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Mechanical failure of a Thompson's hemiarthoplasty stem 28 years post-implantation: an investigation with electron microscopy

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Abstract The authors would like to report a mechanical failure of a Thompson's prosthesis, 28 years post-implantation. A detailed examination of the specimen revealed no defects in the prosthesis and a dominating 'brittle *component*' fracture of the stem. In this context the detailed fractographic study by scanning electron microscopy (SEM) revealed no detrimental manufactural defects that may have produced microcracks and consequently risked initiating the fracture propagation. In contrast, the fracture was mainly a fatigue one with a mixed mode of microscopic trans- and intergranular crack propagation. To the best of our knowledge, such a mechanism of implant failure in a cementless stem has never before reached 28 years neither in a Thompson's nor any other type of prosthesis, and in the already reported case, it exceeded 30 years [N. Wolson and J. P. Waadell, *Can. J. Surg.* **38**(6) (1995) 542], however the stem's ultrastructure has never been investigated under electron microscopy, which arguably can provide a useful assessment of a fatigue fracture. The authors introduce the question of revising our standards when evaluating the newly designed and expensive implants and propose re-focusing on surgical technique, rather than purely on implant properties.

Case report

A 95-year-old lady (S.P) (BW 70 kg/height 166 cm) was admitted to our hospital following a fall. She was otherwise fit and healthy. She was mobilizing without any walking aides and she had a good level of pre-injury function. A thorough medical investigation was carried out and apart from a history of mild diabetes which was under dietary control (and on investigation was found to be within the normal range) all other findings were otherwise unremarkable. On examination, shortening and external rotation of the involved limb (right femur) was apparent. No neurovascular compromise was found on the fractured limb. On radiographs, a periprosthetic fracture and a fracture of the implant (stem) were found. Patient's medical records revealed a Thompson's hemiarthroplasty performed 28 years ago. A careful history revealed that she did not trip over and fall of her own accord, but instead she reported hearing and feeling something crack, and then fell down. X-ray revealed radiolucent lines (Fig. 1) and loosening of the prosthesis in zones A and Z according to Dunn's classification [1]. She was

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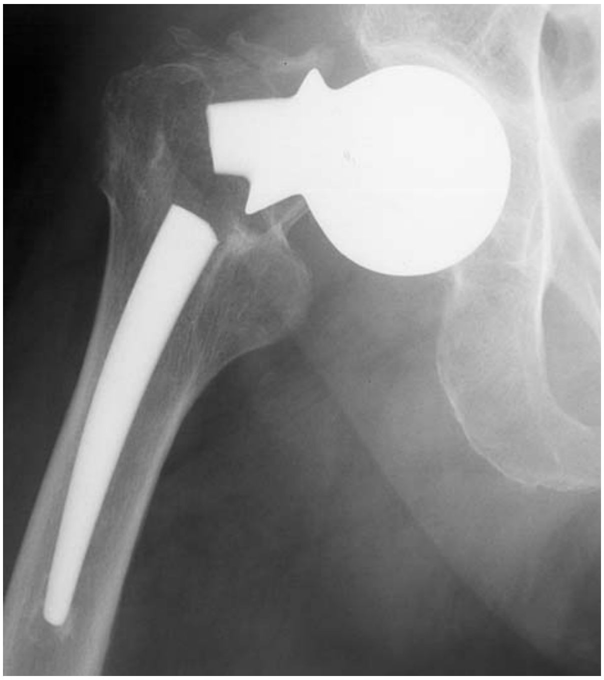

Fig. 1 Radiograph of the hip with the broken stem

taken to surgery and although the central part of the prosthesis was easily removed, the distal part was very well bonded to the bone and was unable to be removed. In order to avoid prolonging the operative procedure and risk additional blood loss, we decided to leave the distal stem in place and convert it to a Girdlestone resection arthroplasty.

Two years post-operatively, the patient is mobilized with a walking frame and the appropriate shoe modification (7 cm heel raise).

Discussion

Although the literature reports a case of a Moore hemiarthoplasty functioning well for 33 years [2], there is no report of a Thompson's stem with a life span exceeding 28 years. In this particular case study, a failure of a Thompson's stem in the upper third of the stem was found. Normally, we do not encounter broken stems without some form of violent impact or force acting on it as other preceding factors tend to compromise its operation (death of the elderly patient, infection, loosening, periprosthetic fracture) long before it ever gets a chance to exceed it fatigue strength. Wroblewski [3] reported that 97.5% of fractures occurred at approximately 11 years post-implantation. In a retrospective review of 580 patients with 599 hemiarthroplasties of the hip [4] there was no report of a broken stem. In our case, the stem was intact for 28 years until the patient reportedly heard a 'crack' noise emanating from her hip (possible failure of the implant, although it cannot be safely accepted) and subsequently reports to have fallen down. A distinct area of radiological loosening in zones A and Z was found, according to Gruen's classification [1]. There is no radiological evidence of protrusion (Wiberg angle). Based on the above radiological observation, we can assume that there have been two distinct regions at the bone–implant interface: a loose one (above the fracture site) and a well bonded area within the femur. The difference in micromotion between these two distinct areas caused a plane within the material, which failed, mostly under shearing forces and constantly applied bending moment.

