Densitometric evaluation of bone-prosthetic counterface in hip and knee arthroplasty with modern implants

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Introduction. Recent acquisitions of the complex mechanisms of osseointegration between implants and host bone have gained attention, accordingly to the methods of evaluation of these interactions. DXA analysis is considered an useful tool to assess such phenomena, in order to analyze in a quantitative manner the local metabolic activity of the bone, and to evaluate over the time the integration between host bone and prosthetic components. The purpose of the present study is to report about a preliminary experience in the analysis of osseointegration processes of patients undergoing a primary Total Hip Arthroplasty (THA) or a revision Total Knee Arthroplasty (rTKA).

Materials and methods. Thirty patients undergoing THA and nineteen undergoing rTKA were included in this study. In fifteen cases of THA a standard cementless stem was used; in the other fifteen a short cementless stem was chosen. In all cases a cementless cup was implanted. In all patients undergoing rTKA, all implants had pressfit femoral and tibial diaphyseal stems; only the femoral component and the tibial plateau were cemented. DXA evaluation was performed preoperatively, and at 3, 6, 12, and 24 months postoperatively for rTKA, and at 6 and 12 months for THA.

Results. DXA in THA showed a significant decrease at the femoral ROIs 1 and 7, and an increase in ROI 4. In rTKA a reduction of femoral BMD in R1, R7, and R4 was found, with maximum values of -13.6% in R1 and -11.89% in R7 at 24 months and a value of -2.55% in R4 at 12 months. On the tibial side, an increase in BMD R4 (with values of 2.16% still at 24 months), and a reduction in R7 (progressively lesser over the time) and in R1 (progressively higher) were found.

Conclusions. After a joint replacement a full adhesion of the prosthetic surface to the host bone should be achieved through a local biological process named osseointegration. In some cases this process may not fully realize, so the secondary stability of the implant may fail. DXA is a valuable tool to follow over time the bone remodelling at the bone-prosthesis counterface in THA and in rTKA, in order to early detect any alterations of such phenomenon.

KEY WORDS: total knee arthroplasty; total hip arthroplasty; revision; bone remodelling; DXA.
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Materials and methods

Thirty consecutive patients undergoing THA between 2011 and 2012 and nineteen consecutive patients undergoing rTKA between 2011 and 2013 were selected at the Authors’ Institution for a DXA study before and after surgery at specific intervals. The Institutional Review Board approved the study and follow-up, respecting the principles of the Declaration of Helsinki, and after an adequate informed consent of patients. Inclusion criteria were: adult patients candidate to THA and rTKA; no recent use of corticosteroids (<1 year before surgery) and collaborative patients able to express an informed consent. Exclusion criteria were: peri-prosthetic fractures, use of corticosteroids less than 1 year with respect to the index operation, patients affected by comorbidities treated by corticosteroids or biologic agents (as Rheumatoid Arthritis, Haemophilic Arthropathy) and subjects operated for proximal femoral fractures.

In fifteen cases of THA a PPF\textsuperscript{®} cementless stem (Biomet, Warsaw, IN) was chosen. In all cases a Regenerex\textsuperscript{®} cementless cup (Biomet, Warsaw, IN) was implanted. The use of a stem or another was made according to the age of patients at the time of surgery: subjects <70 years of age were selected for a smaller stem (GTS), while patients >71 years of age received a standard stem (PPF). The overall mean age was 60.3 (range: 50-78), and the mean Body Mass Index (BMI) was 29.4 (range: 25.0-38.6). In all patients undergoing a rTKA the Legion\textsuperscript{®} knee system (Smith & Nephew, Memphis, TN) was used, characterized by cementless femoral and tibial stems. The mean age was 71.3 (range: 49-83), and the mean Body Mass Index (BMI) was 30.3 (range: 20.3-40.4).

The preoperative evaluation was performed by dedicated scores: Knee Society rating Score (KSS) and Harris Hip Score (HHS) (27, 28). The radiographic study was performed following the criteria of DeLee and Charnley and Knee Society Roentgengraphic Evaluation System for THA and rTKA respectively (29, 30). A standard orthopaedic evaluation (Range of Motion, radiographic alignment) was conducted in all patients. At the time of inclusion in the study a DXA was performed for the evaluation of the lumbar and periprosthetic bone (Figures 1, 2). A follow-up by DXA was made at 6 and 12 months for THAs, and 3, 6, 12 and 24 months for rTKAs. In all cases the Hologic\textsuperscript{®} Scanning QDR 4500/DELPHI (HOLOGIC Inc, Zaventem, Belgium) was used. For the evaluation of THAs, the periprosthetic bone was studied by the analysis of the 7 Region of Interests (ROI) around the stem according to Gruen (31) (Figures 3, 4). In case of rTKAs 8 ROI were evaluated (32-34) (Figures 5, 6).

