ORIGINAL ARTICLE

Radiographic changes of the femoral neck after total hip resurfacing

J.-M. Laffosse a,*, K. Aubin b, M. Lavigne b, A. Roy b, P.-A. Vendittoli b

a Musculoskeletal institute, Department of orthopaedic surgery and traumatology, Rangueil Teaching Hospital Center, 1, avenue Jean-Poulhès, TSA 50032, 31059 Toulouse cedex 9, France
b Maisonneuve Rosemont Hospital, Surgery Department, Montréal University, 5415, boulevard de L’Assomption, Montréal, Québec H1T 2M4, Canada

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Summary

Introduction: Significant femoral neck narrowing following hip resurfacing arthroplasty has been observed. Several factors contributing to the physiopathology of femoral neck narrowing have been suggested. The aim of this study was to evaluate the femoral neck radiographic changes observed after hip resurfacing at a minimum follow-up period of 5 years and to determine their causes.

Patients and methods: We conducted a prospective study of 57 hip resurfacing arthroplasties performed in 53 patients (30 men, 23 women) of mean age 49.2 years (32–65) at surgery. These patients were clinically reviewed (inguinal pain during walking, WOMAC and UCLA scores) at 2 years and radiographically examined at 1, 2 and 5 postoperative years. The accuracy of our computer-aided measurement method was 1 mm. Measurement of femoral neck to implant ratio was performed to assess the amount of neck thinning at the femoral neck-implant junction (N/H) and midway between the implant and the inter-trochanteric line (N1/2/H) on an AP radiograph. Neck-thinning greater than 10% was considered as significant. Any other radiographic morphologic change in the femoral neck was investigated. Metallic ion concentration in blood was measured. A univariate and multivariate analysis was performed to determine the correlation with radiographic changes.

Results: In one third of the patients, femoral neck narrowing was greater than 1 mm at 2 and 5 postoperative years. Such result corresponds to a mean decrease in neck to implant ratio (N/H) of 5.9% (range, 2.3 to 9.4) at 2 years and 8.3% (range, 2.5 to 23.8) at 5 years. At 5 postoperative years, an overall neck thinning greater than 10% was reported in 3 patients (with a 10- to 17-% increase in femoral neck narrowing between the 2nd and the 5th postoperative year). In one case, neck thinning was associated with fracture of the femoral stem managed with revision surgery during which femoral neck necrosis was confirmed. Neck thinning was, in these...
cases, circumferential to the neck-implant junction. There was no significant negative impact on clinical scores and no relationship could be established between neck thinning and factors such as BMI or patient activity. Moreover, neck thinning greater than 10% was reported in two cases after 2 postoperative years through the appearance of a localized femoral neck notching which was absent in the postoperative period, secondary to a femoroacetabular impingement.

**Discussion—Conclusion:** Femoral neck narrowing used to be a common phenomenon after HR when polyethylene acetabular bearings were implanted thus inducing osteolysis secondary to PE wear debris. The incidence of such phenomenon has decreased but still occurs after HR when using a metal-on-metal bearing surface. It has an early occurrence but stabilizes after 2 postoperative years. Changes in mechanical stress distribution in the neck region after hip resurfacing have been hypothesized to be a cause of neck thinning. Other aetiologies may be suggested. An overall evolutive femoral neck narrowing after 2 postoperative years should raise the suspicion of necrosis leading to a risk of loosening, fracture or implant failure. Therefore, radiographic monitoring should be conducted. The presence of femoral neck notching secondary to femoroacetabular impingement represents a differential diagnosis which conservative treatment is advocated in the absence of any associated symptoms.

*Level of evidence:* Level IV, retrospective review.

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### Introduction

First generation hip resurfacing arthroplasties (HR) used to combine a metal femoral implant articulating with a polyethylene acetabular cup. Poor results were obtained with a survival rate of only 34% at 10 years [1]. Failures were often associated with femoral neck narrowing and implant loosening due to osteolysis secondary to major volumetric wear of the polyethylene component when articulating with a large diameter femoral head [1,2]. Advances in tribology regarding metal-on-metal bearing couples (MoM) and industrial improvements in terms of implant machining have been applied to the principles of hip resurfacing which experienced a reviewed interest in the 1990s [3]. The published series regarding this last generation of implants report encouraging survival rates (from 90 to 99% at 3–8-years) [4–7]. Early revision surgeries are mainly associated with femoral neck fractures and loosening of the femoral component [3,8]. Femoral component loosenings account for more than 30% of all revision cases and are most commonly induced by avascular osteonecrosis of the femoral head [8]. Such necrosis could be secondary to the selected surgical approach, the cementing technique or idiopathic [3,7,9]. Mechanical loosening has also been related to an excessive varus positioning of the femoral implant which is believed to increase shear forces at the bone-implant interface [10,11].

The occurrence of femoral neck narrowing following metal on metal hip resurfacing has also been described [6,11–15]. Various physiopathological hypotheses (mechanical, vascular, biological...) have been proposed to explain such phenomenon [12,13] but apart from biomechanical studies that were conducted to analyze the amount of stress applied in the neck region after hip resurfacing [16–18], very few clinical, radiographic or biological data could confirm or invalidate these hypotheses [11,12].