In our case, the conclusion to be drawn is that if a stem, although of an old design (with an adequate metallurgical condition) and with a relatively low cost, can withstand all these years, then our expectations for the standards of the new stem designs can and should be upgraded, and perhaps the greater focus should be placed on the importance of surgical technique. The same observation has been mentioned once more in the literature [5], where three stem fractures of three extra-heavy, large Charnley serrated Cobra femoral components were observed in young, heavy, and active male patients, with an average time from implantation to stem failure of 68 months (43, 76, and 86 months). The authors conclude that making prosthesis thicker by using the same material does not solve the problem of fatigue fracture, if the material, design or cement interface are faulty.

There is no need to mention that the surgical technique is of utmost importance and it can dramatically affect the stress state of the implant. In our case, the operating surgeon (currently a retired surgeon working as a clinical director in the same hospital) employed particular principles with the Thompson's prostheses that he extensively used in the past. First, the Thompson's stem was inserted without the use of acrylic cement. In addition the operating surgeon was very meticulous in handling the stem during insertion taking extreme care not to cause any scratches on the prosthetic head or the surface of the stem. He also always tried to place the stem in a valgus position (although the Thompson's stem because of its anatomical shape can be difficult to insert in valgus) in order to reduce the bending moments at the prosthesis. Attempts were made to clean the calcar in detail from the cancellous bone in order for the stem to have a very intimate contact with the strong cortical bone. The insertion of a Thompson's prosthesis is a straightforward procedure for most orthopaedic surgeons and it can be done very quickly in order to decrease the blood loss, which in turn has an impact upon the patient' s survival. Nevertheless, one should not sacrifice good and careful surgical technique simply in order to perform a time saving procedure because meticulous technique may prove beneficial in the overall survival of the implant and of course of the patient as was the case in this particular patient.

Fractography

A thin layer of metal was cut from the broken surface of the stem in order to be examined by SEM, under magnifications varying between 20 and 300 times. These examinations revealed that there were no decisive (dentrimentral) manufactural defects and that the crack was initiated by fatigue damage accumulation from the posterosuperior area (point 2) (Fig. 2). For instance Cobalt Crome, with an elastic modulus around 200 GPa and tensile Yield strength 800 MPa (while stainless steel has only 300 MPa), is a brittle material, although microscopy images reveal that the type of fracture was not completely brittle, but in fact was accompanied by a ductile component. Therefore in this particular situation, there appears to be a mixed type of failure, and as it is predominantly a brittle fracture, the correct terminology should be a quasi brittle mode of fracture and not a 'proper brittle fracture'.

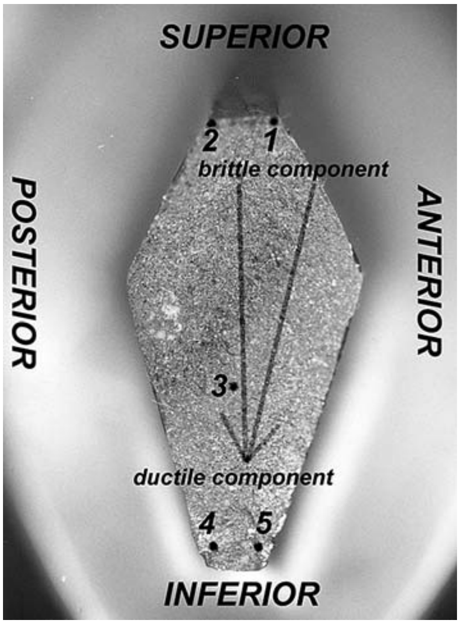

Fig. 2 Section of the broken surface of the stem, showing the different points which were investigated with electron microscopy

Further to this investigation, the authors chose to investigate fracture propagation in the stem.

It is most likely that the failure in our stem was caused by repeated loading and was a fatigue failure. It is also well known, that it is the combination of the repeated number of loadings and the magnitude of the loadings that is important in fatigue failure, an event that does not occur in a catastrophic fashion (like the failure of a material due to a single application of a high load). The number of cycles required to cause failure will vary from a few to a few million, depending upon the amplitude of the applied load, the properties of the material and the size of the structure [6]. In most applications the loading cycles are usually extremely complex and difficult to predict. However, basic and more analytical information about the fatigue properties and the failure type of a material may exclusively be obtained using electron fractography. In this context the main fractographic characteristic features of such a failure are the so-called fatigue striation lines seen in Fig. 3.

