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INFLUENCE OF THE BONE CEMENTS AND CEMENTATION TECHNIQUE ON THE PERFORMANCE OF THE BIRMINGHAM HIP PROSTHESIS

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Abstract

This study's main idea is to explore the interaction between acrylic bone cement and bone tissue in total hip arthroplasty procedures. Acrylic bone cement has been widely used in total hip arthroplasty procedures over the years. The importance of the interaction between cement and bone tissue, as well as the penetration of cement into bone, has been the subject of extensive research. Analyses using SEM and EDAX have examined these aspects in detail, highlighting the importance of uniform cement distribution in strengthening and protecting the implant. Additionally, possible anomalies, such as the formation of voids or fissures in the cement, which can affect the long-term strength and stability of the implant, have been identified. These research findings have made significant contributions to understanding the need for a rigorous cement application technique to avoid such problems and ensure the success of the intervention. Furthermore, a detailed investigation revealed a specific case where acrylic bone cement was applied in an excessively thick layer, leading to significant penetration into the bone tissue. The lack of uniformity and reduced viscosity of the cement exacerbated this issue, emphasizing the need for careful cement application to ensure the stability and durability of the implant.

Keywords: *Acrylic bone cement, Cement-bone interface, BHR Prostheses, SEM analysis.*

Introduction

The modern cementation technique, essential for the success of hip prostheses, especially those of the BHR (Birmingham Hip Resurfacing) type, uses plastic Centro medullary plugs, shaped to the shape of the bore, and a pressure wash-suction system, which cleans the femoral canal of bone and tissue debris, thus preventing serious complications such as fat and spinal cord embolization; This technique also involves pressurizing the cement with the help of a gun, although this procedure can be avoided in elderly patients due to the increased cardiopulmonary risks. Another important aspect is to ensure optimal hip exposure to avoid fittings in abnormal positions and to guarantee maximum bone contact of the implants. Detailed care in preoperative planning includes regularizing the bone edges to allow uniform support of the prosthesis components, checking the anteversion of the femoral tail, and avoiding rotation of the components after cementation to prevent the formation of weak areas in the cement [1, 6].

Proper placement of the femoral plug 1-1.5 cm distal to the tip of the femoral tail, cleaning the femoral canal of debris, using an appropriate jet of water and brushes to achieve a thorough wash, and maintaining anaesthetic hypotension are essential to minimize bleeding and microbial contamination. Adding

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antibiotics to the cement and handling it correctly, including avoiding blood contamination and using a more fluid cement for optimal fixation, are vital steps in the correct cementing technique [7,8].

The use of suitable cement and its careful handling, along with adherence to these rigorous procedures, is critical to avoid the appearance of air bubbles or other irregularities that could compromise the success of BHR dentures and lead to subsequent implant failures.

In the cementation technique, the choice of the type of cement is essential for optimizing the fixation of the femoral prosthesis, so when using components with a porous surface, the surgeon opts for a more fluid cement, which maximizes the adhesion between the cement and the prosthesis; On the other hand, for components with a smooth surface, a more viscous cement is preferred, which makes it easier to maintain the correct orientation of the femoral component until the cement hardens, the fixation being influenced by its consistency [9,11].

As for the cement mantle, it must have a minimum thickness of 2 mm and be evenly distributed around the prosthesis; studies conducted by P. Joshi and his collaborators in 1999 showed that the incidence of decimentation is lowest when the mantle is 3 mm thick around the femoral tail and 6 mm around the acetabular component [12]. In addition, femoral tails cemented with a cement mantle 2-4 mm thick in the proximal medial region of the femur, as well as those that retain a thin layer of cancellous bone, less than 2 mm thick, in the same area after reaming, have demonstrated excellent survival. The success of hip reconstruction implants depends largely on establishing strong connections between the implant and bone using bone cement, but cementation strategies vary significantly depending on the implant model used. For example, some prosthetic designs, such as Durom (Zimmer Orthopaedics, Warsaw, IN, USA), ASR (DePuy Orthopaedics, Warsaw, IN, USA) and Biomet (Biomet Orthopaedics, Warsaw, IN, USA), allow for a cement sheath of about 1 mm due to the larger space provided between the implant and the bone.

