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Failure Analysis of Fixation Devices Used in Broken Bones

Mariana H. Staia*, Julio C. Machado *, Eli S. Puchi*, Sonia Camero* and Rafael Paiva * School of Metallurgy and Materials Science, Faculty of Engineering, Central University of Venezuela, Apartado 49141, Caracas 1042-A, Venezuela, Phone 014-264317, Fax: 58-2-6930629**

****Department of Orthopaedic Surgery and Traumatology, "Carlos Arvelo" Military Hospital, San Martín, Caracas, Venezuela.**

ABSTRACT

Failure analysis conducted on fixation devices retrieved from the *in vivo* environment is presented. The fixation device system was composed of a plate 135°, a dynamic hip screw (DHS) and four cortical screws of the 316L stainless steel. A detailed analysis of the damaged surface and the fractographic study of the devices failed were performed by using conventional optical, scanning and transmission electron microscopy techniques. On the other hand, chemical composition, hardness and microstructural features were determined and compared with the standard specifications with the aim of verifying if the material *per se* is responsible for the produced failures. The results from the microfractographic studies indicated that the predominant morphology is that characteristic to a mechanism of fatigue assisted by corrosion. It has to be pointed out that the combination between different factors as the presence of a osteoporotic bone, patient weight and postoperative activity, the delay in the healing of the fracture and some aspects related to the erroneous indication for the use of the fixation devices have also played an important role in causing the failure.

KEYWORDS

Implants, prosthesis, failure, corrosion, fatigue.

INTRODUCTION

Amongst the different materials which are being implanted in the human body, stainless steel has been and continue to be the most widely used.

The failure mechanisms characteristic to prosthesis and internal fixation devices made from stainless steel do not differ from those encountered for any other engineering component made from the same material which would have performed in such an hostile environment as tissue fluids.

Clinical and radiographic analysis of failed components together with mechanical and materials studies showed the importance of a variety of factors. The design and materials processing, weight and activity of the patient and the surgical technique were frequently mentioned as factors of prime influence on the eventual implant failure [1-6].

Implant retrieval and failure analyses lead to an enhanced understanding of all these factors and will contribute to the inherent standardization process. The present work reports the analysis procedure used to determine the main factors which produced the failure *"in vivo"* of 4 cortical screws used as fixation devices in a hip endoprosthesis system.

MATERIALS AND METHODS

All implants were examined visually for

gross mechanical damage. A stereomicroscope was used at a magnification of 75X to further study the condition of the implants. A detailed failure analysis was followed by using scanning electron microscopy and replica transmission electron microscopy, indispensable tools for the evaluation of fractured and damaged surfaces. For scanning electron microscopy the samples of 5 mm thickness were taken from the area corresponding to the fracture surface of the screws. Also, samples of 1.5 cm thickness taken for the plate area which presented the highest damage were used for this purpose. In the first stage of the analysis, the sample were studied in the as-retrieve condition in order to avoid loosing any information and to detect possible corrosion products by using semicuantitative energy dispersive X-Ray analysis (EDX). In the second stage on the investigation the samples were cleaned from blood and organic tissues by means of ultrasonic cleaning and C-Cr replicas were prepared in order to ascertain the type of failure. Microstructural investigations with the aim of determining inclusions level and grain structure were performed in conjunction with hardness measurements (Rockwell B) of the material on suitable prepared metallographic samples. The chemical compositions were determined by using atomic absorption techniques.

CASE HISTORY

A 72 years old woman (weight 75 kilograms and height 1.58 meters) had suffered a subtrochanteric fracture at the right hip. The patient underwent surgery and fixation with a DHS 135° system, using a DHS and 4 cortical screws. After surgery the patient presented stiffness and pain in the right hip. Three years later, the patient suffered a new fall down and trauma of the same hip. Symptomatology increased and a shortening of the right leg was observed.

A roentgenogram showed that all the four cortical screws had fractured with their distal parts inserted in the femoral diaphysis and osteolysis of the femur was observe close to the screws. A revision surgery of the arthroplasty was done and all metallic pieces were removed and a new osteosynthesis was performed employing a condylar plate and dynamic screw, fixed with seven cortical screws. Also, fibrotic and cartilagineous material were excised of the focus of pseudoarthrosis and bone graft was laid, taken from the right iliac crest. Postoperative evolution was satisfactory.

