Infrared SR Analysis of Trace Vitamin E in an Artificial Joint made of Ultrahigh Molecular Weight Polyethylene (UHMWPE)

Artificial joint substitution for the elderly has been increasing in accordance with their desire for independent living and the recovery of functional use. Also, orthopedic implantations have been increasing in recent years.

In the case of knee joint substitution, a joint made of ultrahigh molecular weight polyethylene (UHMWPE) connected with titanium or Co-Cr-Mo alloy components is placed between the thigh bone and the shin bone. The life of an artificial joint depends on the degree of deterioration of UHMWPE, and the average life is recognized as being 15-20 years. The joint is slowly ablated, oxidized and deteriorated by the weight load and friction. Increased oxidation stability and wear resistance are key features in extending the life of an artificial joint. UHMWPE has good wear resistance but poor oxidation stability to free radicals [1] and low wear resistance to heat treatment [2]. An example of a failed UHMWPE knee component is shown in Fig. 1(a). Many materials have been tested as functional additives to UHMWPE, and vitamin E has been recognized as a promising material. UHMWPE with added vitamin E has similar mechanical properties to pure UHMWPE [3] but also exhibits high oxidation stability [4], high wear resistance [4] and ease of molding.

In this study, we aimed to evaluate the oxidation stability and wear resistance of UHMWPE with added vitamin E by infrared SR analysis.

A tibial component used in total knee arthroplasty (High-Tech Knee II, Nakashima Medical) made of UHMWPE with added vitamin E as shown in Fig. 1(b), was prepared by the direct compression molding (DCM) technique. An accelerated oxidation was conducted by the method of Sun as follows. We first irradiated the sample with 25 kGy gamma rays in air at atmospheric pressure at 80°C. After irradiation, we kept the sample at 23°C for 7 days. The six-station four-axis knee joint simulator (Fig. 2(a)) (AMTI, Boston, MA) was then applied to the sample. The waveform for the simulation was that of normal walking and a 5,000,000-cycle test was carried out, which simulates 7-10 years of use in real life. After the 5,000,000-cycle simulation, the sample lost 30% of its weight as shown in Fig. 2(b).

We carried out measurements of the samples at the infrared microspectroscopy beamline **BL43IR** before (=control) and after applying the accelerated oxidation and the knee joint simulator. Two hundreds spectra were accumulated at a wavenumber resolution of 4 cm^{-1}. The mapping area was 2000 μm × 75 μm wide along the X and Y axial directions, respectively, and the stepping pitch was 25 μm × 25 μm. The quantity of added vitamin E was trace, which was why we used infrared synchrotron radiation instead of FT-IR with a conventional light source. We chose a 500-μm-thick sample to ensure that we obtained the absorption intensity of the trace vitamin E. A sample of this thickness cannot easily be measured by conventional FT-IR, and the highly brilliant synchrotron radiation at SPring-8 is ideal for the measurement.

Figure 3 shows the infrared absorption spectra of UHMWPE with vitamin E concentrations of 0, 0.3, 1

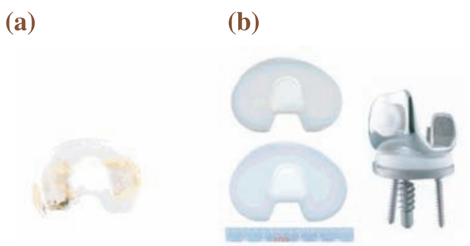

Fig.1. **(a)** Failed UHMWPE knee component due to lack of oxidation stability. **(b)** Test sample (top), control (bottom) and HTK II knee joint.