Therefore, we performed a study to assess the radiographical changes including femoral neck narrowing after metal-on-metal hip resurfacing in order to analyze their possible causes.

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### Material and methods

**Patients**

We prospectively reviewed 57 hip resurfacing implants which were consecutively implanted in 53 patients (between April 2003 and September 2004) with a minimum follow-up period of 5 years. Demographic features of patients (age, gender, body mass index) are reported in Table 1. The initial diagnosis was osteoarthritis of the hip in 45 cases (33 patients out of 45 had osteoarthrosis of the hip secondary to a femoroacetabular impingement mainly of cam type, four of 45 had a pincer impingement (coxa profunda) and no specific cause (primary osteoarthrosis of the hip) could be identified in eight patients of 45), a child disease (Legg-Calvé or hip dysplasia) in six cases, post-traumatic arthritis in four cases, osteonecrosis in one case and ankylosing spondylarthritis in one case. This study was approved by the ethic and scientific committee of our institution and patients had read and signed the consent form which explained the aim of that study.

**Implant and surgery**

The three surgeons (LM, RA, VPA) who performed these arthroplasties used a conventional posterior approach for implantation of a Durom™ prosthesis (Zimmer, Warsaw, IN, USA) combined with a Metasul™ (Zimmer, Warsaw, IN, USA) metal-on-metal bearing couple. After acetabular preparation, a cementless acetabular cup was inserted using a press-fit technique, thus providing primary stability to the component. During femoral head preparation, the synovium was preserved at the level of the neck and osteophytes were removed in a cortical sparing manner. The femoral component was placed within 5–10° of valgus in comparison with its initial positioning (with a minimum neck-shaft angle of 135°). Prior to implant cementation, the femoral bone was abundantly irrigated, with no pressure. The femoral implant was cemented (Simplex™ TOBRA cement, Howmedica Int. S. de RL, Limerick, Ireland) 4 minutes after the beginning
Radiographic changes of the femoral neck after total hip resurfacing

Table 1  Clinical and radiographic data. Data are reported according to the mean ± standard deviation (minimum—maximum).

<table>
<thead>
<tr>
<th></th>
<th>Collective</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of cases/patients</strong></td>
<td>57/53</td>
<td>34/30</td>
<td>23/23</td>
</tr>
<tr>
<td><strong>Age (years)</strong></td>
<td>49.2 ± 7.9 (32—65)</td>
<td>50.3 ± 7.8 (35—65)</td>
<td>47.6 ± 7.9 (32—61)</td>
</tr>
<tr>
<td><strong>Body Mass Index (kg/m²)</strong></td>
<td>26.6 ± 5.4 (17.6—43.7)</td>
<td>28.5 ± 4.9 (21.2—43.7)</td>
<td>24.0 ± 5.1 (17.6—38.5)</td>
</tr>
<tr>
<td><strong>Acetabular cup diameter (mm)</strong></td>
<td>54.3 ± 4.4 (44—64)</td>
<td>57.0 ± 2.8 (52—64)</td>
<td>50.6 ± 3.4 (44—56)</td>
</tr>
<tr>
<td><strong>Inclination angle of the acetabular cup (degrees)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean of the collective</td>
<td>47.7 ± 7.2 (30—59)</td>
<td>46.7 ± 7.6 (30—56)</td>
<td>49.1 ± 6.5 (35—59)</td>
</tr>
<tr>
<td>Hyper-inclination (&gt;55°)</td>
<td>13</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Normo-inclination (35°—55°)</td>
<td>41</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>Hypo-inclination (&lt;35°)</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td><strong>Inclination angle of the femoral implant (degrees)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean of the collective</td>
<td>141.8 ± 7.4 (120 — 156)</td>
<td>140.9 ± 7.2 (120 — 156)</td>
<td>143.0 ± 7.6 (130 — 156)</td>
</tr>
<tr>
<td>Hyper-corrected (&gt;10°)</td>
<td>15</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Normo-corrected (5°—10°)</td>
<td>24</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>Hypo-corrected (&lt;5°)</td>
<td>18</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td><strong>Valgus/Varus</strong>b</td>
<td>39/18</td>
<td>25/8</td>
<td>14/10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Collective</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variation in the femoral implant inclination angle (degrees)a</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean of the collective</td>
<td>7.3 ± 4.8 (−4—16)</td>
<td>8.4 ± 5.0 (−4—16)</td>
<td>5.8 ± 4.2 (−4—13)</td>
</tr>
<tr>
<td>Hyper-corrected (&gt;10°)</td>
<td>15</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Normo-corrected (5°—10°)</td>
<td>24</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>Hypo-corrected (&lt;5°)</td>
<td>18</td>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

a Variation in the femoral inclination angle is the difference between the femoral implant inclination and the native femoral neck inclination.

b When the femoral implant is positioned within more than 5° of valgus relative to the native femoral neck, it is considered as valgus positioning; it is considered as varus positioning in the opposite case.

do of the cement preparation. The femoral stem diameter was smaller than that of the drilling hole, the stem was smooth and cementless. The main function of the stem was to achieve centering during implantation in order to obtain a regular cement mantle. The same postoperative rehabilitation protocol was implemented in all patients and consisted in standing up the day after surgery, weight bearing according to pain tolerance, free range of movement with no hip restrictions and return to home once protected (or not) autonomous walking was achieved. At 3 months, all types of activities were permitted including impact sports.