RESULTS AND DISCUSSION

A comparison between the chemical analysis of the screws and the composition corresponding to grade 1 and grade 2 indicated by the ASTM F 139 standard is presented in **Table I**.

The metallographic study of the alloy revealed the presence of a deformed structure with concentration of straim lines and containing

Table I- Comparison between the actual composition of the stainless steel screws and the required ASTM standard composition.

Element,%	Implant	Grade 1ASTM F139	Grade 2 ASTM F139
C	0.05±0.01	0.06 max.	0.03 max.
Ni	14.7±0.1	13.00 -15.50	13.00 -15.50
Cr	16.4±0.2	17.00 -19.00	17.00 -19.00
Mo	3.3±0.1	2.00 - 3.00	2.00 - 3.00

numerous deformation bands and annealing twins, as it can be observe in the photomicrograph presented in **Figure 1a**. A small amount of inclusions was detected (**Figure 1b**) and hardness was found equal to 98.0 ± 0.3 HRB, according with F 56, F 138 and F 139 ASTM standards.

Figure 1a

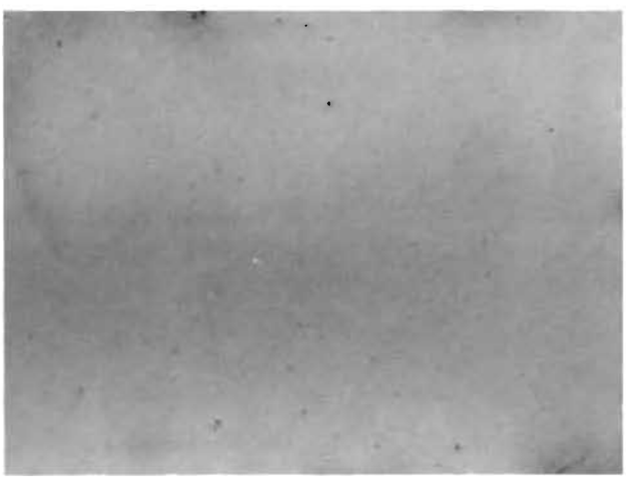


Figure 1b

Figure 1. Optical photomicrographs showing the **a)** alloy microstructure and **b)** level of inclusions of the implant material.

Although the plate did not failed, it presented various parts of its surface damaged, specially those corresponding to the holes, due to the contact with the screws heads. Scanning electron microscopy performed on the surface of one the oval holes of the plate had indicated crevice corrosion evidences with a high degree of pitting as shown in **Figure 2**. Also, fretting was noticed. A selective chemical atack is observed on the slip bands which is characteristic of a highly deformed material. The corrosion products encountered were identified by EDX analysis and the results are presented in **Figure 3**.

Figure 2a

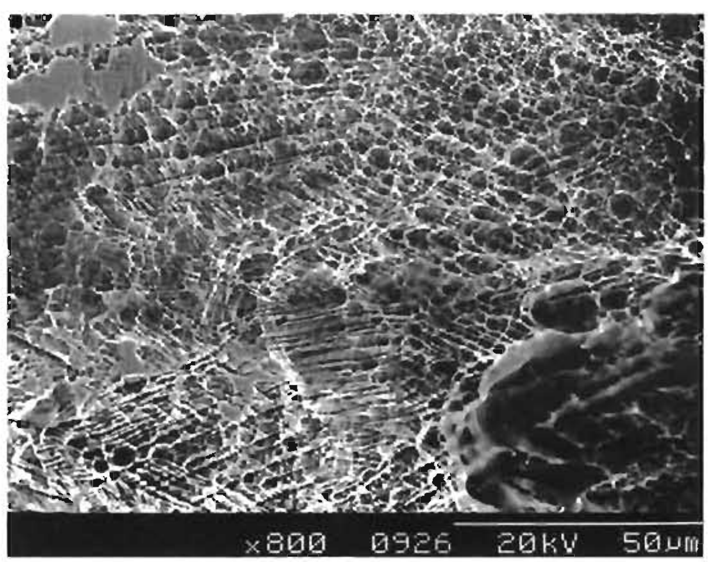


Figure 2b

Figure 2. Scanning electron micrographs showing crevice corrosion on DHS plate. **a)** 20X **b)** 800X

