13 Ceramic-on-Ceramic Total Hip Arthroplasty

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13.1 Introduction

Total hip arthroplasty (THA) is the most successful procedure to treat end-stage osteoarthritis of the hip. The use of contemporary bearings, highly cross-linked polyethylene, metal-on-metal (MoM), and ceramic-on-ceramic (CoC) bearings, which were expected to minimize wear and subsequent osteolysis, enabled surgeons to perform THA in young and active patients [1–4]. Among the contemporary bearings, MoM bearings were almost abandoned due to serious adverse local or systemic reactions [5, 6]. The CoC articulations offer superior wear properties and biocompatibility [7].

13.2 Evolution of Ceramic-on-Ceramic Bearings

In the 1970s, the first-generation CoC bearing was developed in France and Germany. The results of THA using the early-generation ceramic bearings were not satisfactory due to insufficient fixation of the acetabular cup and excessive wear [8]. The lack of bone-ingrown stability of the mono-block cup design and large grain size of the ceramic were thought to be the causes of failure [9–11].

To overcome these problems, third-generation alumina ceramic was developed, and a taper fixation of the ceramic liner in a metal-backed component was adopted in 1995. The mechanical properties of ceramic materials have been improved by hot isostatic pressing, laser marking, and nondestructive proof-testing, which translated to reduced grain size and increased strength of the ceramic composite [12]. Since then, alumina CoC bearings (Biolox Forte; CeramTec, Plochingen, Germany) were popularly used for THA of young patients [13]. This design has generated excellent survival and patient satisfaction compared to conventional metal-on-polyethylene bearing. However,

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W. R. Drescher et al. (eds.), *Advances in Specialist Hip Surgery*,
https://doi.org/10.1007/978-3-030-61830-8_13

ceramic fracture and squeaking appeared as major concerns of the third-generation alumina ceramic bearings [14].

13.3 Ceramic Head Fracture

A 28 mm short-neck head of pure alumina ceramic has a high risk for fracture. In 2008, Koo et al. reported five head fractures (1.4%) among 367 cementless THAs with the use of 28 mm alumina CoC bearing [15]. All fractures occurred in short-neck heads and involved the circumferential portion along the inner edge of the head bore (Fig. 13.1). The same finding was reported by registry studies. In a UK registry data involving 222,852 THAs with the use of contemporary CoC bearings, the use of 28 mm head was the highest risk factor for ceramic fracture (0.382%) [2]. In the Danish Hip Arthroplasty Registry data, ceramic component fracture occurred in 0.35% and all of them occurred in 28 mm femoral heads [4].

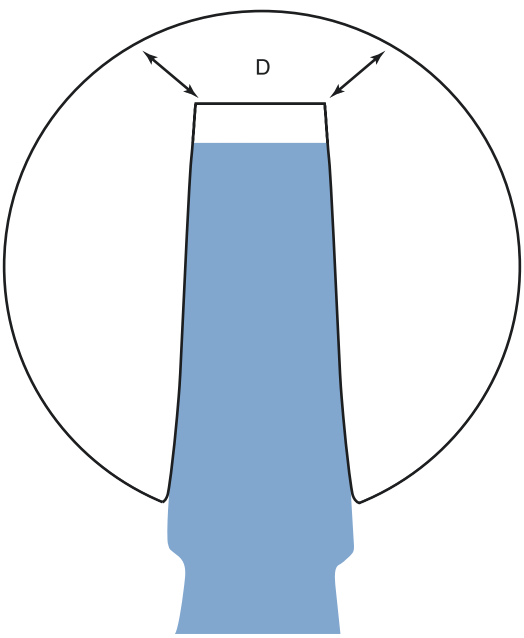

Fig. 13.1 Head bore is a tapered hole in the ceramic modular femoral head. When using a short-neck taper, the contact area between the bore of the ceramic head and the trunnion of the femoral stem is located high, nearest to the dome

In 2004, Delta ceramic (Biolox Delta; CeramTec), a composite of 82% alumina, 17% zirconia, and 1% mixed oxides, was developed to reduce the rate of ceramic fracture [16]. This newest ceramic composite has a smaller grain size (less than 0.8 μm), higher bending strength, and increased toughness than previous alumina ceramic [17]. The strong toughness of Delta ceramic allowed the use of larger femoral heads and thinner liners, which increased the range of motion and reduced the rate of dislocation.