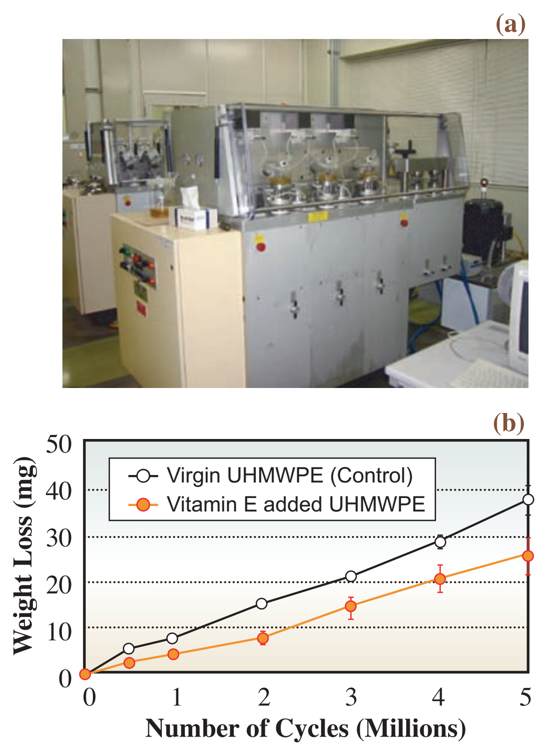

Fig. 2. **(a)** AMTI knee joint simulator. **(b)** Weight loss of the samples during the simulation.

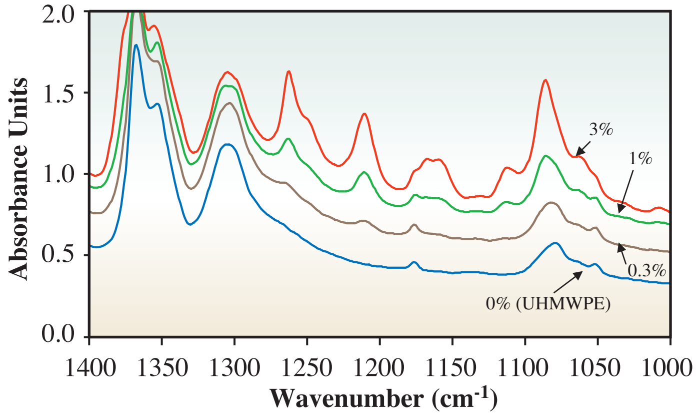

Fig. 3. Infrared absorption spectra of UHMWPE with various concentrations of added vitamin E.

and 3%. In the spectra, we confirmed the presence of -OH and -C-O-C- functional groups in the chromane ring of vitamin E at *ca*. 1050 - 1300 cm^{-1}. In the mapping images shown in Fig. 4, we found vitamin E distributed near the surface before (=control) (Fig. 4(b)) and even after applying the accelerated oxidation and the knee simulator (Fig. 4(a)), which suggests that vitamin E in UHMWPE plays an important role in preserving the joint under conditions simulating oxidation, weight load and friction that occur in daily use.

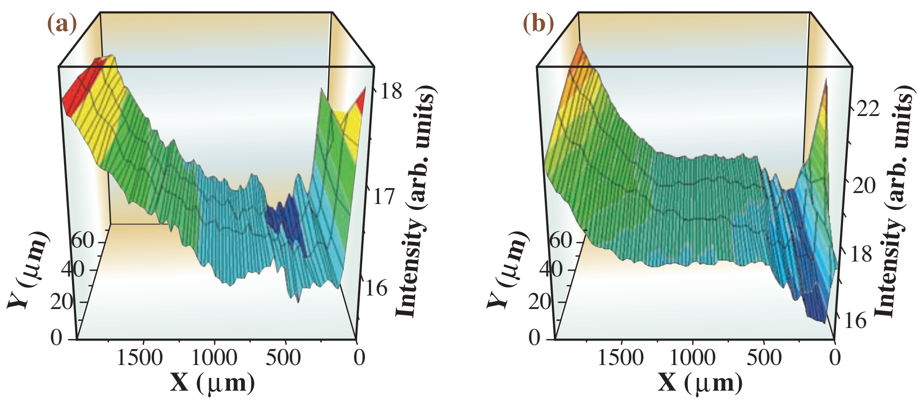

Fig. 4. Mapping images of the -OH functional group of the chromane ring in vitamin E. The X axis is along the depth direction and the Y axis is along the surface of the artificial joint. **(a)** After accelerated oxidation and knee simulator. **(b)** Before accelerated oxidation and knee simulator (control).

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