The fatigue fractured surface of a metallic component normally consists of two distinct regions [6, 7]. The relatively smooth region is characterized by the so-called striation or ripple marks as shown in Fig. 3 [7]. These marks indicate the various positions at which the crack was arrested as it propagates intermittently through the component in response to the varying load. The second region is either granular or fibrous in appearance. The markings in this region often allow the origin (or origins) of the fracture to be located,

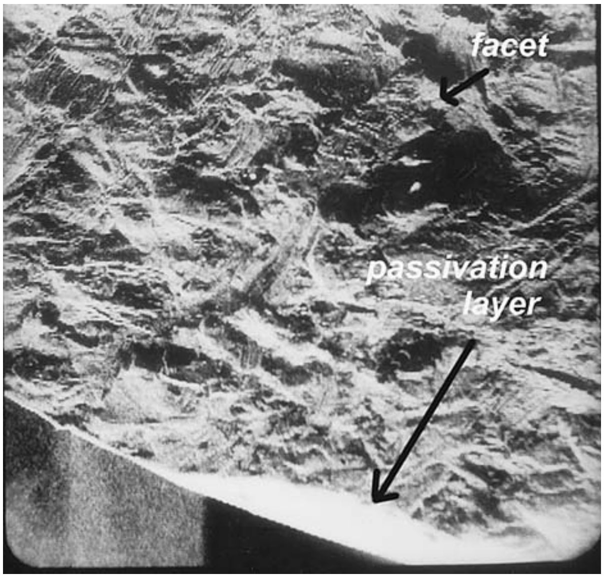

Fig. 3 Photograph showing the passivation layer (outer surface) in the lower area of the stem (magnification ×200)

which in our case was the posterosuperior area of the stem (Fig. 2). The origin is indicated on the fatigue fractured surface shown in point 2 of the stem (Fig. 2) (posterosuperior area), (Fig. 4A) as well as in Fig. 5A where the crack's front entrance can be seen.

In the present fractographs, it can be seen that there is no typical type of failure but, as described at the beginning, the brittle component of fracture predominates. In addition, there are very few intrinsic structural defects (metallurgical inclusions) in the material (Fig. 4C) that may have not contributed to it failing. The initiation site of the crack in the posterosuperior area can also been seen as expected, due to the magnitude of the alternating (tensile) loads that causes it to fail from the outer surface in a centripetal trajectory. For instance, in the points indicated by arrows in Fig. 4A and also in Fig. 5A of the stem there is a localized mirror-like zone of initiation of a brittle microfracture [8]. This point is located in the posterosuperior zone of the stem, the area of maximum tensile stress. At the same point a large dimple can be depicted, in a point just below the outer surface, where the fracture propagation has started (Fig. 5A). Furthermore, in area 2-1 (Figs. 2 and 4B) where the bending moment is being applied, there is a region dominated by tensile stresses in which mostly a brittle fracture occurs. On the other hand in point 3 of the stem (Figs. 2 and 4C) the appearance of the fracture surface changes and becomes more ductile one in the sense that compressive forces, may cause even, a more smooth-type of ductile fracture (See arrow in point 3 (Figs. 2 and 4C)). The same occurs at the lower part of the stem because although at the point of tensile failure, there is an abrupt brittle initiation, at point 3 (Fig. 2) the material was found to fail in compression. In point 5 of the stem, (Figs. 2 and 4D) two grains can be seen and a number of distinct cleavage steps within them. Cleavage steps represent characteristic fractographic features of a transgranular (intragranular) brittle mode of fracture and are created within a grain of the polycrystalline material in the direction of weakest crystallographic resistance during fracture propagation. In this aspect, the microfailure behavior was transgranular (Fig. 5B) mixed-mode (Fig. 5C) and intergranular (Fig. 5D).

It can also be stated that there are no abnormally coarse crystals, no large non-metallic inclusions or inclusion agglomeration, neither undissolved master alloy particles nor gas porosity from which fracture could have been initiated. The passivation layer can also be seen in point 4 (Fig. 2) of the stem, (Fig. 3), which is a metal oxide layer giving anti-corrosion protection and is well preserved, even 28 years post-implantation.