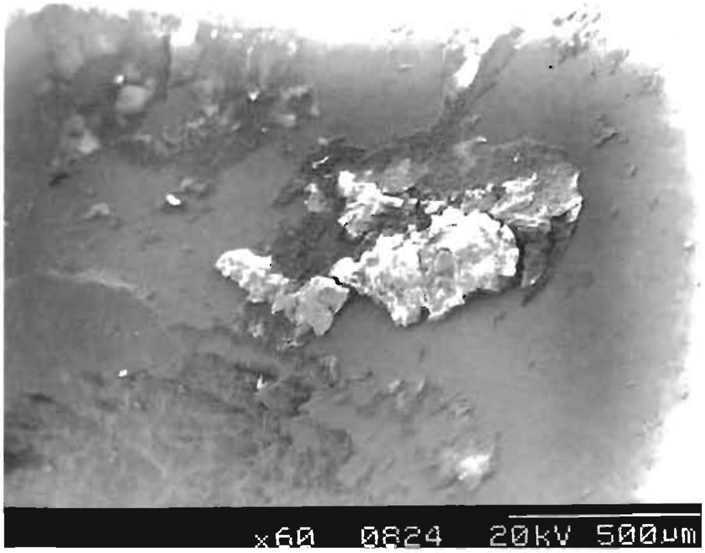


Figure 3. Scanning electron micrograph and EDX analysis of the corrosion products.

Figure 4 represents a scanning electron micrograph of the fracture surface of a cortical screw. It can be observed that the crack has progressed to nearly 90% of the area without producing an appreciable plastic deformation. In spite of the presence of apparent radial propagation lines, the examination of the samples both under the SEM and TEM revealed the existence of fatigue striations. The arrow A indicate the initial fatigue crack on the surface of the cortical screw. Fracture initiated at the surface, in the zone of highest stress concentration.

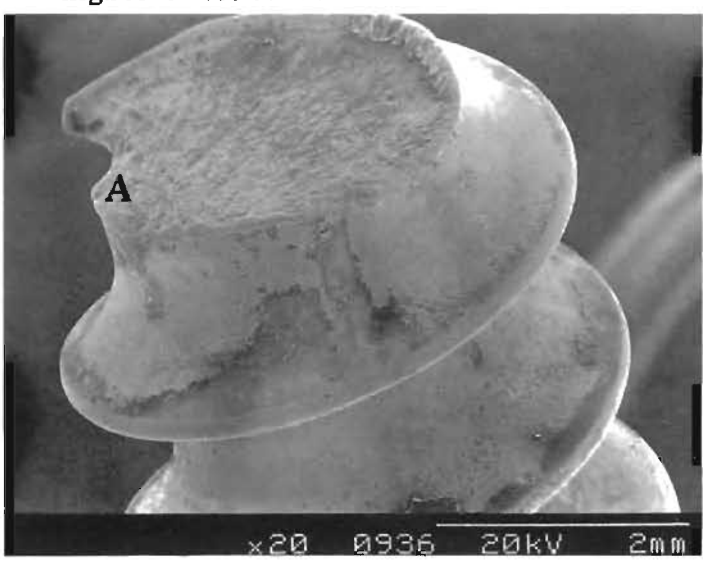
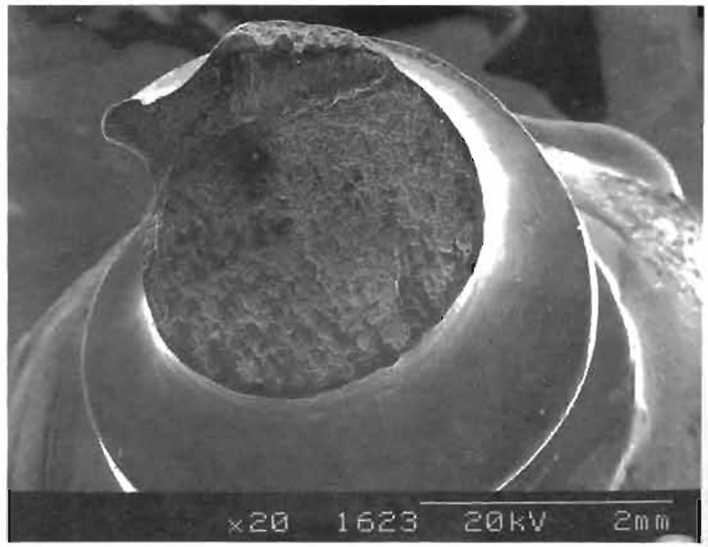


Figure 4. Macroscopic fracture cross section of the cortical screw which suffered initial failure.

