% and he suggested that autologous bulk bone graft should be used only when the acetabular bone stock was extremely deficient.

1.1.2 Cementless technique

More positive results have been reported in the literature using cementless acetabular cups. Tsukada (43) analyzed 22 operated hip joints using uncemented cups. With an average 8.3 years' follow-up, they found a 100% survival rate, without loosening.

Abdel (1) also reported on 35 operated hips with a mean follow-up of 21.3 years. The twenty-year survivorship free from acetabular revision was 66%, all bone grafts incorporated to the pelvis.

1.2 Autologous iliac crest bone and iliac sliding structural grafts

After the femoral head, iliac crest bone graft is a commonly used autograft during dysplastic THA. Both the anterior and posterior portions of the iliac crest are often used for grafting (Fig. 5).

Systematic review reporting the overall complication rate by this technique was 19.37%, including infection, fracture, chronic donor site pain, hernia, poor cosmetic outcome, and hematoma formation (44). Postoperative complications were reported significantly higher when the donor site was the anterior iliac crest compared to the posterior iliac crest (2).

In 1988, Solonen (39) described the use of vascularized pedicle iliac crest grafts in the reconstruction of large acetabular defects in three patients. Based on the deep circumflex iliac artery, it seems to be ideal due to the adequate length and diameter of the pedicle vessels (Fig. 6). Although he reported satisfactory results, this technique has not gained popularity since then.

Both Karakurum (21) and Delimar (9) separately reported through 6 and 10 cases of cadaver studies that pedicle iliac graft with deep circumflex artery and vein might be placed into any position in the acetabular roof and might serve as a method of choice in patients with combined hip dysplasia and deficient bone stock that need to undergo total hip replacement.

Ikeuchi (18) introduced the iliac sliding graft technique and applied to 19 cases of acetabular dysplasia in 2005 (Fig. 7). With a mean 3.4 years' follow-up he declared that this technique could be a useful alternative. The relative advantages include intimate host-graft contact and good stability of the graft compared with a femoral head autograft. The disadvantage of the iliac sliding graft is its limited availability. Thickness of the graft should be limited to 12 mm to 14 mm.

Therefore, even though this technique is not widely used, however when no other method seems feasible for dysplastic hips, iliac bone grafts still could be a suitable alternative choice.

1.3 Intraosseous structural graft ISG technique

Szabó (40) reported the ISG technique. Through 3D model and cadaveric studies, he concluded that this method provided good primary stability with a more favorable biological bone incorporation. A proximally fixed cortico-spongous plate is made for the cranial defective quadrant of the acetabulum (Fig. 8). Patients' x-rays showed stable fixation within short follow-up time.

1.4 Autologous morselized bone graft

Instead of the bulk bone graft, some studies also evaluated the use of autologous morselized bone graft. Studies sug-

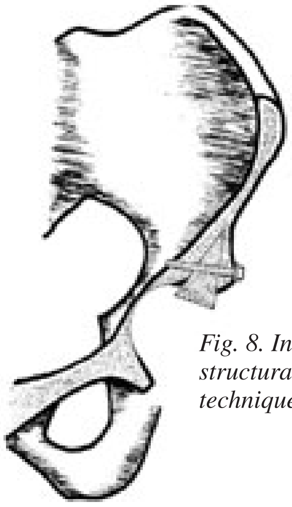


Fig. 8. Intraosseous structural graft ISG technique.

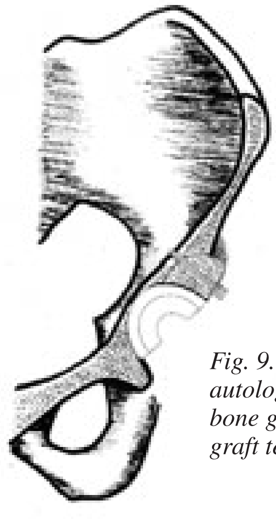
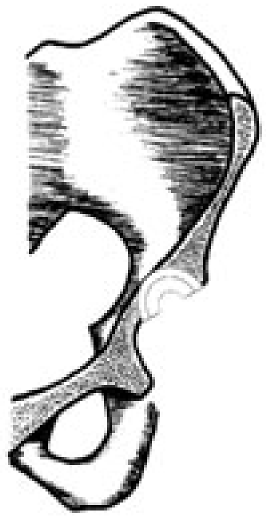


Fig. 9. Combined autologous morselized bone graft and bulk bone graft technique.

