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ORIGINAL PAPER

Ten different hip resurfacing systems: biomechanical analysis of design and material properties

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Abstract This study gives an overview of the main macro- and microstructural differences of ten commercially available total hip resurfacing implants. The heads and cups of resurfacing hip implants from ten different manufacturers were analysed. The components were measured in a coordinate measuring machine. The microstructure of the heads and cups was inspected by scanning electron microscopy. The mean radial clearance was 84.86 μm (range: 49.47–120.93 μm). The implants were classified into three groups (low, medium and high clearance). All implants showed a deviation of roundness of less than 10 μm. It was shown that all implants differ from each other and a final conclusion about the ideal design and material combination cannot be given based on biomechanical data. Widespread use of specific designs can only be recommended if clinical long-term follow-up studies are performed and analysed for each design.

Résumé Le but de ce travail est d'évaluer les différences observées de 10 implants différents de resurfaçage de la hanche. Matériel et méthode: les têtes et les cupules de différents fabricants ont été analysées. Les différents composants ont été mesurés dans une machine particulière. La micro-structure des têtes et des cupules a été également analysée par microscopie électronique. Résultats: la clearance radiale moyenne a été de 84,86 μm (de 49,47 μm à 120,93 μm). Les implants ont été classés en trois groupes (basse, moyenne et haute clearance). Tous les implants montrent un écart de sphéricité de 10 μm. En conclusion: il est clair que tous les implants diffèrent l'un de l'autre et que le design idéal se situe entre les différentes combinaisons d'implants et ne peuvent être basés sur les données biomécaniques. Une diffusion des designs les plus répandus peut seulement être recommandée après un suivi à long terme analysé pour chaque type d'implant.

Introduction

In the last ten years interest in total hip resurfacing as an alternative to conventional total hip replacement has been rising, especially with respect to younger patients. The possibility of performing a bone-preserving total hip replacement (on the femoral side) with physiological load transfer is an attractive alternative for many surgeons. The first published midterm results are encouraging with survival rates above 94% after a follow-up of up to eight years [2, 7]. Total hip resurfacing represents the fastest growing section in orthopaedic surgery today [4].

Modern total hip resurfacing implants are a further development of surface replacement systems of the 1970s and 1980s. Most of the older systems were metal-on-polyethylene systems with a totally cemented fixation [3, 17]. These systems failed due to excessive polyethylene wear, subsequent osteolysis and loosening [13]. In the 1990s, Harlan C. Amstutz in Los Angeles and Derek McMinn in Birmingham developed the first modern

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generation total hip resurfacing implants. Today there are many systems on the market. While manufactures have to obtain US Food and Drug Administration approval before market introduction in the USA, many companies are selling different implants in Europe today. There are at least ten different implant systems, which have been in clinical use in Europe for more than two years. Short-term clinical results are available only for a few of these designs.

The aim of this study was to investigate different design and material properties of ten commercially available hip resurfacing systems.

Materials and methods

Ten different commercially available hip resurfacing systems were investigated in this study. Nine implants were available with a 46-mm head diameter and corresponding cups; one system was only available with a 48-mm diameter (Cormet™, Corin Group, Cirencester, UK). None of the systems were pre-selected by the manufacturers and all have been in clinical use for more than two years.

The following systems were evaluated:

- ACCIS™ (Van Straten Medical, Netherlands; Implantcast, Buxtehude, Germany)
- ADEPT™ (Finsbury Orthopaedics Ltd., Leatherhead, UK)
- ASR™ (DePuy Orthopaedics Inc., Warsaw, IN, USA)
- Birmingham Hip Resurfacing (BHR)™ (Smith & Nephew, Memphis, TN, USA)
- BS™ (Eska Implants, Lübeck, Germany)
- Conserve Plus™ (Wright Medical Technology Inc., Arlington, TN, USA)
- Cormet™ (Corin Group, Cirencester, UK)
- Durom™ (Zimmer Inc., Warsaw, IN, USA)
- Icon™ (IO International Orthopaedics Holding, Geisingen, Germany)
- ReCap™ (Biomet Inc., Warsaw, IN, USA)

Most investigated hip resurfacing systems are primarily designated for a hybrid fixation. The femoral component has to be cemented onto the prepared femoral head and the acetabular component is intended for a press-fit cementless fixation. Some systems also offer an option to use a cementless femoral component. The BS is the only design with a cementless acetabular shell in combination with a modular metal insert. All implants are made of a CoCr alloy. The ACCIS implants have a TiN-coated surface.