Table 1 - Total Hip Arthroplasty: BMD variations at 6 and 12 months (values are expressed in %).

<table>
<thead>
<tr>
<th>AREAS</th>
<th>6 mo</th>
<th>12 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short stem</td>
<td>Standard stem</td>
</tr>
<tr>
<td>R1</td>
<td>-0.5</td>
<td>-4.0</td>
</tr>
<tr>
<td>R2</td>
<td>0.9</td>
<td>-1.5</td>
</tr>
<tr>
<td>R3</td>
<td>1.0</td>
<td>2.8</td>
</tr>
<tr>
<td>R4</td>
<td>1.6</td>
<td>2.2</td>
</tr>
<tr>
<td>R5</td>
<td>1.2</td>
<td>3.2</td>
</tr>
<tr>
<td>R6</td>
<td>-0.1</td>
<td>-1.8</td>
</tr>
<tr>
<td>R7</td>
<td>-0.9</td>
<td>-3.8</td>
</tr>
</tbody>
</table>

Table 2 - Revision Total Knee Arthroplasty: BMD variations in Tibia and Femur at 3, 6, 12 and 24 months (values are expressed in %).

<table>
<thead>
<tr>
<th>AREAS</th>
<th>3 mo</th>
<th>6 mo</th>
<th>12 mo</th>
<th>24 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tibial Stem</td>
<td>Femoral Stem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>-1.62</td>
<td>-1.93</td>
<td>-2.42</td>
<td>-5.80</td>
</tr>
<tr>
<td>R2</td>
<td>-15.05</td>
<td>-11.63</td>
<td>-11.49</td>
<td>-14.15</td>
</tr>
<tr>
<td>R3</td>
<td>2.48</td>
<td>0.13</td>
<td>-3.80</td>
<td>-6.82</td>
</tr>
<tr>
<td>R4</td>
<td>9.67</td>
<td>4.86</td>
<td>5.18</td>
<td>2.33</td>
</tr>
<tr>
<td>R5</td>
<td>10.74</td>
<td>7.03</td>
<td>6.91</td>
<td>2.18</td>
</tr>
<tr>
<td>R6</td>
<td>0.63</td>
<td>-5.73</td>
<td>7.69</td>
<td>-6.11</td>
</tr>
<tr>
<td>R7</td>
<td>2.07</td>
<td>-11.97</td>
<td>-3.20</td>
<td>-12.71</td>
</tr>
</tbody>
</table>

Results

All patients completed the minimum follow-up of 12 months for the group of THA and 24 months for the group of rTKA. No intraoperative or postoperative complications and no failures were reported at the latest follow-up in both groups. The mean HHS showed an increase from a mean score of 42.1 to 63.7. Similarly, the mean KSS increased from a mean preoperative value of 41.3 to 73.4. Non progressive and <1mm radiolucencies were found in 2 THAs in zone 2 of DeLee and Charnley, without any complaint of patients and no indications to revision. No radiolucencies were founded at the radiologic follow-up of all rTKAs. All patients referred satisfaction for the procedure, showed an increase of ROM after surgery and a good level of functional ability.

At 12 months DXA showed a decreased BMD in ROIs 1 and 7 in all patients after THA for both stems, with lower values for GTS. On the contrary, an increased BMD was found in ROI 4 in all THAs, with higher values for PPF stems. The other ROIs remained substantially unchanged. The overall BMD similarly showed a decrease in ROIs 1 and 7, and an increase in ROI 4 (Table 1).

At 24 months in the group of patients treated by rTKAs, BMD showed a clear reduction in ROIs 1, 4, and 7 of femur. In the tibial side BMD increased significantly in ROI 4, particularly at 3 months and decreased in ROI 1 and 7 (Table 2).
Discussion