On the other hand, other models such as BHR (Smith & Nephew PLC, London, UK) or Cormet (Corin Medical, Cirencester, UK) have a tighter femoral component, which allows for minimal cement sheathing or even works without cement. Early failure of these implants can be caused by fractures of the femoral head or aseptic weakening of the femoral component [13,18].

In long-term follow-up sessions, soft tissue adverse reactions to metal wear play a significant role in prosthesis failure in a subset of patients, including phenomena such as metallises, pseudotumor formation, excessive intraosseous lymphocyte infiltration, desquamative proliferative synovitis, and lymphocyte vasculitis-associated aseptic lesions (ALVAL), all reported in cases reviewed for unexplained groin pain [19,22]. The use of improper cementation techniques is an important adverse factor for the long-term survival of hip reconstruction arthroplasty. Possible causes of failure include inadequate initial fixation, thermal osteonecrosis, and intermediate biological reactions [23,28].

A morphometric and histopathological analysis of a large collection of recovered femoral components, with a mean time to failure of 8.3 months ± 11.0, revealed that the morphological changes associated with the cementing technique differ substantially from the recommendations on the depth of penetration of cement into the bone obtained in the laboratory. The cement canton and its penetration into the bone were quantified in six distinct regions of interest, and the histopathological analysis of the bone-cement interface was performed on the non-decalcified processed bone tissue, thus confirming that most cases deviate significantly from the recommended standards.

Materials and Methods

In a large study conducted at the Colentina Clinical Hospital in Bucharest, 300 Birmingham Hip Resurfacing (BHR) implantation surgeries were analysed. In this total, it was found that 10% of the implants failed, of which 10 cases were attributed to an unfavourable cementation technique. Detailed analysis of these cases revealed several critical irregularities that contributed to implant failure. From the macroscopic point of view, three major punctual defects were observed (Fig. 1).

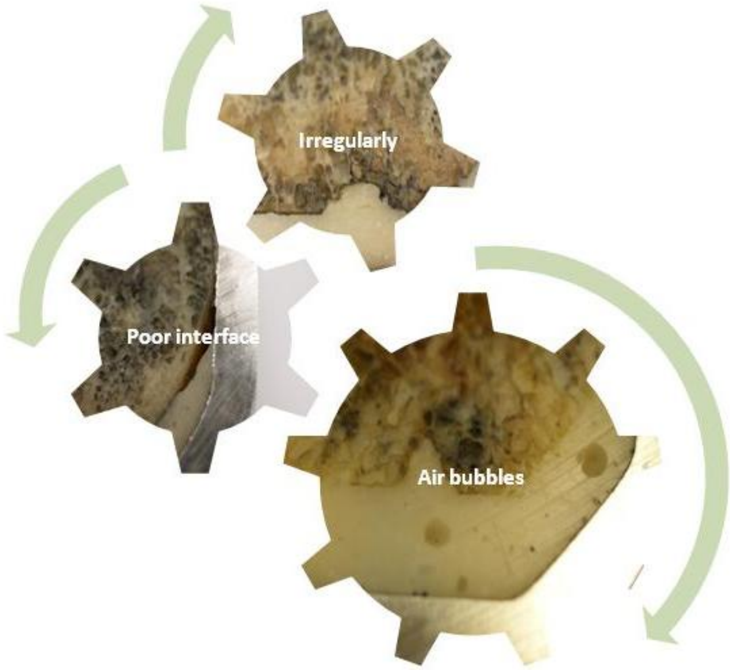

Fig. 1. Diagram of irregularities arising from an inadequate cementing technique

One of the major problems observed was the presence of air bubbles in the cement mantle. These air bubbles were caused by insufficient or inadequate mixing of the cement, which resulted in the formation of air voids that compromise the structural integrity of the cement (Fig. 2).

These gaps prevented the cement from providing a firm and uniform fixation of the implant to the bone, contributing to the instability of the prosthesis.