The dimensions of all components were measured using a coordinate measuring machine (Mahr Multisensor, MS 222, Göttingen, Germany). The radial clearance, deviation of roundness of the femoral and the acetabular components and thickness of the cup wall at the rim were measured. The accuracy was ±2 μm and checked between the measurements with standard calibration ceramic spheres. Each measurement was performed three times in a temperature-controlled inspection room and the mean value of the measurements was calculated. The surface roughness was measured at six different locations on the femoral and the acetabular components using a Perthometer M2 (Mahr, Göttingen, Germany). The mean of all measurements was calculated for each component.

Additionally, the surfaces of all components were investigated using scanning electron microscopy (SEM, LEO 440). Surface images were taken using the scanning electron mode. The back scatter electron mode was used for element weighted images. Element analysis was performed with the energy dispersive X-ray (EDX) technique (Oxford D. 7060) to identify carbides and to determine the alloy composition. Element distribution maps were taken to identify individual elements. Using the SEM images and the information about carbon content, manufacturing process and heat treatment, the characteristic carbide shapes and distributions were analysed.

Results

Clearance

The measurement of the clearance showed a range of the radial clearance between 49.47 and 120.93 μm (mean: 84.86 μm). The implants were grouped by their radial clearance into low, medium and high clearance implants (Table 1).

Wall thickness, roughness and roundness

The wall thickness differed from 3.1 mm to 5.6 mm (mean: 3.8 mm). Because the Biosurf is a modular component, its

Table 1 Measured implants grouped by clearance

Implant	Radial clearance (μm)	
ReCap	120.93	High (100–125 μm)
Icon	120.67	
BHR	105.10	
Cormet	97.67	Medium (75–100 μm)
ADEPT	86.37	
Conserve Plus	78.90	
BS	68.37	Low (50–75 μm)
Durom	68.23	
ACCIS	52.93	
ASR	49.47	
Mean	84.86	

acetabular shell is significantly thinner (1.5 mm) and was not included in the calculation of the mean thickness. The wall thickness was highly dependent on the measurement area because in most systems the wall thickness increases toward the dome of the cup. Some manufacturers also supply two acetabular implants with different outer cup dimensions fitting to the same femoral head size (e.g. ADEPT, BHR, Cormet, Icon). The standard version was measured in this study (Table 2).

The roughness of all implants was very similar between 0.02 and 0.036 µm. The ACCIS components with the TiN surface showed a reduction to 0.012 µm.

Deviation of roundness was in all cases less than 10 µm (0.9–7.3). The heads showed a higher mean deviation of roundness than the acetabular implants (4.1 compared to 2.6 µm).

Manufacturing method, heat treatment and carbon content

The manufacturing method, subsequent heat treatment protocols and the carbon contents are shown in Table 3. All implants are made of a CoCr alloy, which differs slightly depending on the manufacturing method. Except for two designs, all implants were casted and some of them were treated with subsequent heating methods. In hot isostatic pressurisation (HIT) heat of about 1,200°C is applied for four hours in an argon atmosphere with a pressure of 103 MPa. In contrast, in the solution annealing (SA) method the implants are heated for four hours up to a temperature of 1,200°C in a vacuum. With regards to temperature, the sintering process used for porous coated acetabular implants is comparable to the solution annealing process. The BS implant has an as cast manufactured head and a wrought acetabular component. It is the only system that combines a high (head)-low (cup) carbon combination.