The macroscopic fracture cross section shows the evidence of a brittle fracture with a very narrow shear lip. The experimental evidence indicates that this screw was probably the first in failing and its study is fundamental in determining the mode of failure. All the other screws did not present an appreciable plastic deformation, as can be observed in **Figure 5**. On the fracture surface, near to the shear lip of every screw, high quantity of pits were observed due to the crevice corrosion mechanism that occurred in the crack.



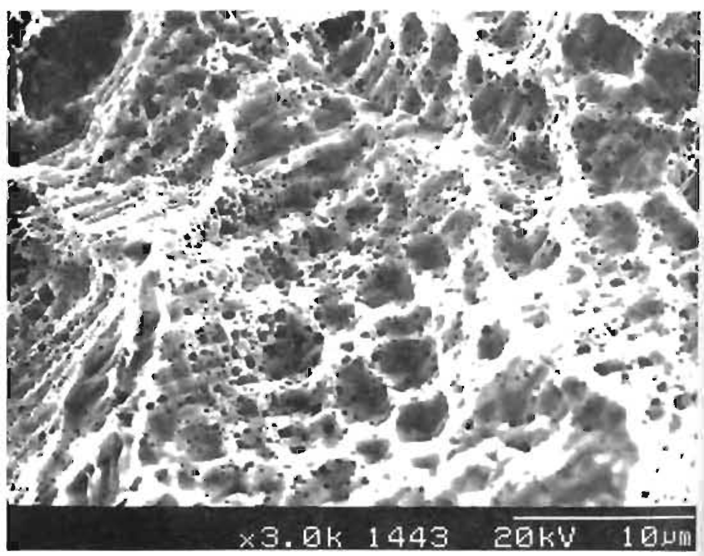


Figure 5. a) Macroscopic fracture cross section of one of the three cortical screws which had fractured presenting a brittle behaviour. **b)** scanning electron micrograph of the same surface fracture, nearer to the shear lip.

Figure 6 presents a number of photomicrographs showing typical characteristics of a fatigue process assisted by corrosion and the presence of secundary cracks. Here, again a selective chemical atack is noticed on the slip bands which are characteristic of a highly deformed material.

Moreover, the analysis of the two-stage replicas of the fracture surface by transmission electron microscopy demonstrated the presence of fatigue striations and a high degree of pitting as it could be observed in **Figure 7**.

The fretting corrosion noticed in the fracture surface of all four screws is not related to crack propagation. It is merely the result of the screws rubbing over the plate after their complete fracture, in the presence of the aggressive environment.

The high quantity of the corrosion products encountered on the fracture surface in **Figure 3** also supports that this screw was probably the first in braking, since the degree of the corrosion is dependent on the length of time in which the fracture surface was exposed to the environment.

CONCLUSIONS

The failure mechanim encountered was fatigue assisted by corrosion. The failure of the hip endoprosthesis system was mainly due to an erroneous indication in the use of the fixation device. This fact combined with a osteoporotic bone and a bad healed fracture, produced extreme functioning conditions, that decreased the fatigue life of the fixation screw. The crevice corrosion observed is inherent to the design of this system, due to the crevice produced by the contact of the plate with the screw. It is believed that the oxygen poor region of the crevice challenges the stability of the passive film by forming pits on the metal surface, as it was observed.