Fig. 10. Cranial placement of the acetabular cup for hip dysplasia.



gested that faster bone integration could be attributed to better vascularization and the osteointegration achieved with bone particles compared with bulk bone grafts. Gross (29) packed the morselized autograft bone against the ilium and the shelf (femoral head) graft and found it useful in the dysplastic acetabulum (Fig. 9). He suggested that the abductor muscles both protect and help to consolidate the graft and even if the component fails, the bone bed is provided for revision. He called this 'flying buttress graft'. However, since the morselized bone is usually difficult to fit, this method is not widely accepted.

1.5 Homologous structural bone graft

Allografts could offer some advantages over autologous bone because they are available even at large amount. They usually originate from living donors' femoral head (freeze dried graft processed by a bone bank) or fresh frozen graft from multiorgan donors.

The scaffold structure makes sure that it has good osteoconductivity. For freeze dried bone it is mainly composed of Type I collagen. Protein and factors like BMP-2, BMP-7, IGFs have also been reported to participate in this process. Therefore, allograft might be an ideal source for acetabular reconstruction. However, bone allograft application should be cautious not only for a lower integration rate, but also risks of HIV and hepatitis C virus infection and possibility of bacterial contamination. Usually fresher the graft, higher the risks. Most studies about its application were mainly for hip revision cases.

Blackley (4) studied 63 hips in which the prosthesis was cemented with a proximal femoral allograft. He reported that the success rate for the patients was 77% after an average of 11 years of follow-up.

Azuma (2) used cemented cups and corticospongious allografts (repeatedly packed the femoral-head allograft chips into the acetabular defect and temped until a solid cancellous wall was produced) for 24 cases of severe acetabular bone deficiency. With mean 5.8 years follow up, he reported two components migrated but none of the patients had revision because of loosening or infection.

Traina (42) used structural allograft and primary press-fit cup for 23 patients with severe acetabular deficiency (impacting the grafts into the acetabular defect before reaming), with average 7.6 years of follow-up. All cups were stable and grafts were integrated and anatomy was restored. He suggested results are satisfactory for a very demanding procedure.

Shinar (38) used cemented cups and studied 55 cases with autologous grafts comparing with 15 allografts cases for reconstruction of the acetabulum in THR (no detailed method was mentioned in their paper). With 16-year-average follow-up, he declared that both the structural autologous grafts and the structural allografts used in acetabular reconstruction in total hip replacement functioned well for the initial 5 to 10 years. By the average 16.5 years, 60% hips treated with allografts and 29% treated with autologous grafts had been revised.

2 PLACING THE CUP OUT OF PRC

2.1 High Hip Center

As the superolateral acetabular bone stock deficiency is important in Crowe II-III types, the original anatomical hip rotation center might no longer be suitable for the cup placement during arthroplasty. Therefore, according to some surgeons proximal placement of the socket is recommended when less than 50% coverage of the socket could be achieved at PRC. But how high should it be? Normally the distance between the anatomical hip center and the inter-teardrop line ranges from 12 to 15mm. In some studies, high hip center (HHC) was defined twice as long as this distance, the highest even reaches to 60mm above the inter-teardrop line. Some defined the distance as "locating more than 35mm from the inter-teardrop line or 15mm higher than the approximate femoral head center". There is no consensus on the clinical grounding of this technique (Fig. 10).

2.1.1 Arguments in favor of HHC

Due to numerous factors affecting the clinical results and the lack of standard evaluation system, it is still debatable whether HHC technique could achieve satisfactory clinical results. Generally, it has advantages such as no need of bone grafting, better cup coverage without bone grafting and shorter operation time.

Kaneuji (20) reported that hip center elevation (26.8±4.8mm from the bottom of the teardrop) with cementless cups without lateralization and structural bone graft was well tolerated for hip dysplasia and is a durable alternative solution. 30 hips were included in his study, and the average follow up was 15.2 years. No loosening or Trendelenburg limping sign were identified in the end.

Hampton (15) reported on 20 hips with HHC more than 35mm proximal to the interteardrop level, after cementless THA combined with cancellous bone grafting. The average 16.3 years' survival could reach 92%.

Christodoulou (6) used the biconical threaded Zweymüller cup and included 34 hips, the mean follow-up was 8.3±3.5 years. No grafts were used. The mean distance of the cups from the interteardrop line was 39.7mm. Results showed the mean polyethylene wear rates and the cup survivorship rates in the near-normal and HHC groups were not different.