**Clinical and radiographic evaluation**

The postoperative clinical assessment was performed by a non-operator observer (JML). The degree of pain while standing and walking on flat ground was evaluated using the Likert Scale rating pain from 0 to 4 (0: no pain; 1: low pain; 2: mild pain; 3: severe pain; 4: extreme pain with walking incapacity) [19] associated with the WOMAC score [20] and the UCLA Activity Score [21]. Hip flexion was measured by means of a goniometer. Standard AP and lateral radiographs were made preoperatively and postoperatively at 1, 2 and 5 years. The whole radiographic analysis was performed by two non-operator observers (JML and KA) using the TraumaCad 2.0 software (Orthocrat software, Petach-Tikva, Israel). Acetabular cup inclination was measured according to the Sutherland technique [22]. Femoral component inclination was measured relative to the axis of the femoral shaft [23] and was compared to the native femoral neck inclination in order to assess the changes in inclination between the pre- and postoperative period. Femoral implants were considered hyper-corrected with more than 10° of valgus, normocorrected between 5 and 10° of valgus and hypocorrected under 5° of valgus. For distance measurements, radiographs were calibrated using the known diameter of the femoral component (H). The width of the femoral neck was measured at the neck-implant junction (N) and midway between the neck-implant junction and the inter-trochanteric line (N1/2) (Fig. 1). The values and changes in neck to implant ratios observed at the neck-implant junction (N/H) and midway between the implant and the inter-trochanteric line (N1/2/H) were calculated during postoperative radiographic controls at 1, 2 and 5 years. We also investigated significant radiolucent lines (more than 1 mm width and evolutive on the successive postoperative radiographs taken between 2 and 5 years) that could be identified around the acetabular component by precising their location on AP (zones I, II and III) [24] and lateral radiographs (zones IV, V and VI) [25] as well as around the femoral stem on AP (zones 1, 2 and 3) [11] and lateral radiographs (zones 4, 5 and 6) [25]. Lytic areas around the
Table 2  Biological data: metal ion concentration in blood expressed in μg/l. Data are reported according to the mean ± standard deviation (minimum—maximum)a.

Overall population

<table>
<thead>
<tr>
<th></th>
<th>Neck thinning greater than 1 mm</th>
<th>No neck thinning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 year</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of samples available</td>
<td>24</td>
<td>6</td>
</tr>
<tr>
<td>Chromium</td>
<td>1.50 ± 0.90 (0.4—4.5)</td>
<td>1.73 ± 0.5 (1—2.4)</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.57 ± 0.23 (0.25—1.21)</td>
<td>0.51 ± 0.21 (0.25—0.8)</td>
</tr>
<tr>
<td>Titanium</td>
<td>3.03 ± 1.59 (1.0—6.5)</td>
<td>2.67 ± 1.03 (1.6—4)</td>
</tr>
<tr>
<td><strong>At 2 years</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of samples available</td>
<td>26</td>
<td>7</td>
</tr>
<tr>
<td>Chromium</td>
<td>1.49 ± 0.67 (0.6—3.0)</td>
<td>1.23 ± 0.62 (0.7—2.1)</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.55 ± 0.22 (0.2—1.05)</td>
<td>0.47 ± 0.3 (0.2—1.05)</td>
</tr>
<tr>
<td>Titanium</td>
<td>1.96 ± 0.76 (0.61—3.6)</td>
<td>1.93 ± 0.67 (1.3—3.1)</td>
</tr>
</tbody>
</table>

a For correlation calculations between ion concentration rates and decrease in ratios, only the cases where neck thinning was beyond the 1 mm accuracy of our measurement method were retained.

cup were investigated by precising their location on AP (A: superior and B: inferior) and lateral views (C: anterior and D: posterior). Reactive lines and pedestal formations were also investigated on AP radiographs and classified according to Pollard et al. [26]. Only good quality radiographs were used for radiographic measurements. The quality criteria were: sacrum centered on the pubic symphysis, a 2- to 3-cm distance from pubic symphysis to sacrum comparable in all views, symmetrical obturator foramina, neutral femoral rotation and comparable in all views. All patients were taken immediate postoperative radiographs of satisfactory quality, 47 patients at 1 year, 53 at 2 years and 56 patients at 5 years.

Table 3  Femoral neck thinning at different locations (neck-implant junction: [N/H] and midway: [N/1/2/H]. According to the different postoperative follow-up periods. Data are reported according to the mean ± standard deviation (minimum—maximum).