Table 2 Wall thickness, surface roughness and deviation of roundness

Implant	Wall thickness at rim (mm)	Surface roughness (µm)	Mean deviation of roundness (µm)	
			Head	Cup
BS	1.5[a]	0.032	6.0	1.0
ACCIS	3.4	0.012	6.0	3.3
BHR	3.6	0.029	0.9	0.9
Icon	3.4	0.035	2.0	4.9
Cormet	5.6	0.030	7.3	3.8
ASR	3.1	0.025	3.4	3.8
ReCap	3.4	0.031	3.2	1.9
ADEPT	3.4	0.036	2.5	2.2
Conserve Plus	3.8	0.020	3.2	1.8
Durom	4.6	0.034	6.1	2.5
Mean	3.83	0.028	4.1	2.6

[a] Modular implant, not included in calculation of mean wall thickness.

Table 3 Manufacturing methods and carbon content. *HIP* hot isostatic pressurisation, *SA* surface annealing, *TiN* TiN coating

Implant	Manufacturing method and heat treatment		Carbon content
	Head	Cup	
ADEPT	As cast	As cast	High
BHR	As cast	As cast	High
Icon	As cast	As cast	High
ReCap	As cast	As cast	High
ASR	As cast	HIP/SA	High
Cormet	HIP/SA	HIP/SA	High
Conserve Plus	HIP/SA	HIP/SA	High
ACCIS	TiN	TiN	n.a.
BS	SA	Wrought	High/low
Durom	Wrought	Wrought	High

Low carbon components are defined by a carbon content of <0.15%. All other bearing couples are high carbon components (≥0.15%). The Durom hip resurfacing is the only design where both components are wrought. The ACCIS implant has a TiN (titanium nitride)-coated surface.

The manufacturing method and subsequent heat treatment had a significant influence on the surface topography of the implants (Fig. 1). The heat-treated components generally showed small carbides, whereas the non-heat-treated components showed bigger, “blocky” carbides. The same pattern was observed for wrought and as cast components. The forging process of the wrought components leads to smaller carbides compared to the bigger carbides of the as cast components.

Discussion

The aim of the study was to give an overview of the main macro- and microstructural differences of commercially available total hip resurfacing implants. It is indisputable that a low surface roughness and high sphericity improve the wear behaviour. Radial clearance, manufacturing process and heat treatment are, however, discussed controversially.

Hip simulator tests have shown that, in general, a lower clearance leads to better wear properties. A small clearance and a low surface roughness allow better fluid film lubrication and result in a more evenly distributed contact pressure [9, 14]. Surface roughness was very similar for all implant systems studied, with the TiN-coated implant having the lowest roughness. The minimal clearance should not fall below a certain limit. An overly tight clearance bears the risk of equatorial contact and may result in a “brake drum” effect. It must be noted that since clearance can vary depending on implant size, the clearances

