Although controversy surrounding the use of metal-on-metal (MoM) arthroplasty implants continues to exist, satisfactory clinical and radiological outcomes have been reported following Birmingham Hip Resurfacing (BHR) at long-term follow-up, leading to an Orthopaedic Data Evaluation Panel (ODEP) rating of 1.3A. The purpose of this study was to systematically review the literature to evaluate the functional outcomes, radiological outcomes and revision rates following BHR at a minimum of 10 years follow-up. Using the PRISMA guidelines, two independent reviewers performed a literature search using Pubmed, Embase and Scopus databases. Only studies reporting on outcomes of BHR with a minimum of 10 years’ follow-up were considered for inclusion. A total of 12 studies including 7132 hips (64.8% males), with mean follow-up of 11.5 years (10-15.3), met our inclusion criteria. Of included patients, 94.3% of patients underwent BHR for osteoarthritis at a mean age was 52.0 years (48-52). At final follow-up, 96% of patients reported being satisfied with their BHR, with mean Harris Hip Scores of 93.6 and Oxford Hip Scores of 16.5. Rates of radiological femoral neck narrowing of greater than 10% and non-progressive radiological loosening were reported as 2.0% and 3.8% respectively. At final follow-up, the overall revision rate was 4.9% (334/7132), deep infection rate was 0.4%, metal allergy/insensitivity rate was 1.6%, metal reaction rate was 0.3%, rate of peri-prosthetic fracture was 0.9% and aseptic loosening rates were 1.6%. This systematic review demonstrates that BHR results in satisfactory clinical outcomes, acceptable implant survivorship, low complication rates and modest surgical revision rates in the long-term at minimum 10-year follow-up.

Keywords: Birmingham hip, hip resurfacing, metal-on-metal, long-term, 10 years.
variety of studies have reported their experiences with BHR in patients with a minimum of 10-years follow-up, to the best knowledge of the authors of this study no systematic review has previously been performed to evaluate such outcomes further for BHR alone despite renewed interest in BHR continuing to grow in to the 21st century. Therefore, the purpose of this study was to systematically review the literature to evaluate the clinical outcomes, radiological outcomes and revision rates following BHR at a minimum of 10 years follow-up.

MATERIALS & METHODS

A systematic review of the literature was performed using two independent reviewers (M.S.D. and K.M.) with specific reference to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. A search of the PubMed, Embase and Scopus databases was carried out as a literature search on 21st March 2021 the using the following search terms: ((long-term or long term or 10 or ten or follow-up or follow-up) and (hip resurfacing or hip arthroplasty) and (metal-on-metal hip or birmingham hip)). Prior to search commencement, the authors agreed that no time limit would be applied to the search. After removing duplicate studies, both reviewers manually screened the titles and abstracts of all studies independently from the initial search whilst applying our exclusion criteria, with the senior author (C.G.M.) acting as an arbitrator in cases whereby discrepancies in opinion between the two reviewers. Following this, both independent reviewers assessed the full texts of the remaining 303 studies in order to evaluate for eligibility. Overall, a total of 12 clinical and radiological studies, (5) cadaveric studies, (6) abstract only or conference papers, and (6) case reports.

The pre-determined data collection sheet was utilized by both independent reviewers in evaluation of each of the published manuscripts of the included studies with a focus of gathered all relevant data.

Study characteristics and patient demographics of interest included: (1) mean follow-up, (2) minimum follow-up, (3) study design, (4) level of evidence (LOE), (5) methodological quality of evidence (MQOE), (6) number of included hips which underwent BHR, (7) mean patient age, (8) patient gender, and (9) number of patients who under BHR for hip OA. The criteria previously described by Wright et al. and Robertson et al. were applied in evaluation of the LOE and MQOE of each included study respectively.

Clinical outcomes of interest included: (1) reported pain levels, (2) range of motion, (3) patient satisfaction, (4) mean pre-operative and post-operative (a) Harris Hip scores (HHS), (b) Oxford hip scores (OHS), and (c) University of California Los Angeles (UCLA) scores. Complications highlighted as outcomes of interest included: (1) deep infection, (2) residual pain, (3) subluxation, (4) dislocation, (5) aseptic loosening of the (a) femoral component, or (b) acetabular component, (6) metal allergy/sensitivity, (7) ARMD, (8) PPF, (9) necrosis, and (10) surgical revisions.