<table>
<thead>
<tr>
<th></th>
<th>Immediate postoperative - 1 year</th>
<th>Immediate postoperative - 2 years</th>
<th>Immediate postoperative - 5 years</th>
<th>2 years — 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neck-implant junction: (N/H)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cases greater than 1 mm</td>
<td>14±/47</td>
<td>21±/53</td>
<td>23±/56</td>
<td>14/53</td>
</tr>
<tr>
<td>Mean thinninga (mm)</td>
<td>−1.8 ± 0.5 (−2.6—1.3)</td>
<td>−2.2 ± 0.7 (−3.7—−1)</td>
<td>−3.0 ± 1.9 (−1.1—−8.6)</td>
<td>−2.5 ± 1.4 (−1.2—−5.6)</td>
</tr>
<tr>
<td>Variation in neck to implant ratio (%)a</td>
<td>5.0 ± 1.4 (3.1—8.0)</td>
<td>5.9 ± 1.9 (2.3—9.4)</td>
<td>8.3 ± 5.4 (2.5—23.8)</td>
<td>7.0 ± 4.9 (3.1—16.9)</td>
</tr>
<tr>
<td>Neck thinning &gt;10% (number of cases)</td>
<td>1±b</td>
<td>2±c</td>
<td>5±c</td>
<td>3±d</td>
</tr>
</tbody>
</table>

| **Midway: (N1/2/H)** |
| Number of cases greater than 1 mm | 17/46                          | 17/53                          | 17/56                          | 6/53 |
| Mean thinninga (mm) | −1.9 ± 0.6 (−1.2—−3.2)          | −1.9 ± 0.7 (−1.1—−3.8)         | −1.9 ± 0.7 (−1.1—−3.5)         | −1.6 ± 0.5 (−1.1—−2.5) |
| Variation in neck to implant ratio (%)a | 4.7 ± 1.3 (2.8—7.1)             | 4.7 ± 1.4 (2.8—8.2)            | 4.7 ± 1.8 (2.6—7.8)            | 4.1 ± 1.1 (3.1—5.7) |
| Neck thinning >10% (number of cases) | 0                               | 0                              | 0                              | 0|

a Due to the accuracy of the measurement method used in the present study, only neck thinnings greater than 1 mm were included in our calculations. Cases of impingement were also excluded from our calculations since they belong to another physiopathologic mechanism.

b Out of which 1 case of early impingement.

c Out of which 2 cases of early impingement.

d These 3 cases correspond to an overall circumferential thinning.
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− deviation. Therefore, 97.5% of the values ranged from 0.3-mm standard deviation. At 1 month interval demonstrated a 0.3-mm standard deviation. Therefore, 97.5% of the values ranged from −0.9 mm (−3DS) to +0.9 mm (+3DS). We only retained neck thinning when greater than 1 mm for our calculations. An intra-observer (JML) and inter-observer (JML and KA) reproducibility analysis was performed to validate the measurement and calculation method of the femoral neck narrowing at the neck-implant junction (N/H) and mid-way between the implant and the inter-trochanteric line (N1/2/H). The intra-observer analysis reported a \( k = 0.97 \) coefficient (IC 95%: 0.95−0.99) for \( (N/H) \) ratio measurement and a \( k = 0.92 \) coefficient (IC 95%: 0.87−0.95) for \( (N1/2/H) \) ratio measurement while the inter-observer analysis reported a \( k = 0.94 \) coefficient (IC 95%: 0.92−0.96) for \( (N/H) \) ratio measurement and a \( k = 0.91 \) coefficient (IC 95%: 0.87−0.93) for \( (N1/2/H) \) ratio measurement. For comparison analysis, the normal distribution of values was assessed. In case of normal distribution, a Student t-test was used; non-parametric tests were used when data were not normally distributed. A multivariate analysis (MANOVA) was performed to assess the possible correlations existing between \( (N/H) \) and \( (N1/2/H) \) ratios and the various factors such as age, gender, body mass index, femoral implant orientation, acetabular cup inclination, activity. The significance threshold was set to \( P<0.05 \).

Results

No intraoperative complication was reported in this series such as femoral neck notching during surgery. The radiographic data relative to the acetabular and femoral implant positioning are reported in Table 1. The whole results relative to the cases in which neck thinning was greater than 1 mm as well as absolute values in millimeters and relative values expressed in % (neck to implant ratio at the neck-femoral implant junction \( (N/H) \) and midway between the femoral implant and the intertrochanteric line \( [N1/2/H] \) are reported in Table 3.

**Measurement of ion concentration in blood**

Measurement of metal ion concentration (chromium, cobalt and titanium) in blood was performed using a high resolution HRICP-MS spectrometer (Inductively coupled plasma mass spectrometry, Thermo Fisher Scientific GmbH, Bremen, Germany) preoperatively and at 1 and 2 years postoperatively. Sixteen patients with a contralateral implant (HR, total hip or knee prosthesis) or osteosynthesis device were excluded from this analysis. The blood sampling method and details of the analyses have already been published [27]. The number of patients included in our analysis is reported in Table 2 (\( n=24 \) at 1-year follow-up and \( n=26 \) at 2-year follow-up).

