FLUORESCENCE AND XAFS SPECTROSCOPY OF ION RELEASE FROM METAL IMPLANTS IN HUMAN TISSUE

The aim of the present study is to use the focused beam from a synchrotron radiation source to measure the distribution and chemical states of trace elements (Fe, Cr, Ni, *etc*.) incorporated into a matrix of human tissue.

In our previous studies, we used photo-induced X-ray emission (PIXE), microbeam PIXE, and SR-excited X-ray fluorescence (SR-XRF) to investigate ion release. Materials from long-term implants were shown to release metallic or polymeric elements into tissue, possibly due to chemical and frictional interactions between the surface of the implant and surrounding tissue [1]. Ion release and evaluation of the toxicity of the released elements have been the subject of several *in vivo* and *in vitro* studies. The distribution and chemical state of these trace elements must be explored further in order to elucidate a mechanism of dissolution of the implant material in the human body and toxicity of the released elements.

Nine sections from different parts of a total hip joint system were obtained from one 55-year-old diagnosed arthrotic female patient who had a total hip replacement with a hydroxyapatite- (HAp-) coated prosthesis. The implant consisted of a stem and a metal backing made of Ti-6Al-4V, an implant head made of stainless steel, and a polyethylene (PE) cup. Both the stem and the metal backing had a plasma-sprayed, 155 μ-thick HAp surface coating. Accelerating PE wear was diagnosed, leading to re-operation 5.4 years after insertion. This hip functioned painlessly until a few months before re-operation. At revision, one could observe excessive wear: the femoral head had created a wear hole through the PE-inlay and the steel was fretting directly on the Ti-alloy-made backing. 10-micron ground sections were stained and prepared for light microscopy. Thin 50-micron unstained loose ground sections were also prepared for SR-XRF (SR-excited X-ray fluorescence) spectroscopy.

Due to mechanical friction or chemical reactions that cause dissolution of the implant material, metal ions were released into the surrounding tissues from the metal implant. Large areas of black-stained tissue as well as large PE particles, internalized in multinucleated cells, were observed

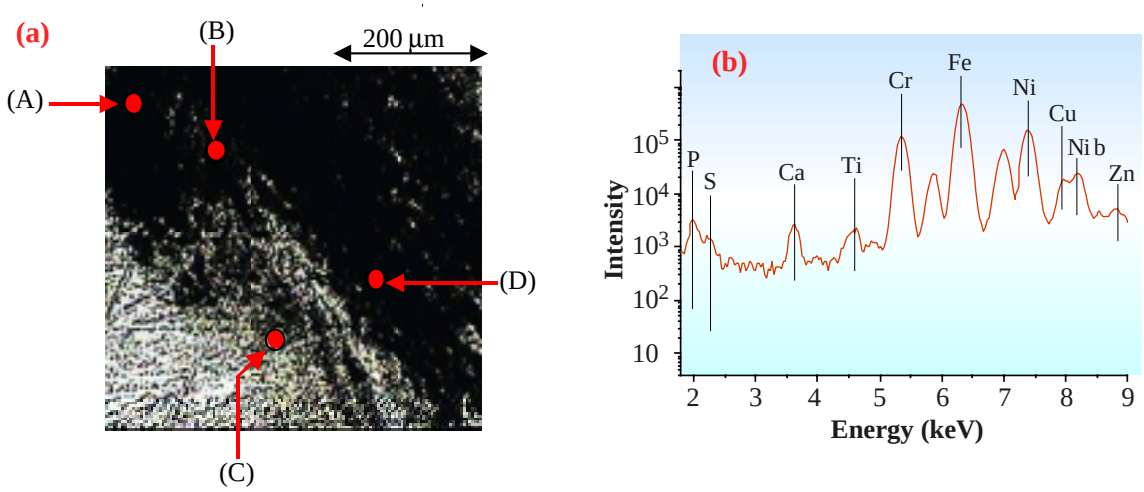

Table 1. Relative contents of elements

	(A)	(B)	(C)	(D)
Cr:Fe:Ni	1:2.20:0.44	1:2.24:0.44	1:2.47:0.46	1:2.30:0.45

Fig. 1. ***(a)*** *Optical microscopic photograph of the tissues around a failed hip replacement prosthesis.* ***(b)*** *XRF spectra of the point (B) in Fig. 1* ***(a)****. The measurement time was 100 sec, beam size was 10 μm², and beam energy was 10.5 keV. This spectrum shows that Fe, Cr and Ni are incorporated in the soft tissues in a high level.*