Radiological outcomes of interest included: (1) femoral stem-neck angles, (2) femoral neck narrowing of greater than 10%, (3) acetabular cup (a) inclination, and (b) anteversion, (4) non-progressive radiological loosening, and (5) osteolysis of (a) the femoral component, or (b) the acetabular component. Biochemical outcomes of interest included: (1) cobalt (Co), and (2) chromium (Cr) levels at final follow-up.

All collected data was stored on the pre-determined data sheet. This was thereafter tabulated with subsequent qualitative statistical analysis was performed using Microsoft Excel (Redmond, WA, USA).

RESULTS

The initial literature search resulted in a total of 4242 studies. After the removal of 1169 duplicate studies, the remaining 3073 studies were screened using our pre-determined exclusion criteria. Thereafter, our pre-determined inclusion criteria was applied to the full texts of the remaining 303 studies in order to evaluate for eligibility. Overall, a total of 12 clinical studies including 7132 hips met the inclusion criteria of this study. A summary of the literature search
with respect to PRISMA guidelines is illustrated in Figure 1.

The 12 included studies composed of 7132 hips that underwent BHR at minimum 10-years follow-up. All included studies represented level III evidence, with a mean MQOE of 55.9 (43-61). Overall, 94.3% of patients underwent BHR for OA of the hip (6239/6619). Additionally, 64.8% of included patients were male with a mean age of 52.0 years ± 2.3 and mean follow-up of 11.5 ± 2.3 years. A summary of study characteristics and patient demographics is further illustrated in Table I.

The most commonly utilized outcome score was the HHS, which was reported in 5 studies. A total of 3 studies (n=440) reported mean pre-operative HHS of 50, with a total of 5 studies (n=1547) reported mean post-operative HHS of 93.6 at minimum 10-years follow-up. Additionally, a total of 4 studies (n=1307)

Table I. — Patient demographics & study characteristics

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>LOE</th>
<th>Mean F/U (Yrs)</th>
<th>Range (Yrs)</th>
<th>Hips N</th>
<th>Males</th>
<th>OA</th>
<th>Mean Age (Yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azam et al.</td>
<td>2016</td>
<td>III</td>
<td>12.05</td>
<td>10-15</td>
<td>244</td>
<td>153</td>
<td>244</td>
<td>57</td>
</tr>
<tr>
<td>Daniel et al.</td>
<td>2014</td>
<td>III</td>
<td>13.7</td>
<td>12.3-15.3</td>
<td>1000</td>
<td>665</td>
<td>763</td>
<td>NR</td>
</tr>
<tr>
<td>Hastie et al.</td>
<td>2021</td>
<td>III</td>
<td>Min 13</td>
<td>Min 13</td>
<td>123</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Hollandet al.</td>
<td>2012</td>
<td>III</td>
<td>11.5</td>
<td>10-13</td>
<td>100</td>
<td>74</td>
<td>79</td>
<td>51.3</td>
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<tr>
<td>Hunter et al.</td>
<td>2018</td>
<td>III</td>
<td>Min 10</td>
<td>Min 10</td>
<td>121</td>
<td>76</td>
<td>104</td>
<td>52.5</td>
</tr>
<tr>
<td>Jonas et al.</td>
<td>2019</td>
<td>III</td>
<td>17.6</td>
<td>NR</td>
<td>63</td>
<td>41</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Malek et a.</td>
<td>2011</td>
<td>III</td>
<td>10</td>
<td>10-13</td>
<td>100</td>
<td>66</td>
<td>NR</td>
<td>51</td>
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<tr>
<td>Mehra et al.</td>
<td>2015</td>
<td>III</td>
<td>10.8</td>
<td>10-14</td>
<td>120</td>
<td>63</td>
<td>68</td>
<td>50</td>
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<tr>
<td>Moroni et al.</td>
<td>2017</td>
<td>III</td>
<td>10.8</td>
<td>Min 10</td>
<td>100</td>
<td>56</td>
<td>66</td>
<td>48.9</td>
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<tr>
<td>Stoney et al.</td>
<td>2020</td>
<td>III</td>
<td>11</td>
<td>NR</td>
<td>4790</td>
<td>4790</td>
<td>4790</td>
<td>52</td>
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<tr>
<td>Treacy et al.</td>
<td>2011</td>
<td>III</td>
<td>10.9</td>
<td>10.2-12.2</td>
<td>144</td>
<td>107</td>
<td>125</td>
<td>52</td>
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<td>Van Der Straeten et al.</td>
<td>2013</td>
<td>III</td>
<td>10.8</td>
<td>10-13.6</td>
<td>227</td>
<td>136</td>
<td>NR</td>
<td>50.5</td>
</tr>
</tbody>
</table>