**Statistical analysis**

The statistical analysis was carried out using the Statview™ software (SAS Institute Inc, Cary, NC, USA). The accuracy of neck thinning measurement was evaluated using the TraumaCad 2.0 software (Orthocrat software, Petach-Tikva, Israel). For a known cup diameter, the values of the 50 measurements performed during two successive campaigns at 1 month interval demonstrated a 0.3-mm standard deviation. Therefore, 97.5% of the values ranged from −0.9 mm (−3DS) to +0.9 mm (+3DS). We only retained neck thinning when greater than 1 mm for our calculations. An intra-observer (JML) and inter-observer (JML and KA) reproducibility analysis was performed to validate the measurement and calculation method of the femoral neck narrowing at the neck-implant junction (N/H) and midway between the implant and the inter-trochanteric line (N1/2/H). The intra-observer analysis reported a \( k = 0.97 \) coefficient (IC 95%: 0.95−0.99) for \( (N/H) \) ratio measurement and a \( k = 0.92 \) coefficient (IC 95%: 0.87−0.95) for \( (N1/2/H) \) ratio measurement while the inter-observer analysis reported a \( k = 0.94 \) coefficient (IC 95%: 0.92−0.96) for \( (N/H) \) ratio measurement and a \( k = 0.91 \) coefficient (IC 95%: 0.87−0.93) for \( (N1/2/H) \) ratio measurement. For comparison analysis, the normal distribution of values was assessed. In case of normal distribution, a Student t-test was used; non-parametric tests were used when data were not normally distributed. A multivariate analysis (MANOVA) was performed to assess the possible correlations existing between \( (N/H) \) and \( (N1/2/H) \) ratios and the various factors such as age, gender, body mass index, femoral implant orientation, acetabular cup inclination, activity. The significance threshold was set to \( P<0.05 \).

**Results**

No intraoperative complication was reported in this series such as femoral neck notching during surgery. The radiographic data relative to the acetabular and femoral implant positionning are reported in Table 1. The whole results relative to the cases in which neck thinning was greater than 1 mm as well as absolute values in millimeters and relative values expressed in % (neck to implant ratio at the neck-femoral implant junction \( (N/H) \) and midway between the femoral implant and the intertrochanteric line \( [N1/2/H] \) are reported in Table 3.

**N/H ratio**

At 1 year, 13 patients (out of 47 that is 27.5%) reported neck thinning greater than 1 mm (accuracy limit of our measurement method). They were 19 (out of 53 that is 36%) at 2 years and 21 (out of 56 that is 37.5%) at 5 years. When comparing with postoperative values, the mean decrease in \( (N/H) \) ratio was 5.9% (range, 2.3 to 9.4) at 2 years. A neck thinning of more than 10% was reported twice at 2-year follow-up (10.4 and 14%) with appearance of femoral neck notching, not detected in the postoperative period and secondary to impingement (Fig. 2). These both cases were not included in our calculations. For patients demonstrating neck thinning at 2 years, no significant increase in neck thinning could be observed between 2- and 5-year follow-up (2.21 mm ± 0.69 [range: 1—7.9] versus 2.77 ± 2.1 \( [1—7.9] \), \( P=0.23 \)). At 5-year follow-up, the mean decrease in \( (N/H) \) ratio was 8.3% (range: 2.5—23.8). At 5 years, three other patients with an overall neck thinning greater than 10% were noted (which corresponded to a 10- to 17-% neck thinning having occurred between the 2nd and the 5th year in these three patients) one of whom had a femoral stem fracture (Fig. 3) managed with revision surgery during which femoral head necrosis was confirmed (Fig. 3E). Among the patients with neck thinning greater than 1 mm, no significant change in \( (N/H) \) ratio could be observed between the 2nd and the 5th postoperative years. No correlation between acetabular cup positioning (excessive inclination > 55°, satisfactory between 35° and 55° or insufficient < 35°) and \( (N/H) \) ratio variation could be established at 1, 2 or 5 years (\( P>0.05 \)). There were signifi-
Figure 2  A. Postoperative AP radiograph showing proper femoral implant positioning with no intraoperative femoral neck notching. B. Radiograph of the same patient taken 2 years after surgery, revealing femoral neck notching in the upper region of the neck causing a 13-% neck thinning. C. Radiograph of the same patient taken at 5 postoperative years, showing stabilization of femoral neck notching.

significantly fewer cases of neck thinning greater than 1 mm in the group of patients with hypercorrected femoral implant compared with hypo- or normo-corrected implant positionings. The multivariate analysis could only show a tendency \((P=0.07)\) toward correlation between female gender and higher decrease in \((N/H)\) ratio at 2-year follow-up.

\((N_{1/2}/H)\) ratio

At 1 year, 17 patients (out of 46 that is 37%) reported a neck thinning greater than 1 mm. They were 17 (out of 53 that is 32%) at 2 years and 17 (out of 56 that is 30%) at 5 years. Six patients (out of 53 that is 11.5%) reported an increase in neck thinning of more than 1 mm between 2 and 5 postoperative years. When comparing with postoperative values, the mean decrease in \((N_{1/2}/H)\) ratio was 4.7% (range, 2.8—8.2) at 2 years and 4.7 (2.6—7.8) at 5 years. No cases of neck thinning greater than 10% could be observed at 2-year and 5-year follow-up.

When only taking into account the cases where neck thinning was greater than 1 mm (limit of accuracy of our measurement method), no correlation was found between femoral implant (hypo-, normo- or hyper-corrected) or acetabular cup positionning and the \((N_{1/2}/H)\) ratio value. No significant correlation could be established between acetabular cup inclination and \((N_{1/2}/H)\) ratio variation during controls (1, 2 or 5 years). The multivariate analysis did not reveal any independent factor for this ratio.