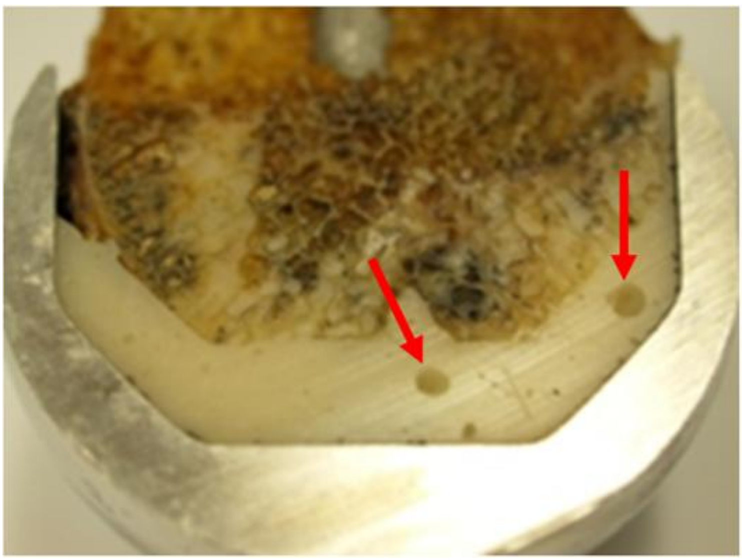

Fig. 2. Air bubbles formed in the cement mantle

Another important irregularity was identified at the level of the interface between bone and cement (poor interface). This resulted from incomplete cleaning of the femoral canal before cement was applied, which allowed bone debris and other tissue materials to interfere with the bond between the cement and bone. The lack of optimal cement adhesion to the bone led to ineffective fixation and subsequent instability of the prosthesis (Fig. 3).

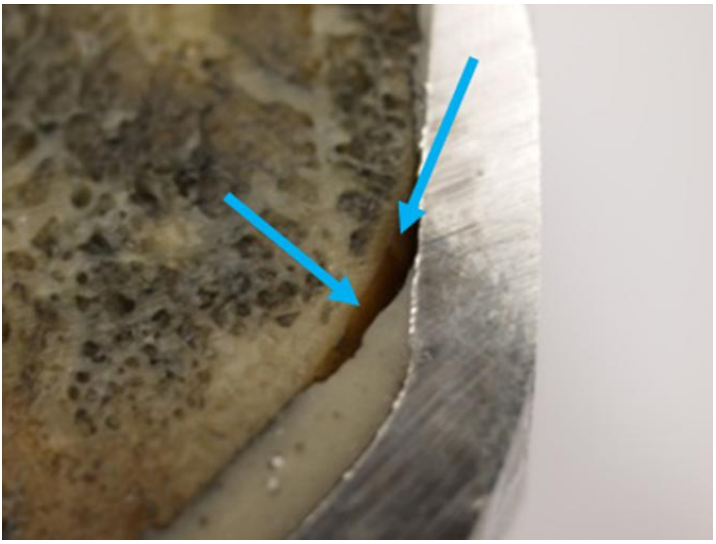

Fig. 3. Cement irregularity at the bone-cement interface

Also, the uneven thickness of the cement mantle (irregular mantle) was a critical factor. This was due to improper cement placement, either by using a cement that was too viscous and not evenly distributed, or by uneven application of pressure during cementing. An uneven cement mantle generated stress points and favoured micro-movements of the implant, which led to accelerated wear and failure of the prosthesis (Fig. 4).