After a joint replacement a local biological process named “osseointegration” usually occurs, theoretically leading to a full adhesion of prosthetic surface to the host bone. This phenomenon is related to several factors: periprosthetic bone remodelling, positioning of the components, and properties of implants surface. If the implant is correctly positioned, a wide distribution of forces occurs at the bone-prosthesis counterface: the integration is oriented to be adequate and long lasting. Empty areas may however be present at the bone-prosthesis counterface. In these gaps, an ischemia followed by a bone resorption immediately occurs. In cases of primary stability of prosthetic components, circulating stem cells are recalled and specialised in osteoblastic elements with a consequent bone formation and increase of the local BMD to achieve a “secondary stability” of the implant. If the implant is not correctly positioned, or in case of host bone alterations, or in case of a poorly adequate bioactive surface (often for the first generation hip and knee implants), the mentioned process may not realize. Gaps may be filled by fibroblastic elements producing a fibrous tissue absolutely not appropriate for a long stability of the components. No bone formation but even resorption may occur with
Densitometric evaluation of bone-prosthetic counterface in hip and knee arthroplasty with modern implants

Figure 2 - Example of a prothetic hip DXA scan: 7 zones are defined. Values of BMD are expressed in g/cm².

Figure 3 - Red areas around a standard stem represent the 7 Gruen zones, in order to analyse BMD variations. R1 and R7 represent the proximal areas, while R4 is related to the tip of the stem.

Figure 4 - Red areas around a short stem represent the 7 Gruen zones. BMD ROIs are the same of Figure 3.
the local BMD decreasing, and configuring the so called “stress shielding” (31, 35-37). This may result in a painful implant or even in an early loosening of the components (19, 20, 30, 38-42). Over the decades, many attempts to quantify or to early reveal any alterations of this process have been proposed, with variable results (35, 37). The radiographic assessment of the host bone-prosthetic components counterface after surgery is completely inadequate and tardive, as demonstrated by several studies confirming that a bone loss from 30 to 50% may actually occur before a radiologic evidence (43, 44).

One of the most useful tool is the DXA, and many studies have confirmed that it represents the most simple and efficient way to analyze the periprosthetic bone remodelling. Dedicated softwares for the densitometric evaluation allow a close analysis of specific areas in order to detect any BMD changes in all zones (45-50). By using DXA at specific intervals over the time it is possible to detect any increase or decrease in the BMD, and to early understand where bone formation or resorption occurs (17, 31, 32).

In the present study primary hip and revision knee implants were selected for the presence of stems, particularly interesting to be studied by DXA. Primary knee arthroplasty was not considered given the absence of stems in osteoarthritic patients. Our preliminary results confirm what reported in literature: in specific zones of femur in THAs there is a postoperative reduction of BMD (ROI 1 and 7), as an increase in ROI 4 (47, 51). Moreover, a short stem (GTS) induces a higher periprosthetic bone remodelling with respect to a standard stem (PPF), preserving also the bone stock. The choice to not consider the acetabular cup depends on the not confirmed precision and accuracy of BMD measurements to identify the bone remodelling around the cup; the difference in patient posture affects the result: Mogens B. Laursen showed on one hand that the time elapsed since surgery does not inflict on reproducibility but on the other hand that scanning of the periacetabular bone can be performed as AP scans, with acceptable precision as long as pelvic tilt of more than 10 degrees is avoided. However he supports the assumption that load is beneficial to bone remodelling. While in the laboratory study small bony defects were found, no differences in bone remodelling in the clinical study related to the use of HA coating of the cups were showed (52).

Regarding rTKAs, our data suggest that in the distal femur and proximal tibia a bone resorption is consistent, while no substantial modification is revealed at the tip of femoral stems (ROI 4). This is significantly different from what reported in a previous study, in which an increase in the femur at the tip of stems has been found (34). By using a high press-fit stem for the tibial component in rTKA we have observed a bone apposition at 3 and 6 months, and a lesser resorption at 24 months compared to the low press-fit implantation (53).

Bone remodelling activity in THA and in rTKA is a process that seems to intensively develop during the first year after surgery, then reducing in the second year (32, 47, 54-57). Such observations, associated to other reported in literature have aroused a great interest in the proposal of bone metabolic therapies to improve the quality of osseointegration, particularly in the first months after an arthroplasty (12, 57, 58-60). However, further studies and randomized trials have to be conducted to ascertain any positive effect in such attempt.

Conclusions

A primary mechanical stability of a prosthetic implant should be intraoperatively achieved followed by a full osseointegration (se-
Densitometric evaluation of bone-prosthetic counterface in hip and knee arthroplasty with modern implants

condary stability). However, in a small percentage of cases this mechanism may not completely realize leading to several clinical settings as painful prostheses, aseptic loosening, and failure of the implant. With respect to the past decades, an early detection of stress-shielding or loosening of the implants by a radiologic eva-

uation and DXA is possible. We consider DXA evaluation an ideal tool to assess early alterations at the bone-component counter-

face in primary THA and rTKA, in order to adopt strategies to li-

mited mechanical failure of the implant.

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