Radiolucent lines and reactive lines

The radiographic results are reported in Table 4. No significant difference could be found in terms of neck thinning \((N\) and \(N_{1/2}\)) despite the presence or absence of a reactive line or pedestal formation. In only one case, a radiolucent line was found around the femoral stem in a female patient reporting impingement and early femoral neck notching.
Figure 3  A. Postoperative AP radiograph showing proper femoral implant positioning in slight valgus, with no intraoperative sign of femoral neck notching. B. Radiograph of the same patient at 2-year follow-up revealing a circumferential neck thinning with no subjacent sclerosis at the neck-implant junction. Neck thinning is only evaluated at 9%. C. Radiograph of the same patient taken at 5 postoperative years showing an increase in circumferential neck thinning evaluated at 24%. D. Neck thinning is associated with fracture of the femoral stem (divergence between the metal axis and the cup). E. Radiograph of the same patient taken during femoral revision surgery demonstrating necrosis of the femoral head and neck associated with fatigue fracture at the stem-femoral implant junction.
Table 4  Radiographic results at 2 and 5 postoperative years.

<table>
<thead>
<tr>
<th>Presence of neck thinning&lt;sup&gt;a&lt;/sup&gt;</th>
<th>No neck thinning&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>At 2 years</td>
<td></td>
</tr>
</tbody>
</table>
| Number of cases                     | 21<sup>b</sup>                | 32  
| Reactive lines and pedestal formations |                               |  
| 1                                  | 11 spread as following        | 15 spread as following       | 0.70  
| 1a                                 | 7                             | 13                          | 0.60  
| 1b                                 | 2                             | 1                           | 0.34  
| 1c                                 | 2                             | 1                           | 0.34  
| 2                                  | 0                             | 0                           |       
| 3                                  | 0                             | 0                           |       
| Lytic area around the femoral cup  |                               |  
| A                                  | 3                             | 0                           | 0.03  
| B                                  | 0                             | 1                           | 0.41  
| C                                  | 0                             | 0                           |       
| D                                  | 0                             | 0                           |       
| Femoral cup positioning<sup>b</sup> |                               |  
| Hypocorrected                      | 9                             | 6                           |       
| Normocorrected                     | 8                             | 15                          |       
| Hyper-corrected                    | 2                             | 11                          | 0.04  
| At 5 years                         |                               |  
| Number of cases                     | 23<sup>b</sup>                | 33  
| Reactive lines and pedestal formations |                               |  
| 1                                  | 18 spread as following        | 24 spread as following       | 0.52  
| 1a                                 | 10                            | 19                          | 0.36  
| 1b                                 | 5                             | 4                           | 0.32  
| 1c                                 | 3                             | 1                           | 0.15  
| 2                                  | 0                             | 0                           |       
| 3                                  | 1                             | 0                           | 0.22  
| Radiolucent lines<sup>c</sup> acetabulum AP |           |                               |       
| I                                  | 2                             | 1                           | 0.34  
| II                                 | 2                             | 1                           | 0.34  
| III                                | 3                             | 2                           | 0.35  
| Radiolucent lines<sup>c</sup> acetabulum lateral |           |                               |       
| IV                                 | 3                             | 2                           | 0.35  
| V                                  | 3                             | 1                           | 0.15  
| VI                                 | 1                             | 1                           | 0.77  
| Radiolucent lines<sup>c</sup> femur AP |           |                               |       
| 1                                  | 2                             | 1                           | 0.34  
| 2                                  | 3                             | 2                           | 0.35  
| 3                                  | 2                             | 0                           | 0.22  
| Radiolucent lines<sup>c</sup> femur lateral |           |                               |       
| 4                                  | 2                             | 0                           | 0.22  
| 5                                  | 3                             | 1                           | 0.15  
| 6                                  | 2                             | 1                           | 0.34  
| Lytic area around the femoral cup  |                               |  
| A                                  | 3                             | 0                           | 0.03  
| B                                  | 0                             | 2                           | 0.25  
| C                                  | 0                             | 0                           |       
| D                                  | 0                             | 0                           |       

Significant differences are in bold characters.

<sup>a</sup> Due to the accuracy of the measurement method used in the present study, only neck thinnings greater than 1 mm at the neck-implant junction were included in our calculations.

<sup>b</sup> Out of which 2 cases of early impingement (excluded from our calculations).

<sup>c</sup> The diagnosis of radiolucent line was made only in the presence of a clear significant line (more than 1 mm width) and evolutive during radiographic assessments at 2 and 5 years.
Clinical results

At 2 years, there was no significant difference between the subjects with neck thinning and those with no neck thinning regarding the percentage of patients who experienced pain while walking on flat ground (P = 0.83), full flexion (P = 0.82), the WOMAC index (P = 0.16) or the UCLA score (P = 0.13) (Table 5). No correlation could be established between neck thinning and the intensity of physical activity.

Results of ion concentration measurements

No significant relationship could be established between the rate of metal ion concentration in blood and the degree of neck thinning. There was no significant statistical correlation between neck thinning at 2 and 5 years and ion concentration rates. The results of ion concentration measurements are reported in Table 2.

Discussion

Our study has several limitations. The accuracy of our computer guided measurement method is only 1 mm. Despite a limited number of cases, this prospective study and the 5-year follow-up period appear sufficient to ensure proper analysis of this phenomenon. Neck thinning was measured on AP radiographs but not in the sagittal plane [6,12,13]. "Cross-leg" of Dunn type views could theoretically allow a lateral measurement of the femoral neck. However, the difficulty in achieving reliable radiographs, thus, limits our analysis. The use of CT scan could have provided accurate measurements [12].