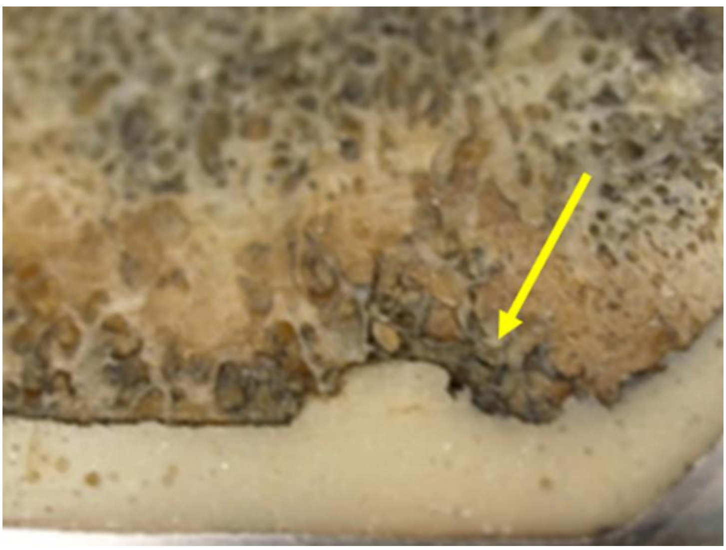

Fig. 4. Cement mantle with uneven thickness

A series of in-depth studies have also been carried out on explants to observe in detail the defects and integration between bone and cement. These analyses were performed using advanced techniques such as scanning electron microscopy (SEM) and histological analysis, each of which made significant contributions to the understanding of Birmingham Hip Resurfacing implant failures.

Scanning electron microscopy (SEM) allows the examination of explant surfaces at extremely high resolution, providing detailed images of the morphology of the bone-cement interface. Through SEM, the researchers were able to observe the presence of microcracks, porosity and air bubbles in the cement mantle, confirming that these structural defects contribute significantly to the instability of the implant. SEM also highlighted irregularities in cement distribution and identified areas of poor adhesion between bone and cement, which were associated with an increased risk of prosthesis failure. As shown in Fig. 5 a), SEM imaging reveals microcracks and porosity within the cement mantle. Fig. 5 b) highlights areas of poor adhesion and irregular cement distribution at the bone-cement interface, contributing to the likelihood of prosthesis failure.

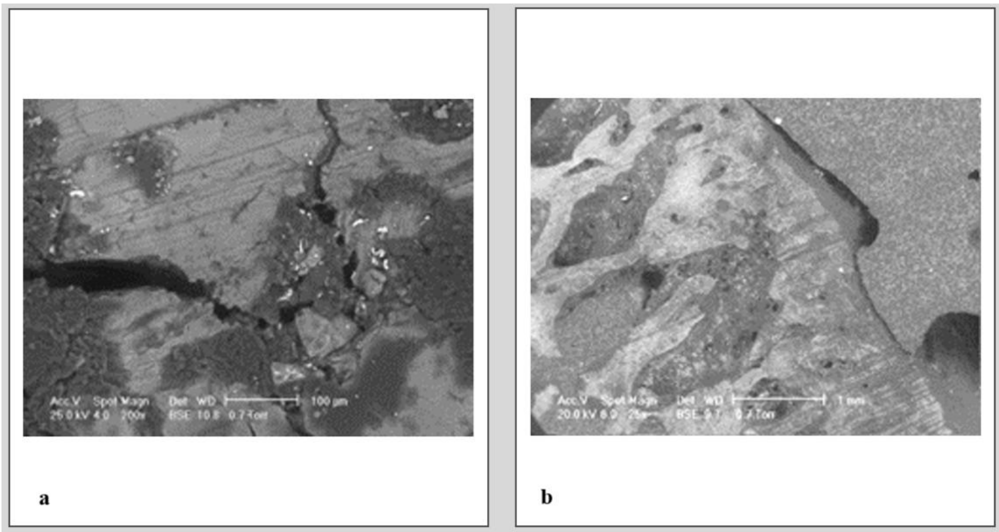

Fig. 5. SEM Analysis of Bone-Cement Interface in BHR Prostheses: a) Microcracks, porosity, and air bubbles in the cement mantle observed at 700x magnification, which may contribute to implant instability; b) Poor adhesion areas between bone and cement, as well as irregular cement distribution observed at 250x magnification, associated with a higher risk of prosthesis failure)

The histological analysis provided a complementary perspective, allowing the evaluation of biological interactions at the tissue-cement interface. By preparing and examining thin sections of non-decalcified processed bone tissue, the researchers were able to observe inflammatory responses, cell infiltration, and fibrous tissue formation around the cement. These observations revealed that, in many cases, the inadequate cementation technique resulted in poor biological integration, favouring the occurrence of adverse reactions such as desquamative proliferative synovitis and aseptic lesions associated with lymphocytic vasculitis (ALVAL). Histological analysis also showed that thermal osteonecrosis, caused by the heat generated during cement curing, contributed to the deterioration of the surrounding bone and reduced its ability to support the implant effectively.