2.1.2 Arguments against HHC

Contrary to the above-mentioned authors, some studies state that HHC diminishes the biomechanical characteristics of the dysplastic hip and should be avoided.

Pagnano (33) performed HHC for 145 hips, without grafting and the mean follow-up period was 14 years. He reported that cemented cups which were more than 15mm superior to the center of the femoral head without lateral displacement had an increased rate of loosening and needed revision for both femoral and acetabular components.

Georgiades (14) included 53 cases of cementless cup, with minimum 10 years' follow-up. He reported that cranial positioning of the acetabular component of more than 25mm (25–35mm) superior to the teardrop line led to statistically significantly higher aseptic loosening of the femoral components.

Nie (32) analyzed 18 patients' pelvic radiologic results one day after the cementless THA surgery and he also studied the biomechanical consequences of superior placement of the hip center. He found that for Crowe type I/II hip dysplasia, HHC (even 5mm above the anatomic hip center) disturbs the biomechanical load above the acetabular dome, which is critical to the stability and survivorship of the acetabular component.

For HHC technique, there is no study directly comparing the difference between cemented and cementless cups. Results with cemented fixation showed acetabular loosening rates ranging from 16% to 42% within 5 years. However, studies of cementless cups showed greater than 80% survivorship even beyond 15 years and no acetabular failures at a minimum of 10 years in THA for Crowe I to III hip dysplasia (31).

2.2 Medial wall protrusion technique (cotyloplasty)

In 1976, Dunn and Hess (11) formulated a method by intentionally crossing the medial wall and placing the cup beyond the ilioischial line to avoid bone grafting (Fig. 11). 22 hips were operated and all had pain relief and gait improvement. Instead of osteotomy, Stamos (17) firstly devised this method by perforating the medial acetabular wall with a reamer in 1978 and defined it as "cotyloplasty".

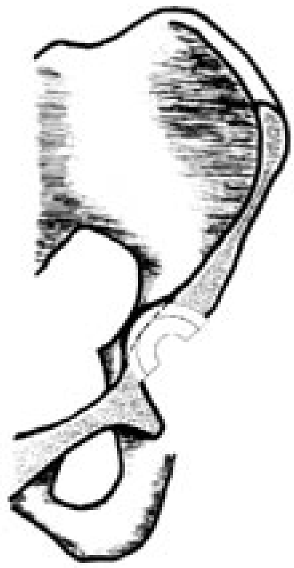


Fig. 11. Medial wall protrusion technique (cotyloplasty).

In 1999, Dorr (10) included 24 hips, with an average 7 years' follow-up reporting that the medial protrusion technique is a predictable, reproducible method for obtaining fixation of a porous-coated, hemispherical acetabular component in a dysplastic acetabulum. He suggested that the anterior and posterior column should not be reamed too thin and the defect must remain only medially (25%), otherwise the press-fit metal shell can cause fracture through the anterior or posterior column.

Kim (23) in his 16 cases filled the medial wall defect with cancellous bone chips acquired from the resected femoral head and inserted a cementless cup. After more than 2 years he observed despite of a large amount of bone chips was impacted, most of them were gradually resorbed. The thin medial wall might be troublesome when performing revision surgery. So the safe margin of protrusion in cotyloplasty seems to be 50-60% of the acetabulum (the amount of cup surface beyond the Kohler's line). Using a larger cup is recommendable as it has more bone contact.

In 2008, Hartofilakidis (16) included 93 hips with a minimum 10 years' follow-up reporting that when 80% of the implant could be covered, a cementless acetabular component appeared to be acceptable and provided durable fixation. Cotyloplasty was used in more deficient hips.

3 SPECIAL IMPLANTS

3.1 Traditional manufacturing

A combined superior and posterior segmental cavitary deficiency will cause an oblong defect. In such situations, hemispherical implants are not suitable as the antero-posterior acetabular diameter doesn't allow large reaming without sacrificing the ventral and dorsal acetabular rim. Large amount of superior bone grafts will be used and the long-term stability remains questionable. The non-spherical cups are usually indicated when the acetabulum presents with a longer longitudinal diameter and shorter transverse diameter. Unlike extra-large uncemented component (the so-called Jumbo cups) which requires extensive reaming, this cup could obtain enough stability in both the anterior and posterior column. There are mainly two types of oblong cups: the bilobed oblong acetabular component (BOFOR cup Smith and Nephew, Plus Orthopaedics AG, Rotkreuz Switzerland, S-ROM Oblong Cup Depuy, Johnson and Johnson, Warsaw, IN)