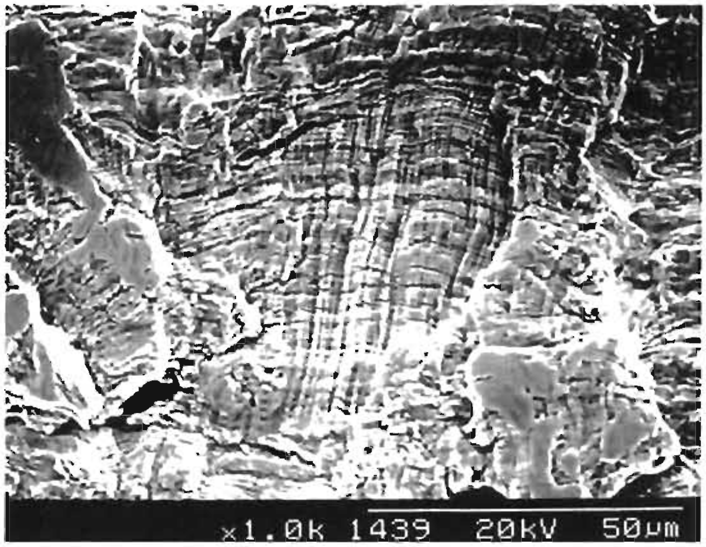


Figure 6. Scanning electron micrographs of the fracture surface of the cortical screw which suffered initial failure.

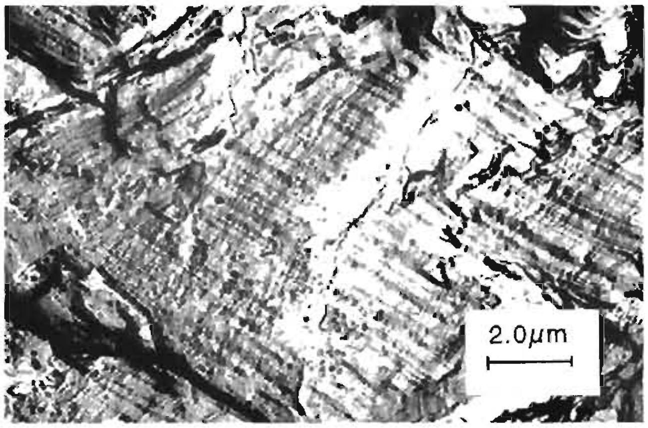


Figure 7. Transmission electron micrograph of the fracture surface of the cortical screw which suffered initial failure.

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RESUMEN

Se ha llevado a cabo un análisis de falla en una pieza de fijación interna extraída de un medio *in vivo*. El sistema de fijación estaba compuesto de una placa de 135°, un tornillo dinámico de cadera (TDC) y cuatro tornillos de cortical fabricados de acero inoxidable 316L. Se realizó un análisis detallado sobre las superficies dañadas y de fractura de las piezas falladas mediante las técnicas de microscopía óptica convencional, microscopía electrónica de barrido y microscopía electrónica de transmisión. Por otro lado, se determinaron la composición química, la dureza y las características microestructurales de la aleación, a fin de compararlas con los standars y las especificaciones del fabricante y verificar si el material *per se* es responsable de la falla. Los estudios microfractográficos indicaron que la morfología de fractura predominante fué característica del mecanismo de fatiga asistido por corrosión. La causa de la falla obedece a una combinación de factores tales como la presencia de un hueso osteoporótico, el peso del paciente y la actividad postoperativa del mismo, una fractura mal consolidada, y algunos aspectos relacionados con una indicación errónea de la pieza de fijación.

REFERENCES

1. Ducheyne P., De Meester P. and Aernoudt E., (1980. Performance Analysis of Total Hip Prosthesis: Some Particular Metallurgical Observation , J. Biom. Mat. Res. Vol.14, 31-43.

2. Galante J. O., (1980). Causes of Fractures of the Femoral Component in Total Hip Replacement. J. Bone Joint Surg., 62A, 70-673 .

3. Rimnac C. M. (1991), Failure of Orthopedic Implants: Three Case Histories. Mat. Charact. Vol. 26, 201-209.

4. Brown S. A. and Simpson J. P., (1981), Crevice and Fretting Corrosion of Stainless Steel Plates and Screws, J. Biom. Mat. Res. Vol.15, 867-878.

5. Greene N. D., (1985). Corrosion of Surgical Implant Alloy : A Few Basic Ideas, Corrosion and Degradation of Implant Materials, Second Symposium, (Eds. A. C. Fraker and C.D. Griffin). ASTM , 5-11.

6. Piehler H. R., (1985). Corrosion Fatigue Prformance of Hip Nails: The Influence of Materials Selection and Design, Corrosion and Degradation of Implant Materials, Second Symposium, (Eds. A. C. Fraker and C.D. Griffin), ASTM , 5-11.