Results and Discussions

The cement mantle, conceptualized as the protective and stabilizing layer of cement interposed between the implant component and the edge of the cancellous bone, is essential to ensure a durable and effective fixation of the implant. Cement penetration refers to the integration of the cement material with the surface of the reworked bone and deeper bone tissue, thus ensuring a solid anchorage (Fig. 6).

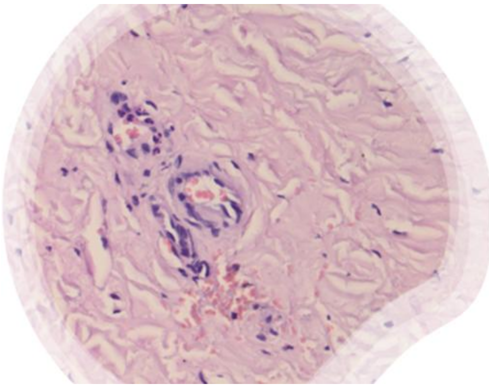

Fig. 6. Evaluation of biological interactions at the level of the tissue-cement performed with the help of histological analysis

These precise measurements were made in three distinct areas of the implant: from the cap dome, referred to as zone 1, which is located at the top of the implant; from the intermediate zone, called zone 2, located in the middle of the implant shaft; and from the radial zone, called zone 3, located on the sides of the implant rod (Fig. 7). This detailed method of measuring the cement thickness on each side of the implant shaft allowed for a comprehensive assessment of the distribution and uniformity of the cement mantle, thus ensuring a better understanding of the factors influencing the long-term stability and success of the prostheses (Fig. 8).

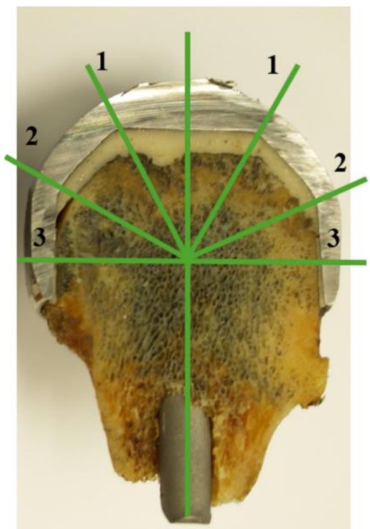

Fig. 7. Systematic schematic representation of cement thickness measurements
(1 - lid zone, 2 - intermediate zone, 3 - radial zone)

Cementing BHR (Birmingham Hip Resurfacing) implants involves applying a layer of orthopaedic cement between the prosthetic component and the host bone, with the aim of ensuring a stable and durable fixation. This procedure requires precision and proper technique to prevent complications and ensure proper implant integration.

BHR implant cementation brings considerable benefits, such as providing immediate and stable implant fixation, essential for patients with low bone quality, and uniform distribution of mechanical forces through a well-applied cement layer, thus reducing the risk of micro-movements and implant wear, while allowing fine adjustments to implant positioning during surgery.

Macroscopic Analysis

However, there are associated risks, such as the possibility of the implant detaching from the bone if the cement is not applied properly, creating stress points and accelerated wear of the prosthetic components due to an uneven or discontinuous cement layer, and the risk of adverse reactions to cement materials, such as inflammation or infection.