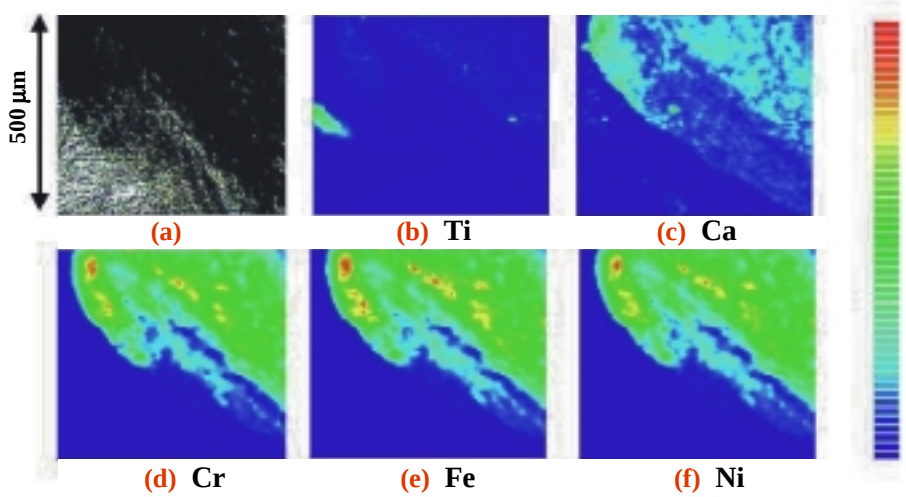

Fig. 2. ***(a)*** *Optical microscopic photograph of the tissues around a failed hip replacement prosthesis.* ***(b-f)*** *Elemental maps of* ***(b)*** *Ti,* ***(c)*** *Ca,* ***(d)*** *Cr,* ***(e)*** *Fe and* ***(f)*** *Ni. The scanning area wa 500 μm². All images are 50 × 50 pixels of 10 μm resolution and the measurement time was 1 sec/pixel. The scale on the right-hand side of the images shows the count of the X-ray intensity. The range of intensity is 84 for Ca, 210 for Ti, 3300 for Fe and 490 for Ni.*

by light microscopy in the specimens used in this study.

A typical spectrum of the SR-XRF analysis is shown in Fig. 1(b) without any absorption corrections. In this spectrum, metal elements such as Ti, Cr, Fe, and Ni are detected with a high intensity. These elements are components of particles that resulted from friction between the head and cup of the hip joint system.

Detailed imaging (Fig.2 (b-f)) shows evidence of the incorporation of micro and nano particles of metallic elements at the single-cell level. These XRF images show that metal elements from the implants dissolved, and were extensively distributed in the tissues.

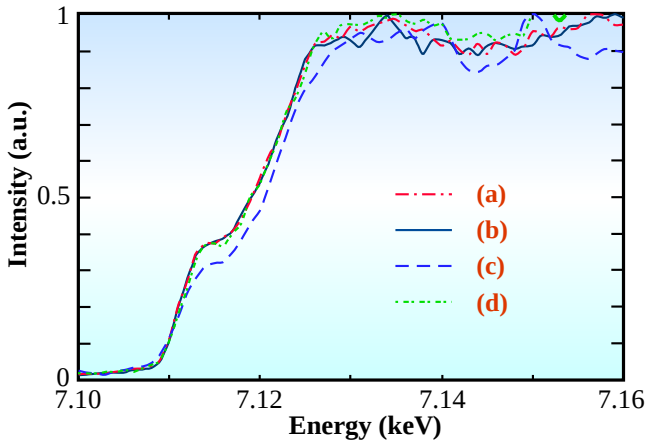

Fig. 3. Fe K-edge XANES spectra measured at point ***(a)****,* ***(b)****,* ***(c)*** *and* ***(d)*** *in Fig. 1****(a)****.*

Fe *K*-edge XANES spectra are shown in Fig. 3. These spectra show that the chemical state of Fe was changed in the tissues. The change of chemical state and Fe/Cr ratio calculated from the X-ray fluorescence spectrum indicates that dissolution of Fe in the tissues was more significant than Cr.

The application of microbeam synchrotron radiation (microbeam XRF and micro-XAFS) to the detection of metal ions allows for wide-range mapping of the elements in biological tissues as well as detailed mapping at the cellular level. Thus, further investigations can be conducted regarding the interactions of the accumulated elements within cells and their consequences for normal cellular function [2].

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References

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[2] A. Ektessabi *et al.* , X-Ray Spectrom. **28** (1999) 456.