Femoral neck remodelling after HR is a well-known phenomenon [6,11—15]. In our study, neck thinning greater than 1 mm at 2 and 5 years was identified in one-third of the patients. In these cases, neck thinning was not significant, sometimes at the limit of the scope of our evaluation. At 2 years, neck thinning is 5.9% and never exceeds 10% (except two cases of localized femoral neck notching secondary to impingement and induced by different mechanisms). At 5 years, neck thinning was 8.3%. We did not find any significant increase in femoral neck resorption between 2 and 5 postoperative years, thus suggesting thinning stabilization after 2 postoperative years [12,13]. After the 5th postoperative year, three cases out of 57 (5%) demonstrated an overall neck thinning of more than 10%, one of which was associated with implant fracture. Most authors report a higher rate (Table 6) [6,12—14,28,29] whereas Steffen et al. [28] are the only authors to report 0% of neck thinning greater than 10% at 5-year follow-up with a BHR type implant cemented on the femur. On the whole, neck thinning (of about 5% of its length that is around 2 mm) occurs up to the end of the 2nd postoperative year, then stabilizes. In physiological conditions, this remodelling is mainly due to the changes in stress distribution in the neck region after HR and to stress-shielding [16,17] with no correlation in this study with an increased or decreased incidence of reactive lines around the femoral stem. Therefore, it was advocated to achieve a valgus positioning of the femoral implant (at least 5 to 8°) relative to the native femoral neck [10] to reduce stress while enhancing compressive forces [17,30]. This seems to be confirmed by the lower number of neck resorptions associated with hyper-correction of the femoral implant (more than 10° of valgus).

In pathologic conditions, other mechanisms may significantly aggravate neck thinning. In the presence of an overall, circumferential neck thinning predominantly occurring at the neck-implant junction (Fig. 3B and C) and progressively developing after 6 postoperative months, failure due to bone necrosis should be suspected. Failure may be progressive through impingement with femoral implant tilt or sinking and collapse of the femoral neck within the femoral implant [3,8], but might also be sudden secondary to a femoral neck fracture at the neck-implant junction [8] or more rarely secondary to implant fracture (Fig. 3D) [16]. The heat released during cementation has been evoked as a contributing factor [15] but Liliakis et al. [15] report a rate of 27% at 2.4 years after implantation of a non-cemented femoral cup and Mc Minn et al. [14] did not observe any difference between cemented and cementless implants in their series. Damage to the femoral circumflex pedicle was also evoked in particular when using a posterior approach as well as the occurrence of an intraprosthetic femoral neck notching [7,31]. Massive local metal ion concentration [32,33] could promote neck thinning through osteolysis secondary to phenomena such as delayed-type hypersensitivity [33,34] but also dose-dependent cytotoxic effects (regarding cobalt) on macrophages and osteoblasts in vitro [35,36]. No correlation could be established between ion concentration in blood and the amount of neck thinning due to the limitations of our study but also because these ion concentration in blood did not accurately reflect intra-articular ion concentration.

In specific conditions, changes may appear with no sign of true neck thinning. This rather corresponds to a local bone remodelling with fraying of the femoral neck and osteocondensation (Fig. 4A and B) corresponding to an impingement area. True femoral neck notchings may appear, sometimes deep and strictly localized in the impingement area [23], mostly at the anterosuperior aspect of the neck, at the neck-cup junction or slightly distal to this junction (corresponding to a combined flexion and internal rotation movement) [37]. Femoral neck notching occurs early during the first 2 postoperative years, then stabilizes once the patient has recovered proper joint mobility. It thus represents a true differential diagnosis of femoral neck narrowing. Femoral neck notching is promoted by sub-optimal acetabular cup (excessive retroversion or anteversion) or femoral implant positioning (anteroposterior mispositionning with lack of head-neck offset restoration) [37]. The cup that was used in this study has an opening angle of 165° which offers a great articular clearance which has no major impact since range of motion is mainly limited by soft tissues or bony contacts rather than by the rim of the acetabular cup [37].

Taking into account the limitations of our study, femoral neck narrowing greater than 1 mm was observed in one-third of the patients at the neck-cup junction. Neck thinning was stable after the 2nd postoperative year. When femoral neck resorption appears or increases beyond this period of time and exceeds 10%, a close monitoring should be carried out to detect any bone necrosis which may remain asymptomatic or slightly symptomatic and lead to neck fracture or implant rupture. In case of impingement, the radiographic aspect is
Table 5  Clinical results at 2 and 5 postoperative years. Data are reported according to the mean±standard deviation (minimum—maximum).