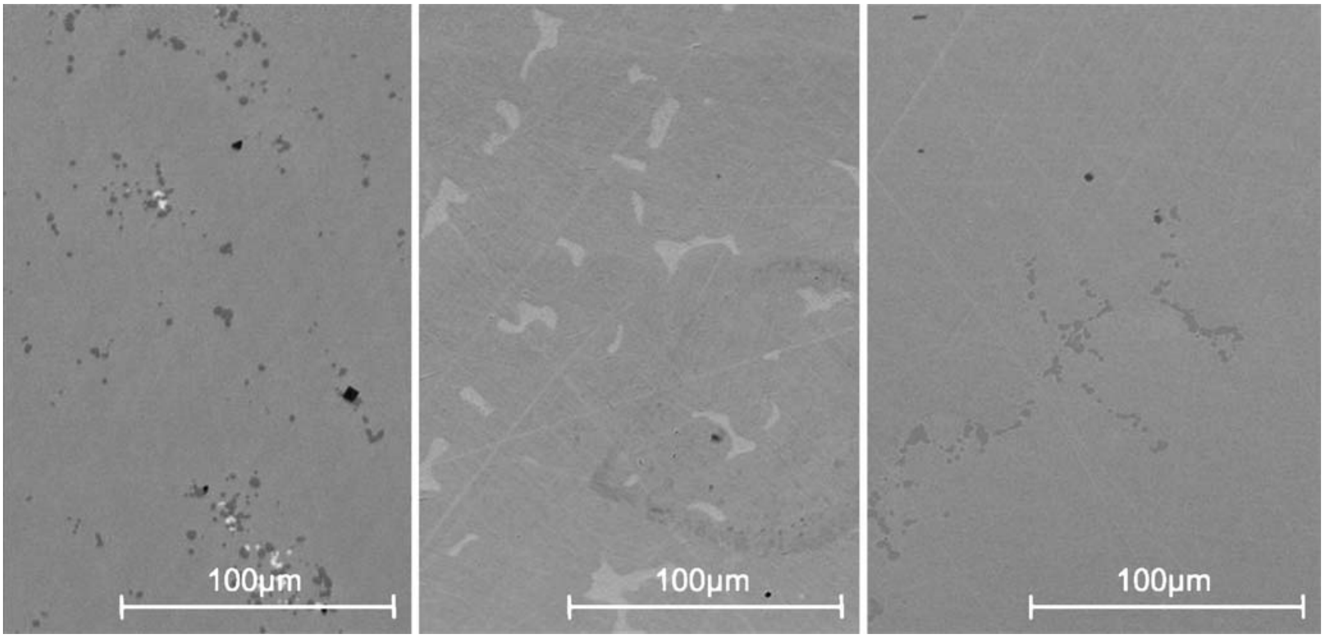

Fig. 1 Scanning electron microscopy of a wrought compared to an as cast and a heat-treated casted implant surface (*left to right*)

measured in this study only apply to the investigated implant size.

It has to be taken into account that an acetabular component can deform depending on wall thickness and cup size during and after implantation. Lin et al. showed in an experimental set-up that a reduced wall thickness and increased under-reaming lead to cup deflection [12]. The critical minimum clearance for a specific wall thickness is not exactly known as other factors like bone quality and stiffness, as well as surgeon-dependent variables, may also influence cup deformation. Clinical data for low clearance implants have to be critically reviewed in the future, but no increased rates of early failures have been reported for low clearance implants to date [4].

The deviation of roundness of components may also influence the clearance directly; it was, however, in all cases below 10 μm. Deviation of roundness was higher for the heads than for the cups. This is related to the higher elastic deformation of thinner parts during the manufacturing process and differing cooling rates depending on wall thickness. Generally, the wall thickness of the acetabular and femoral components is larger at the dome than at the rim/opening, with the opening of the femoral component being the thinnest of all areas.

Manufacturing process and subsequent heat treatment lead to variable microstructures on the implant surfaces. The carbides on the surface get smaller in size and number with heat treatment and the forging process. However, carbide structure and number do not seem to influence wear resistance significantly. The difference in wear resistance between cast and wrought components seems to be only marginal [6, 8]. Hip simulator tests have shown that low carbon implants have inferior wear properties and therefore most devices are made of high carbon content alloys [10].

This study provides an overview of commercially available total hip resurfacing implants. It was shown that design parameters and material properties of all implants differ from each other. A final conclusion about the ideal design and material combination cannot be drawn. At this point in time, it is not possible to derive clinical performance expectations from differences in design, material or manufacturing method. Hip simulator tests seem to favour some material and design combinations [5, 8, 9, 10], but clinical data for each implant are necessary for complete evaluation of each resurfacing system. Widespread use of a specific design can only be recommended if long-term clinical follow-up studies are performed and analysed with respect to the design parameters examined in this study. Most published midterm results today are published by the inventors of the studied implants. At the end of five years, a 98% survivorship has been reported for the BHR [16]. For the Conserve Plus, a five-year survivorship of 94% has been reported (97.8% for patients with good bone quality without cystic defects larger than 1 cm) [1]. Medium-term (five years) results have been published by independent centres only for very few hip resurfacing systems. For the BHR system, Hing et al. [11] reported a survivorship of 97.8% after a mean follow-up period of five years. Steffen et al. [15] reported a 96% survivorship after a mean follow-up period of 5.3 years (5–7.6 years). The Registry of the

Australian Orthopaedic Association includes numerous different designs and will hopefully yield meaningful long-term data in the future [4]. At present, surgeons can base their decisions regarding which implant design to use clinically on the technical data presented in this study.

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