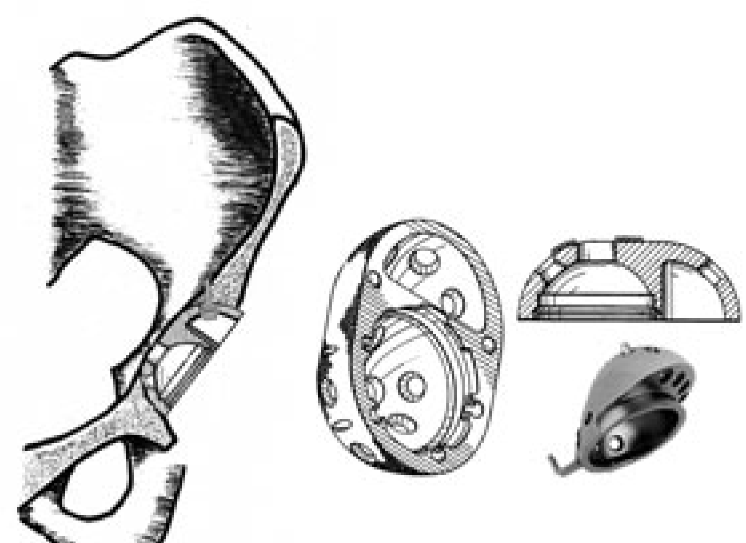


Fig. 12. Oblong cup for dysplastic hip arthroplasty.

and the Längsovalen Revisionspfanne (LOR) cup (Langs-Ovale Revisionspfanne [L.O.R.], Allopro, Switzerland). Among traditionally manufactured implants the Oblong cup or Bilobs cups are especially designed for the restoration of the PRC (Fig. 12).

The main advantage is relocating the hip center to a normal level and the increased surface contact area between the porous component and native host acetabular bone. However, the disadvantage is the thick metal wall, the implant's weight, the lack of bone stock restoration and the high price. Even though there are some studies already reporting encouraging results, they are more used in revision surgeries. Also, technical difficulties such as acetabular reaming for bilobed cups were reported. The use of tantalum augments in case of peri-acetabular bone stock deficiency is a new way for the bony restoration, also useful in dysplastic cases. It is a challenging and promising way; however, it doesn't mean that all problems encountered in such cases would be solved with it.

3.2 3D printed implant

Because of their excellent mechanical strength, porous metals were considered as an optional structural bone graft substitute. So far, porous titanium and tantalum has been clinically used and still are under development. These augments have different shapes and sizes, this way can be applied in complex acetabular reconstruction cases (3). Jafari (19) retrospectively compared titanium and tantalum cups in hip arthroplasty with follow-up more than 3 years. They reported that for moderate to severe acetabular deficiency in revision surgery, the tantalum cups appeared to have a superior performance. But for primary total hip arthroplasty, the bone ongrowth potential of titanium cup was more important.

Highly interconnected porous surfaces with pore sizes ranging from 200–400 m and porosities of 45–65% are most ideal for maximizing bone-implant integration. 3D printing could allow manufacturing implants with this geometry requirements. The latest progress is the application of 3D printed custom-made cups. However, still only preliminary results can be obtained so far. Despite the actual high price, the use of these supersophisticated machines and the option to customize the implants, we are still looking for a radical change of the technique, with a larger availability.

CONCLUSIONS

DDH is a clinical disorder that not only affects the hip joint, but also the femur and related connective tissues. Due to the pathological characteristics, sooner or later it leads to secondary OA. Numerous techniques have been reported for the dysplastic hip arthroplasty with their own advantages and disadvantages. There are some limitations in this review: as differences exist not only in technique but also in patients' age, health condition, physical activity, follow-up time and other factors, even with the same operative method still could very possibly achieve different results. The long-term results are variable, even considering the same technique. Therefore, little clear conclusion can be drawn from the available data. Usefulness of each technique for very difficult hip dysplasia cases is still lack of evidence. However, in our belief biomechanically the restored PRC with cementless cup could achieve better long-term result. The short-term result of personalized 3D printed augments and cups application is also encouraging. New types of bone substitutes provide surgeons more choices. So far, management of hip dysplasia case depends on the overall medical condition of the patients, as well as the experience of the surgeon.

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