Heifetz clip failure

A metallurgical study

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A metallurgical analysis of a fractured Heifetz aneurysm clip is described. The authors assign the failure to a stress-corrosion mechanism.

KEY WORDS • aneurysm clip • metal implant • scanning electron microscopy

Blade fracture of Heifetz aneurysm clips is a rare but recently observed postoperative complication. There are few reports of this occurrence in the literature, but none deals with the fracture properties of the defective clips. This report concerns the blade fracture of a Heifetz aneurysm clip, and our investigation of the cause through analysis of the clip's mechanical and metallurgical properties.

Case Report

This 75-year-old man was hospitalized in April, 1977, with severe bifrontal headaches, a loss of sexual potency, gynecomastia, and a loss and coarsening of body hair. Endocrinological studies confirmed panhypopituitarism. Neurological examination included computerized tomography, cerebral angiography, and pneumoencephalography. These studies showed pituitary tumor with slight suprasellar extension, and a large, broad-based aneurysm of the right internal carotid artery (ICA) near the posterior communicating artery junction (Fig. 1).

A right frontotemporal craniotomy was performed and a chromophobe adenoma was excised. The ICA aneurysm was then clipped with a Heifetz aneurysm clip* of Drake's design to preserve a crossing anterior cerebral artery A1 loop. N-butyl ester of a-cyanoacrylate glue was applied to the clip to stabilize its position. The patient recovered and was discharged 3 weeks after his admission.

In September, 1977, the patient was again hospitalized with severe gastrointestinal hemorrhage from a peptic ulcer; he was comatose and in shock. Subsequently, he developed pneumonia and a urinary tract infection, and died after 1½ months. At postmortem examination, a small amount of residual tumor and an organizing hematoma were noted in the sella turcica. The circle of Willis was dissected and the aneurysm was demonstrated with the clip in place. The aneurysm sac was completely thrombosed, and one blade of the clip was found to be fractured near the spring mechanism (Fig. 2).

Metallurgical Analysis

Method

The surfaces of the fractured clip were examined with a Cambridge Stereoscan II scanning electron microscope (SEM)† (Fig. 3). A block of n-butyl ester of a-cyanoacrylate glue residue investing the spring was analyzed with energy-dispersive x-ray (EDAX)‡

*Heifetz aneurysm clip Catalog No. 65920 manufactured by Edward Weck and Company, Weck Drive, P.O. Box 12600, Research Triangle Park, North Carolina.

†Cambridge Stereoscan II scanning electron microscope (SEM) manufactured by Cambridge Instrument Company, 40 Robert Pitt Drive, Monsey, New York.

‡Energy-dispersive x-ray manufactured by EDAX International, P.O. Box 135, Prairie View, Illinois.
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and chemical spectrography. After the preliminary examinations, "Endox" electrolytic cleaner was used to remove oxides and other residues from the surface of the clip without affecting the base metal. The clean clip was then re-examined with SEM and EDAX. Finally, the intact blade of the clip was intentionally fractured in the laboratory and the surfaces were examined for comparison.

Results

The spectrographic analysis of the n-butyl ester of a-cyanoacrylate glue residue investing the clip indicated contamination by Mg, Na, Cl, Fe, Pb, Si, Ti, and P (Table 1). The SEM examination of the accidentally fractured blade revealed a surface covered with a thin layer of oxide and glue that masked the underlying details. A particularly thick deposit band ran along the inner side of the fractured surface (Fig. 4 A). An x-ray spectrum (Fig. 4 C) of a deep deposit (Fig. 4 B) showed that the ratio of Fe, Cr, and Ni were proportional to the ratio in the base metal. In addition, Na, Cl, K, Ca, and a very high level of P were detected. We subsequently analyzed three brand-new Heifetz clips and found traces of phosphorus in each clip.

After the deposits in the recovered clip had been cleaned with Endox, the fractured surface was generally similar to that of the intentional laboratory fracture. Both sides exhibited a fracture characteristic of materials that break after a fair amount of plastic deformation (Fig. 5 B). However, areas along the heavy deposit band (Fig. 4 A and B) revealed sharp

FIG. 1. Skull films, lateral view. A: An enlarged sella turcica can be seen. B: A broad-based aneurysm of the right internal carotid artery is demonstrated near the posterior communicating artery junction.

FIG. 2. The recovered fractured Heifetz clip.