F/U: Follow-Up, LOE: Level of Evidence, N: Number, NR: Not reported, OA: Osteoarthritis, Yrs: Years
reported mean pre-operative OHS of 16.5 at minimum 10-years follow-up.

Patient reported satisfaction was reported in a total of 4 studies with 96.2% of patients being satisfied (2354/2446) at minimum 10-years follow-up. Additionally, residual pain was reported in a total of 4 studies with 0.9% of patients reporting residual pain in any anatomical location believed to be secondary to the BHR (23/6024) at minimum 10-years follow-up.

Overall, 3 studies including 427 patients reported mean Co and Cr levels at minimum 10-years follow-up. The mean Co and Cr levels were 1.1 μg/L and 1.8 μg/L respectively. A summary of clinical and biochemical outcomes is further illustrated in Table II.

A total of 7 of the included studies (n=1935) reported on radiological outcomes at minimum 10-years follow-up. The most commonly reported radiological finding was mean acetabular cup inclination, which was reported in 6 studies as 44.3° (n=1691). Additionally, a total of 3 studies each reported mean acetabular cup anteversion as 13.9° (n=447) and mean femoral stem-neck angles as 142.2° (n=1244).

Overall, the rate of radiological osteolysis was reported as 2.0% in 4 studies (29/1471). This included a total rate of femoral and acetabular osteolysis of 1.1% (16/1471) and 0.9% (13/1471) respectively. A total of 3 reported the overall rates of radiological loosening as 3.8% (18/471). Additionally, a total of 2 studies reported the rate of femoral component narrowing of greater than 10% to be 2.0% (22/1100).

Overall implant survivorship was reported in 11 of the included studies (n=7032), with a mean BHR implant survivorship of 94.0% at minimum 10-years follow-up. All included studies reported rates of surgical revisions, with the total rate of surgical revisions was 4.7% at minimum 10-years follow-up. The most commonly reported complication following BHR was PPF, which was reported in 11 studies as 0.9% (64/7032).

The overall rate of aseptic loosening was reported as 1.9% in 8 studies (106/6619), with 7 and 4 studies reporting aseptic loosening of the femoral and acetabular components as 1.8% (34/1935) and 0.3% (4/1508) respectively. A total of 5 and 2 studies reported the rates of ARMD and metal allergy/insensitivity as 0.3% (21/6133) and 1.6% (6/371). Furthermore, the overall rates of dislocation and subluxation were reported in 4 studies each as 0.1% (5/5254) and 0.2% (1/608). Additionally, the rates of deep infection, residual pain and necrosis were 0.4% (28/6519), 0.3% (14/5161) and 0.3% (16/5264) respectively. A summary of radiological findings, complications and surgical revisions is further illustrated in Table III.

**DISCUSSION**

The most important findings in this study were that BHR resulted in excellent clinical outcomes, high rates of patient reported satisfaction and excellent radiological outcomes at minimum 10-years follow-up. Additionally, this study found excellent implant
Birmingham hip resurfacing: a systematic review of outcomes at minimum 10-years follow-up

survivorship with low complication rates and modest revision rates following BHR at long term follow-up.