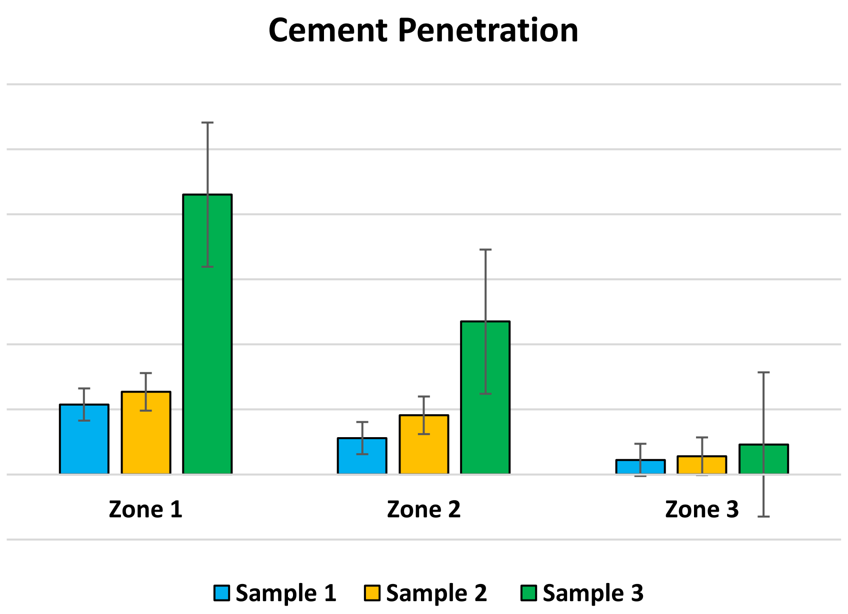

Fig. 8. Cement penetration in the different areas of BHR acetabular components

In our study, we analysed three explants of failed BHR prostheses, dividing the acetabular component into three zones (Fig. 9): the cap dome (zone 1), the intermediate zone (zone 2), and the radial zone (zone 3). Using macroscopic analysis and the AxioVision app, we measured the thickness of the cement layer in each area. Our analysis revealed the following:

Zone 1 and Zone 2: No substantial differences were identified in prosthetic designs and cement mantle thickness.

Zone 3: Exhibited a substantially smaller cement sheath. In some cases, irregularities have formed, with the cement mantle not completely covering this area.

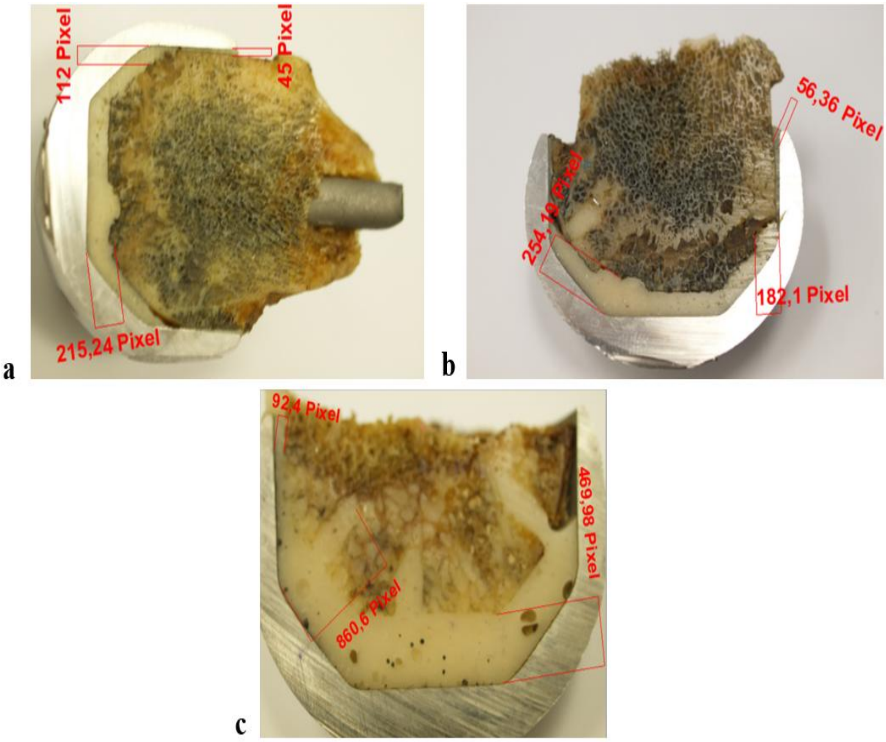

Fig. 9. The analysis of the cement mantle thickness in three zones of the BHR implants:
a) zone 1; b) zone 2; c) zone 3