FIG. 3. Orientation of the parts of the fractured clip that were examined.
grain facets, trenches of missing material, and cracking along the grain boundaries, which suggest that the fracture occurred by an intergranular corrosive mechanism (Fig. 5 A). This cracking and penetration of the grain boundaries was also observed along the edge of the clip near the fracture site (Fig. 6).

Discussion

Quest and Countee\textsuperscript{6} discovered a partially broken Heifetz aneurysm clip, which they attributed to mechanical failure, while Hayakawa, et al.,\textsuperscript{3} and Servo and Puranen\textsuperscript{7} hypothesized that the failure may have been due to metal fatigue. However, our study indicates that the force of clip closure causes a bending stress far below the blade's yield point. Clearly, other factors were involved.

Venable, et al.,\textsuperscript{9} established that each of the commonly used implant metals is electrolytically active, and that damage to the metal is proportional to the amount of electrochemical action. McFadden\textsuperscript{4} reported that austenitic stainless steels are approved for surgical implantations because they are relatively inert to electrochemical attacks. Molybdenum-containing type 316 steels and the equivalent series (Fe-Al-Ni) are preferable to the less inert alloys that do not contain molybdenum; but McFadden has shown that the electrochemical activity of even these relatively inert steels is greatly enhanced by capping or coating only part of the implant with a polymer.\textsuperscript{4}

The recovered Heifetz clip was partially coated with an isobutyl-cyanoacrylate glue which deprived a region of oxygen and established an electrolytic potential along the clip blade\textsuperscript{1} (Fig. 7 B and C). As a result,
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FIG. 5. Surfaces after Endox cleaning. × 2000. A: Fractured surface depicted in Fig. 4 A and B, after removal of the deposit. Similar details were observed at numerous locations along the inner edge previously covered by the heavy deposit. This fractured surface indicates that failure occurred by an intergranular corrosive mechanism. Note the sharp grain facets, trenches of missing material and cracking along grain boundaries. B: Typical appearance of the fresh fracture surface produced in the laboratory. It exhibits dimpled, ductile fracture, indicative of material that breaks after a fair amount of plastic deformation.

TABLE 1

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cu</th>
<th>Fe</th>
<th>Mg</th>
<th>Na</th>
<th>Pb</th>
<th>Si</th>
<th>Ti</th>
<th>P</th>
<th>Cl†</th>
</tr>
</thead>
<tbody>
<tr>
<td>residue</td>
<td>0.001</td>
<td>0.02</td>
<td>0.01</td>
<td>0.3</td>
<td>0.03</td>
<td>0.01</td>
<td>0.001</td>
<td>0.2</td>
<td>0.0040</td>
</tr>
<tr>
<td>pure glue</td>
<td>0.0001</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

*The value of these solids is given in weight percent, based on total weight of the polymer sample. ND = not detectable.
†Chlorides analysis.

FIG. 6. Polished edge of the broken blade. × 1200. Notice the cracks penetrating the grain-boundaries along the entire inner edge (arrows). N = Normal grain; E = Elongated grain structure, indicative of cold metal working.

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FIG. 7. A: Bend stress ($\sigma$) at the fracture area. $b$ = blade width; $h$ = blade thickness; $p$ = measured force at the blade's midpoint. Blade separation is 0.25 mm. B: Electrolytic activity of the blade. $G$ = glue. C: Coating only part of the clip with the glue resulted in the formation of an electrolytic potential along the blade. The region under the glue acted as the anode, while the uncovered region became the cathode.

The findings of this study can be summarized by the following four points:

1. An electrochemical cell was formed by the partial coverage of the clip with glue.

2. The clip material is biphasic and therefore it amplified the potential of the electrochemical cell.

3. Phosphorus, that may have resulted from the electropolishing step, could have accelerated the ongoing electrochemical corrosion.

4. The high bend stress at the fracture point may have accelerated the preferential chemical dissolution and may have reached the critical level under these conditions.

We are assigning the failure of the Heifetz aneurysm clip to a stress-corrosion mechanism. The bending moment on the inner surface of the clip blade accelerated chemical dissolution, resulting in preferential attack at the grain boundaries. This led to a gradual weakening of the material and final fracture. Since the chemical dissolution originated from galvanic action, we recommend that partial coverage of surgical implants by glue or other coating material be avoided.

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References


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