Mechanical characteristics and surface elemental composition of a Yasargil titanium aneurysm clip after long-term implantation

Technical note

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The mechanical properties of titanium-alloy aneurysm clips after long-term implantation in the human cranium are unclear. The characteristics of a Yasargil titanium aneurysm clip were evaluated after long-term implantation for 12 years in a patient with a cerebral aneurysm. The closing forces of the retrieved clip before and after implantation were approximately equal. The bending test showed no differences between the retrieved and control clips. Titanium oxide and calcium were identified on the surface of the retrieved clip, which indicated the formation of corrosion-resistant layers. Titanium-alloy clips retain their mechanical properties in the human cranium for a long time.

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KEY WORDS • aneurysm • aneurysm clip • implantation • titanium

Aneurysm clips used for the treatment of intracranial aneurysms must be highly biocompatible and must provide adequate permanent closing force. The titanium alloy used for aneurysm clips is a biocompatible material with adequate strength, resistance to corrosion, and MR imaging compatibility. The reliability of the clip material has been tested and approved by International Organization for Standardization. However, titanium alloy is inferior to cobalt-chromium alloy in both yield and tensile strength. Furthermore, the mechanical properties of titanium clips after long-term implantation in the human cranium are unclear.

We evaluated the mechanical characteristics and surface elemental composition of a Yasargil titanium aneurysm clip removed after long-term implantation for 12 years in a patient with a cerebral aneurysm.

Methods

Surgery for regrowth of a previously repaired unruptured middle cerebral artery aneurysm was performed in a 70-year-old woman. The clip implanted for 12 years was retrieved, and the aneurysm was repaired with a new aneurysm clip of the same type. The retrieved clip was a 7-mm mini straight Yasargil titanium clip (Aesculap AG) made of titanium 6-aluminum 4-vanadium alloy (code number FT720T). The retrieved clip was compared with an unused Yasargil titanium aneurysm clip of the same type as a control.

The surfaces of the clips were carefully examined macroscopically. Then, a clip force meter, which was designed for testing intracranial aneurysm clips based on the ASTM F1542 and ISO 9713 guidelines, was used to automatically measure the closing force of the clips at a

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point one-third along the length of the blade from the tip at a blade separation distance of 1.0 mm.\textsuperscript{1,6} The closing force of the retrieved clip before implantation had been measured using the same method by the manufacturer. The bending test was conducted on the clips using a tension tester (Autograph AG-250KNI, Shimadzu Co.). The applied test speed was 1 mm/minute. This bending test was performed to evaluate the elastic limit, 0.2% proof load, and ultimate load, which are, respectively, the maximum load not causing permanent deformation, the load causing 0.2% deformation, and the load at the maximum point of the load curve. Finally, the elemental composition and the oxidative state of the surface at the center of the clip blades were analyzed by x-ray photoelectron spectroscopy (XPS)\textsuperscript{3,8} using a scanning microprobe (Quantum 2000, ULVAC PHI, Inc.) with aluminum monochromatic x-rays. X-ray photoelectron spectroscopy uses x-rays to cause the ejection of electrons, known as photoelectrons, from atoms. The photoelectrons are separated according to their energies in an electron analyzer. The energy of each ejected photoelectron is characteristic of the atomic origin, so the resulting electron energy spectrum can be used to identify the elements present. X-ray photoelectron spectroscopy evaluates the chemical composition from the surface to a few nanometers in depth. The composition at different depths of the surface layer was determined by a combination of repeated argon ion sputtering and XPS.

**Results**

Macroscopic examination of the retrieved clip and comparison with the control clip showed no deformity or corrosion (Fig. 1). The closing forces of the retrieved clip before and after implantation were 110 g and 106 g, respectively. The stress-strain curve of the bending test showed no differences in the elastic limit, 0.2% proof load, and fracture load between the retrieved and control clips (Fig. 2). The XPS depth profiles of each clip are shown in Fig. 3. Titanium oxide was the predominant constituent on the surface of both clips. The concentration of calcium on the surface of the retrieved clip was higher than that on the control clip. In the deeper portions of the clips, there was no difference between the retrieved and control clips in the concentrations of any element.

**Discussion**

The closing forces of the retrieved clip before and after implantation were approximately equal. Furthermore, the bending test found no difference between the retrieved and control clips. These findings suggest that titanium alloy aneurysm clips retain their mechanical properties in the human cranium for a long time, 12 years in this case.

Titanium oxide was the predominant constituent on the surface of the retrieved and the control clips. Titanium

![Fig. 1. Photographs depicting the retrieved (upper) and unused (lower) Yasargil titanium clips (FT720T).](image1)

![Fig. 2. Graph showing the stress-strain curves of the bending test for the retrieved and unused clips.](image2)

![Fig. 3. Graphs showing the XPS depth profiles of the retrieved (upper) and unused (lower) clips.](image3)
has a high affinity for oxygen, so an oxidized layer called a passive film is formed in both human body fluid and atmospheric conditions.\(^{10}\) This oxidative layer acts as a corrosion-resistant barrier, which prevents dissolution of metal ions into the solution, migration of anions from the solution to the metal, and migration of electrons across the metal-solution interface.\(^7\)

The calcium concentration on the retrieved clip was higher than that on the control clip. Calcium ions are adsorbed by phosphate ions, leading to calcium phosphate formation.\(^2\) Eventually, apatite is formed in vivo, which is characteristic of implanted titanium instruments. This apatite layer also acts as a further corrosion-resistant barrier.\(^11\) The titanium oxide and apatite layers also retain their mechanical properties in the human cranium for a long time, which confirms the reliability of titanium alloy aneurysm clips for long-term implantation.

**Disclaimer**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**References**


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