Initially designed as a highly durable implant which preserves larger quantities of bone stock in hope of greatly reducing the risk of dislocation, the emergence of BHR in the 1990s sought to enable the young, active patient a similar quality of life to their active peers. In a previous systematic review, satisfactory functional outcomes were reported following BHR, suggesting that in the medium-term this may indeed be the case. Our study found similar outcomes in the long-term, with excellent post-operative HHS and OHS as well as very high rates of patient-reported satisfaction at minimum 10-years follow-up post-BHR. Furthermore, the authors not only acknowledge the excellent functional outcomes reported in the literature following BHR, but the high rates of return to physical activity also in the athletic patient. Therefore, the findings of this study support previous literature suggesting that there is no apparent step-off of functional outcomes during the transition from medium- to longer-term follow-up post-BHR.

Concerns have previously been raised in relation to elevated serum metal ion levels with MoM implant usage. De Smet et al. reported that measurements of serum Co and Cr concentrations can be used to estimate the amount of wear taking place in MoM hip-replacement devices, as well as potential metallosis. Following an expert consensus meeting on the topic, a consensus was found that serum ion concentration levels greater than 10 μg/L of Co or Cr are concerning for excessive wear of metal articular surfaces. Furthermore, Savarino et al. found that in the context of MoM implant utility, serum Co and Cr levels appear to be higher post-HR versus THR implantation at baseline. This study found low concentrations of serum Co and Cr ions at long-term follow-up post-BHR, with these findings echoed by the excellent clinical results and low failure rates reported in this review. Despite the low metal ion levels reported in this review, the authors do respect that implementation of regular, interval biochemical monitoring of patients following BHR as routine is should be deemed mandatory to ensure early detection of any potential failures of BHR in future.

This study found low rates of subluxations and dislocations post-BHR at long-term follow-up. Van der Straeten et al. found that 118 hip resurfacing experts reached a consensus not to perform hip resurfacing in case of a femoral head size smaller than 46 mm in diameter. The BHR implant possesses a large diameter femoral head, intent on reducing subluxation and dislocation rates with respect to those reported following conventional THR. Therefore, the enhanced stability afforded by the large diameter implant design is evidenced in the results reported in our study; with minimal dislocation and subluxation rates reported at minimum 10-years follow-up post-BHR.

Despite predominantly positive clinical and biochemical outcomes reported at long-term follow-up, the use of MoM hip implants remains controversial over the past 3 decades. Cohen et al. reported rates of failure of MoM HR and THR of approximately 12% and 13% at 8-years follow-up respectively, compared to rates of less than 5% when non-MoM implants are utilized. This study reports findings in contrary to such literature, with a surgical revision rate of less than 5% reported in this study. Furthermore, all included studies reported a revision rate of less than 10% at minimum 10 years follow-up, with overall pooled survivorship of BHR of approximately 94%. Given the globally high revision rates reported for resurfacing implants in the previously published 17th National Joint Registry report, the authors of this study feel that perhaps dissociation of the BHR implant from other models of hip resurfacing implants is necessary when reporting long-term outcomes of these procedures in future. With respect to these results, the authors of this study therefore suggest the use of BHR is at least comparable, if not superior in the young, active patient in the context of surgical management of hip pain, particular related to OA.

This study is a systematic review of the literature, so it therefore inherently suffers from the innate limitations of all included studies. Furthermore, all 12 included studies in this review are retrospective in nature, therefore representing studies of lower LOE. Analysis of the data gathered for this study is limited, with the majority of quantitative analysis being pooled by pre-determined outcome of interest. Additionally, a number of the included studies in this systematic review failed to report results that represent the outcomes of interest outlined in this study. Finally, there is potential for many surgical approaches or techniques to be used for BHR; this may ultimately vary amongst the included studies themselves, which may potentially be a confounding variable, which may influence the outcomes of this study.

CONCLUSION

This systematic review demonstrates that BHR results in satisfactory clinical outcomes, acceptable implant survivorship, low complication rates and modest surgical revision rates in the long-term at minimum 10-year follow-up.
REFERENCES