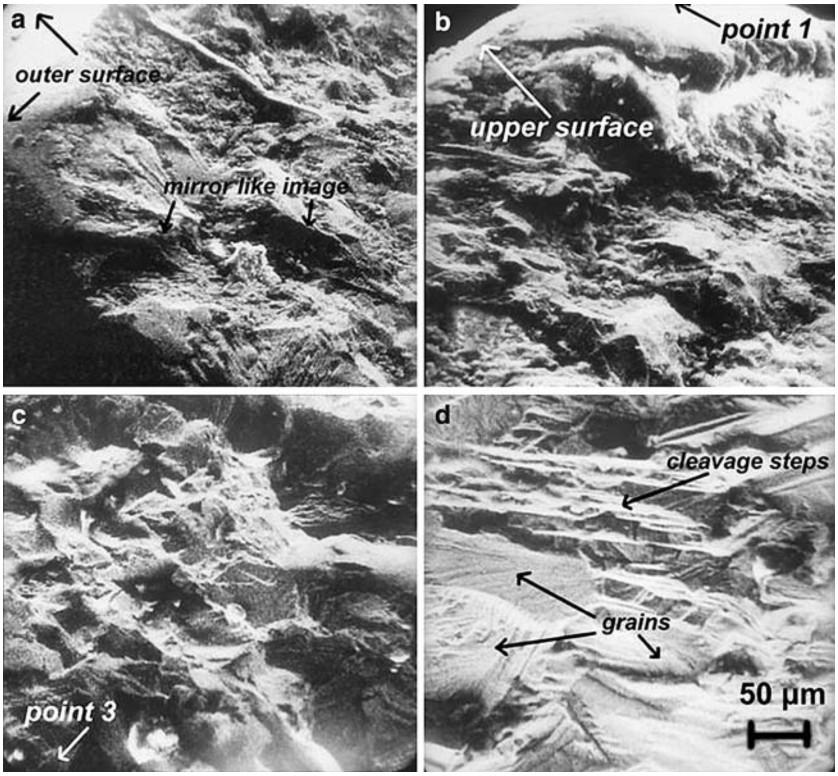

Fig. 4 (**A**) Area of initiation of a fracture in the posterosuperior area of the stem (magnification ×200). (**B**) Area in the upper surface of the stem revealing no metallurgical defects (magnification ×200). (**C**) Area in the middle of the broken surface, mostly with a brittle type of failure but with a ductile component as well (magnification ×200). (**D**) Photograph showing two grains and a number of cleavage steps between them (brittle fracture) (magnification ×300)

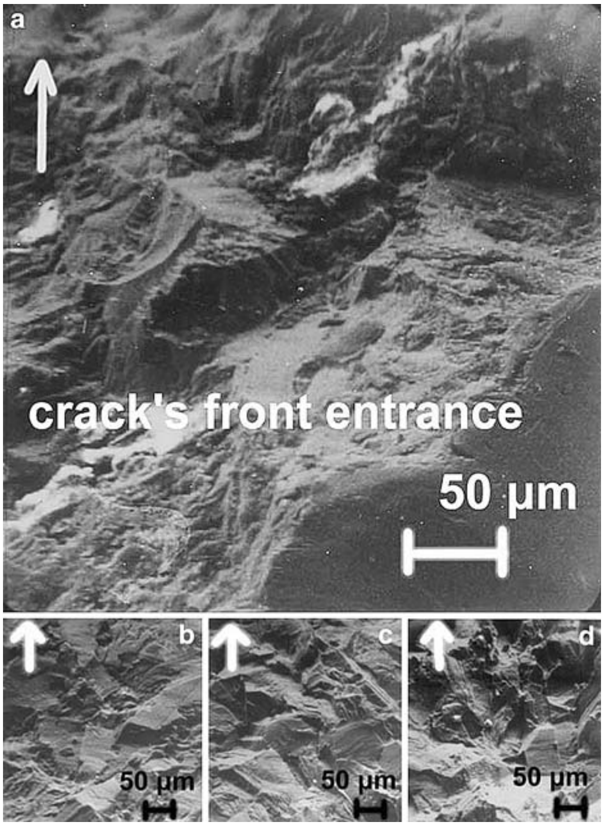

Fig. 5 (**A**) Initiation site of crack propagation (crack front entrance) with high magnification (×300). (**B**) Transgranular dominated propagation (magnification ×200). (**C**) Mixed-mode of crack propagation (magnification ×200). (**D**) Intergranular dominated crack propagation (magnification ×200). White arrow in **A**–**D** pictures, indicates the direction of crack propagation

Conclusions

The purpose of this investigation yielded an important issue regarding the life-time expectancy of prosthetic implants. Fractographic data showed a fatigue-assisted type of failure with a dominating brittle component expressed mainly by a mixed mode of trans- and intergranular microscopic crack propagation. Although one cannot expect to draw definitive conclusions from this isolated case report, it has demonstrated that it may prove beneficial to review the current expectations of performance and durability of the modern and costly implants, particularly given current improvements in stem fixation. Excellent results can be obtained with a simple and time saving surgery and we would emphasize again the importance on refocusing attention on the quality of the surgical technique and procedure employed rather than fixating purely on the physical properties of the material as a cause for prosthesis failure or be necessarily led by the higher cost of a newer more sophisticated prosthesis. It is not our intention to abjectly support the use of the original Thompson stem, but one should at least consider raising the standards and our expectations of the modern expensive prosthesis accordingly.

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