Recently, midterm results of THA with the use of Delta ceramic bearings have been reported [1, 3, 18–22]. The risk of head fracture has been reduced with the use of Delta ceramic (Table 13.1).

No fracture was seen in the Delta ceramic heads in the UK Registry data, and only one fracture was noted in 28 mm Delta heads in the Danish Registry data [2, 4].

13.4 Ceramic Liner Fracture

Although the use of Delta ceramic markedly reduced the incidence of ceramic head fracture, it did not significantly reduce the incidence of liner fracture. The overall survivorship of ceramic liners was similar between alumina and Delta ceramics. In the registry data from the UK, the fracture incidence was 0.112% (35/31258) in alumina liners and 0.126% (101/80170) in Delta liners [2]. The incidence of ceramic liner fracture from single-cohort studies ranged from 0 to 1.2% in alumina liners and from 0 to 0.8% in Delta liners (Table 13.1).

Incomplete/asymmetric seating of the ceramic liner into the metal shell and dent of metal shell is a possible cause for liner fracture [23, 24]. Surgeons should be cautious to achieve firm symmetric seating of the liner along the Morse taper inside the metal cup [14, 22, 25, 26]. Heavy body weight has been reported as a risk for the liner fracture. The risk may be attributable to the difficulty of liner insertion during the operation of patients with high body mass index [22, 27, 28].

Table 13.1 Incidence of third- and fourth-generation ceramic fracture from single-cohort studies which had used cementless total hip arthroplasty

Study name	Ceramic bearing information	N of hips	N of head fracture	N of liner fracture	Mean follow-up (years)
Lee 2017	Delta: 36 mm (39 hips), 32 mm (247 hips)	286	0 (0%)	1 (0.3%)	5.6
Lim 2017	Delta: 36 mm (472 hips), 32 mm (277 hips)	749	0 (0%)	2 (0.3%)	6.5
Salo 2017	Delta: 40 mm (102 hips), 36 mm (222 hips), 32 mm (12 hips)	336	0 (0%)	0 (0%)	2.1
Hamilton 2015	Delta: 36 mm (168 hips), 28 mm (177 hips)	345	0 (0%)	3 (0.8%)	5.3
Aoude 2015	Delta: 36 mm (98 hips), 28 mm (35 hips)	133	0 (0%)	0 (0%)	6
Park 2015	Forte: 36 mm (366 hips), 28 mm (211 hips)	577	14 (2.4%)	7 (1.2%)	5.9
Lee 2014	Forte: 32 mm (55 hips), 28 mm (52 hips)	107	0 (0%)	0 (0%)	6.3
Kiyama 2013	Forte: 36 mm (23 hips), 32 mm (149 hips), 28 mm (11 hips)	183	0 (0%)	1 (0.6%)	5.6
Amanatullah 2011	Forte: 32 mm (135 hips), 28 mm (61 hips)	196	1 (0.5%)	2 (1%)	5
Mesko 2011	Forte: 36 mm (152 hips), 32 mm (699 hips), 28 mm (79 hips)	930	0 (0%)	3 (0.3%)	5.9
Garcia-Rey 2009	Forte: 32 mm (300 hips), 28 mm (37 hips)	337	0 (0%)	1 (0.3%)	5.6
Lusty 2007	Forte: 32 mm (278 hips), 28 mm (23 hips)	301	0 (0%)	1 (0.3%)	6.5

The use of a multi-bearing metal shell, which can be coupled with hard liners as well as polyethylene liner, appeared as a risk factor for malseating of the ceramic liner. This type of metal shell has an inner taper angle of 10° [1, 21]. In 2017, Lee et al. compared malseating rate of ceramic liners between two metal shell designs: one with an inner taper angle of 18° and the other with an inner taper angle of 10°. The malseating rate in the 10° metal shell was higher than that in the 18° metal shell (23.3% vs. 0%) (Fig. 13.2) [29]. Currently, most manufacturers have adopted 18° as the inner taper angle of metal shells for ceramic liner.

Thin metal shell is a risk factor of liner malseating. During firm impaction of a thin metal shell into sclerotic and inelastic acetabulum, a permanent deformation of the metal shell can occur. This deformation induces an uneven contact between the metal shell and the ceramic liners, which can lead to malseating and subsequent fracture of the ceramic liner [30]. This deformation of the thin acetabular component may not make a problem when coupled with a polyethylene liner, which is soft and elastic and easily slides into the deformed metal shell. However, the ceramic liner is plastic and would not be completely seated into the deformed metal shell [31].