SEM Analysis

Our study highlighted significant variability in cement sheath thickness in failed BHR implants. In some cases, it was observed that the cement sheath was completely absent in zone 3, which led to the formation of irregularities and, ultimately, the failure of the prosthesis. These findings underscore the critical importance of proper cementation and cement layer uniformity to ensure the long-term success of BHR implants. Our macroscopic analysis showed that zone 1 consistently had the highest cement layer thickness, and in some cases, the cement exceeded the reference area, interacting directly with the bone. In contrast, zone 2, although generally within normal parameters, showed small inconsiderable deviations.

To obtain a more complex analysis, we also used SEM analysis, which allowed us to investigate in detail the macroscopic defects observed on the explants, such as air bubbles, poor interface and irregularities, thus highlighting the impact of the unfavourable cementation technique on the success of the implants.

In the analysed samples, various defects were identified that led to the failure of BHR implants. In Fig. 10 a), the mixing technique used for the preparation of acrylic cement was not efficient, highlighting the presence of air bubbles in the mass of the material. Also, the viscosity obtained did not have the necessary value for an efficient application, resulting in the same unevenness of the cement mantle, although the measurements indicate values close to the required standard size. In Fig. 10 b), a coarse air gap is observed between the cement mantle and the bone, which prevents the formation of a proper cement-bone interface. Fig. 10 c) also illustrates the lack of cement-bone interface, caused by improper cement application, and shows a much more advanced bone necrosis state compared to previous cases; The cement penetrated the bone unevenly due to inadequate viscosity. The dark, porous-looking areas represent the necrotic bone, and the lighter areas around them indicate how the cement has penetrated the bone.

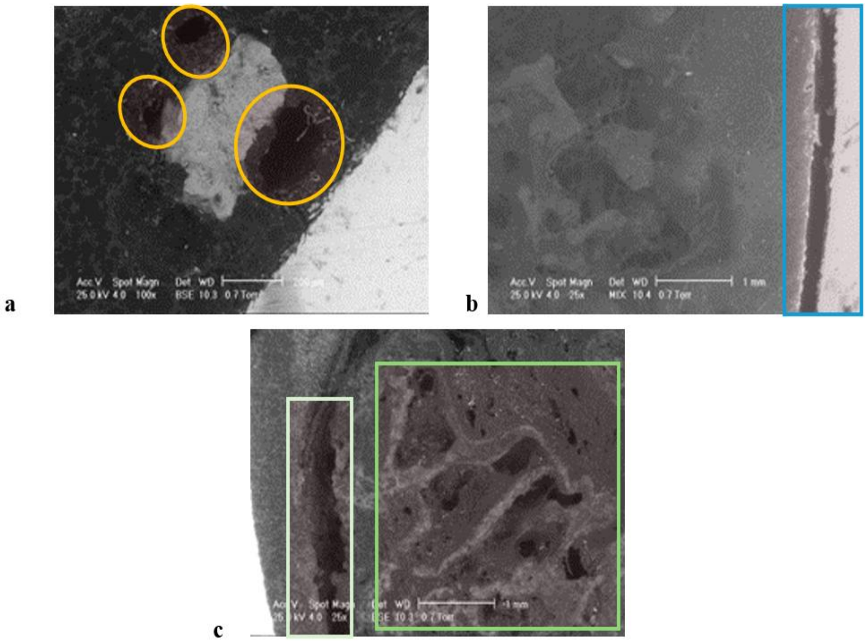

Fig. 10. SEM analysis of structural defects arising from the unfavorable cementing technique: a) Voids and porosity in the cement structure, circled in yellow, observed at 100x magnification, which may lead to mechanical instability; b) Delamination at the cement-bone interface, highlighted by the blue box, observed at 25x magnification, indicating poor adhesion; c) Microscopic surface irregularities within the cement mantle, highlighted by the green box, observed at 25x magnification, which can contribute to implant failure

Histological Analysis

Finally, in order to emphasize with maximum clarity, the importance of cementation, the cement used and the appropriate cementation technique, a series of histological analyses were carried out. Histological analysis is an essential method in investigating the interaction between tissues and implants, providing detailed insight into the body's response to inserted materials. To better understand the causes of implant failure, tissue was taken from near the explant, allowing the symptoms and tissue reactions to be observed.