<table>
<thead>
<tr>
<th>Presence of neck thinninga</th>
<th>No neck thinninga</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>At 2-year follow-up</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cases</td>
<td>21b</td>
<td>32</td>
</tr>
<tr>
<td>Painful groin (number)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>WOMAC index (%)</td>
<td>90.0 ± 13.1 (56.3—100)</td>
<td>96.9 ± 3 (88.5—100)</td>
</tr>
<tr>
<td>UCLA activity score</td>
<td>7.0 ± 2.1 (4.0—10)</td>
<td>7.8 ± 1.3 (4.0—10)</td>
</tr>
<tr>
<td>UCLA global score</td>
<td>33.4 ± 6.5 (18—40)</td>
<td>36.7 ± 2.2 (30—40)</td>
</tr>
<tr>
<td>Hip flexion (degrees)</td>
<td>107.1 ± 11.0 (90—130)</td>
<td>103.3 ± 18 (30—130)</td>
</tr>
<tr>
<td><strong>At 5-year follow-up</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cases</td>
<td>23b</td>
<td>33</td>
</tr>
<tr>
<td>Painful groin (number)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>WOMAC index (%)</td>
<td>94.4 ± 9.1 (65.6—100)</td>
<td>94.6 ± 7.8 (65.6—100)</td>
</tr>
<tr>
<td>UCLA activity score</td>
<td>7.2 ± 2.5 (2—10)</td>
<td>7.8 ± 1.5 (5—10)</td>
</tr>
<tr>
<td>UCLA global score</td>
<td>35.2 ± 3.7 (29—40)</td>
<td>36.3 ± 2.3 (29—40)</td>
</tr>
</tbody>
</table>

a Due to the accuracy of the measurement method used in the present study, only neck thinnings greater than 1 mm at the neck-implant junction were included in our calculations.
b Two cases of early impingement excluded from our calculations since they belong to another physiopathologic mechanism.

Table 6  Results of the literature: thinning % of the femoral neck after hip resurfacing.

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Implant/opening angle</th>
<th>Number of cases</th>
<th>Follow-up</th>
<th>Approach</th>
<th>% of thinning greater than 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heilpern et al. [6]</td>
<td>Birmingham hip resurfacing, (Smith and Nephew Inc, Memphis, TN, USA) /160°</td>
<td>110</td>
<td>71 months (60—93)</td>
<td>Posterior</td>
<td>14.5</td>
</tr>
<tr>
<td>Hing et al. [12]</td>
<td>Birmingham hip resurfacing, (Smith and Nephew Inc, Memphis, TN, USA) /160°</td>
<td>163</td>
<td>5 years (4—6)</td>
<td>NA</td>
<td>27.6</td>
</tr>
<tr>
<td>Spencer et al. [13]</td>
<td>Cormet 2000 cimenté (Corin, Cirencester, United Kingdom) /180°</td>
<td>40</td>
<td>5.3 ans (2—7)</td>
<td>Posterior</td>
<td>15</td>
</tr>
<tr>
<td>Mc Minn et al. [14]a</td>
<td>Non cemented non HA coated /160°</td>
<td>70</td>
<td>3 years</td>
<td>NA</td>
<td>Mean thinning 1.47 mm at 3 years &lt;1 mm: 40% 1—2 mm: 16% &gt;2 mm: 44%</td>
</tr>
<tr>
<td>Mc Minn et al. [14]a</td>
<td>Non cemented + HA /160°</td>
<td>6</td>
<td>43</td>
<td>116</td>
<td>Hybrid (cemented femoral component and non cemented acetabular component) /160°</td>
</tr>
<tr>
<td>Mc Minn et al. [14]a</td>
<td>All cemented /160°</td>
<td>43</td>
<td>116</td>
<td>116</td>
<td>Hybrid (cemented femoral component and non cemented acetabular component) /160°</td>
</tr>
<tr>
<td>Steffen et al. [28]</td>
<td>Birmingham hip resurfacing, (Smith and Nephew Inc, Memphis, TN, USA) /160°</td>
<td>85</td>
<td>5 years minimum</td>
<td>Posterior</td>
<td>0</td>
</tr>
<tr>
<td>Gross and Liu [29]</td>
<td>Cormet 2000 version-I non cemented (Corin, Cirencester, United Kingdom) /180°</td>
<td>19</td>
<td>7.4 ans (5.3—8.3)</td>
<td>3 post16 AL</td>
<td>10 (2 cases out of 19: bilateral case of one patient)</td>
</tr>
<tr>
<td>Our series</td>
<td>Durom (Zimmer, Warsaw, IN, USA) /165°</td>
<td>57</td>
<td>5 years</td>
<td>Posterior</td>
<td>5</td>
</tr>
</tbody>
</table>

NA: non available; HA: hydroxyapatite.
a In this study, thinning was expressed in absolute value (in mm) and not in percentage.
Radiographic changes of the femoral neck after total hip resurfacing

Figure 4  A. Early postoperative AP radiograph (3 months) showing proper positioning of the femoral implant in a female patient practicing yoga exercises. Slight remodelling and fraying of the upper femoral neck region. B. Radiograph of the same female patient revealing a localized femoral neck notching on the upper region of the neck and subjacent sclerosis secondary to impingement.

very different: early appearance, rapid and sometimes disturbing but stabilizing after a period of 18 to 24 months once the patient has recovered proper joint mobility. These cases are conservatively managed in the absence of any associated symptoms.

Disclosure of interest

Dr P.A. Vendittoli is consultant for Zimmer, Stryker and Wright Medical. Dr M Lavigne is consultant for Zimmer and Wright medical. Drs Laffosse, Aubim and Roy, no conflict of interest.

References