13.5 Squeak

The squeaking has been reported as a complication of modern CoC bearings. Although the methods of measuring squeaking are not standardized, the incidence of squeaking after CoC THA ranged from 0.5 to 17% in the literature [23, 32, 33]. The exact mechanism of squeaking is unrevealed, but it seems to be multifactorial. To date, three contributing factors, (a) metal shell design, (b) metal shell position, and (c) patient's constitution, have been known for the development of squeaking. A squeak occurs when the fluid film, which separates the ceramic head from the ceramic liner, is disrupted to allow a friction at the joint and to excite an audible vibration. The lubrication by synovial film is broken in specific conditions such as joint separation due to impingement, stripe wear, edge loading, and metal transfer [33–35].

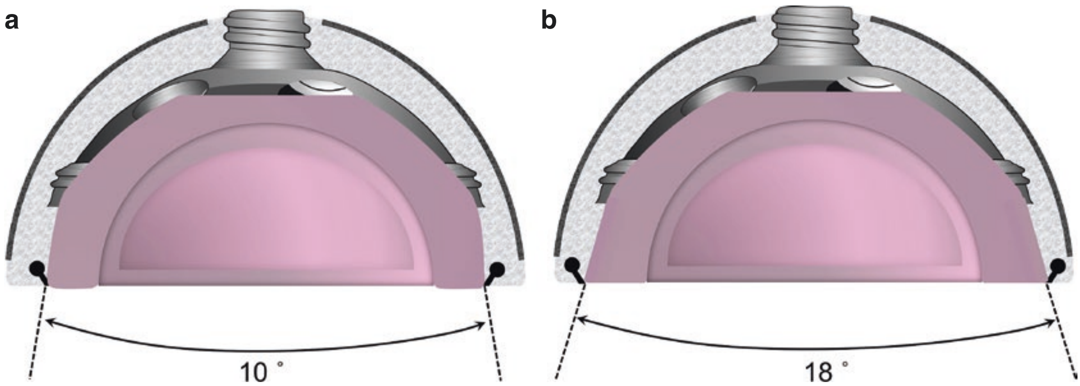

Fig. 13.2 (**a**) The acetabular metal shell had a 10° inner taper angle. (**b**) The acetabular metal shell had a 18° inner taper angle

Fig. 13.3 Titanium-backed ceramic liner to prevent impingement between the stem neck and the ceramic liner rim

The acetabular cup with an elevated metal rim (Trident® system; Stryker Orthopaedics, Mahwah, NJ, USA) has been known as a risk for squeaking (Fig. 13.3) [36]. This metal shell was designed to prevent an impingement between stem neck and brittle ceramic liner. However, it was associated with a reduced range of motion, leading to metal-to-metal contact between the stem neck and rim of metal shell. The metal-to-metal contact generates metal debris, which disrupts the fluid-film lubrication in the ceramic bearing surface and leads to squeaking. The neck-rim impingement increases the chance of lever out of the ceramic head, which leads to edge loading, stripe wear, and squeaking. Furthermore, elevated metal rim increases the resonance, which amplifies squeaking [35, 36].

Walter et al. showed that excessive or insufficient anteversion or inclination of the acetabular cup was associated with squeaking [37]. In their study, 94% of non-squeaking patients had 25° ± 10° of cup anteversion and 45° ± 10° of cup abduction, while 35% of squeaking patients had this range of cup position. Stem neck-metal shell impingement and edge loading in improperly positioned metal shells were the possible explanations for the squeaking.

Mai et al. reported that patients who had squeaking were taller than those who did not have [38]. Sexton et al. also reported that taller, heavier, and younger patients were more likely to squeak [39]. In the meta-analysis by Stanat and Capozzi, high body mass index was the only significant patient risk factor of squeaking [40].

13.6 Conclusions

Contemporary CoC bearings offer major advantages over other bearings. When surgeons use CoC bearings for THA, they should choose optimal implants, should be cautious about adequate positioning of implants, and should not make a scratch on the ceramic surface during the operation to minimize the risk of fracture and squeaking.

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