Histological analysis can identify signs of inflammation, rejection reactions, integration of the implanted material into the surrounding tissue, as well as the degree of healing and tissue regeneration.

The interaction between the host tissue and the implanted material is particularly revealed in Fig. 11 a), where rare perivascular inflammatory elements, predominantly lymphocytes, are highlighted. This histological appearance indicates a moderate inflammatory response around the cemented implant, in which lymphocytes, as elements of the immune system, are involved in the process of reaction to foreign material. This observation suggests that cementation had little impact on the surrounding tissue and may be associated with a relatively favourable integration of the implant into its biological environment.

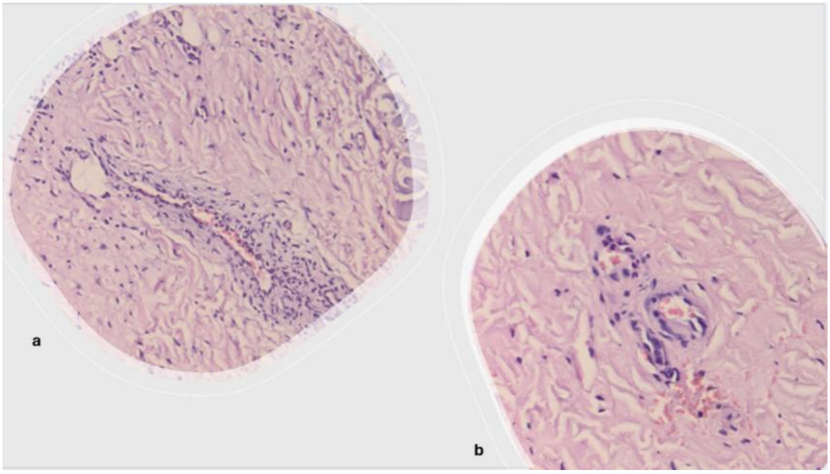

Fig. 11. Histological analysis performed on tissue collected from the implant area:
a) perivascular inflammatory elements, with a predominance of lymphocytes (HE x200);
b) minor interstitial blood extravasations and rare perivascular neutrophils (HE x400))

Next, in Fig. 11 b), small interstitial blood extravasations and rare perivascular neutrophils are noted. These findings indicate a mild inflammatory reaction, characterized by the limited presence of neutrophils, the cells responsible for phagocytosis and the elimination of pathogens, around the blood vessels. This inflammatory response may be associated with minimal trauma induced by the implantation and cementation process, suggesting a satisfactory tolerability of the materials used.

Conclusion

In the context of sustained research, the fundamental importance of the cementation technique in the context of hip implants is clearly confirmed, with particular emphasis on Birmingham Hip Resurfacing (BHR) implants. The detailed analysis of the factors associated with the failure of these implants emphasizes the need for a precise and systematic approach in the application and management of the cementation process.

By combining the results obtained from SEM and histological analyses, the study provided a comprehensive picture of the factors contributing to the failure of Birmingham Hip Resurfacing implants. These techniques allowed for the precise identification of structural defects and biological responses, emphasizing the importance of proper cementation technique and meticulous attention to detail to ensure the long-term success of hip implants. Thus, research has highlighted the need for optimized surgical practices and strict cementation protocols to minimize the associated risks and improve clinical outcomes for patients.

Overall, the histological analysis highlighted that the use of an appropriate cementation technique, together with the choice of a suitable cement, can help minimize the inflammatory response and improve the integration of the implant into adjacent tissues. These findings underscore the importance of a precise approach in implant management and support the need for further research to optimize clinical outcomes in implant surgery.

The data obtained through the combination of investigation methods, including electron microscopy and histological analyses, bring to the fore conclusions that the application of an appropriate cementation technique can considerably reduce the incidence of complications and can positively influence the clinical evolution of the treated patients.

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