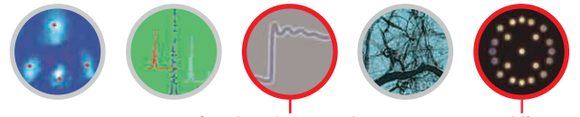
Development of Long-Lasting Artificial Joints

A new direction in designing materials to prevent oxidation and degradation of artificial joints

Research method



Beamlines used at SPring-8: Infrared Materials Science (BL43IR) and Structural Biology II (BL40B2)

Achievements

- Development of the first artificial joint consisting of **ultra-high molecular weight polyethylene*** containing **vitamin E**** to prevent oxidation and degradation
- Contribution to product management and future materials design through confirmation of antioxidant capability of vitamin E by precisely analyzing trace amounts of vitamin E
- First observation of the age-related deterioration of artificial joints at the crystallographic level

R&D facility: Nakashima Medical Co., Ltd.

***Ultra-high molecular weight polyethylene (UHMWPE):** UHMWPE is a highly advanced plastic based on polyethylene, but with a much higher molecular weight. Compared to commodity plastics, UHMWPE has superior impact and wear resistance, and is self-lubricating. Applications of UHMWPE include gears, bearings, and machine tools; due to its stability in the body, it can also be used to form artificial bones.

****Vitamin E:** A fat-soluble vitamin that protects cells from oxidation and maintains good health. Vitamin E, which has a chemical structure called a chroman moiety, suppresses oxidation and degradation via reactions between hydrogen atoms desorbed from the hydroxyl (OH) group of the chroman moiety and free radicals produced in metabolism. Vitamin E is also used as an antioxidant food additive.

Role of SPring-8

Background

The frequency of joint replacement procedures has been rising in recent years. However, patients with osteoarthritis who received joint replacements in their 60s need to have another replacement surgery in their 80s because existing artificial joints last only 10–20 years. Therefore, development of long-lasting artificial joints has been a major priority.

Polyethylene, which has been commonly used in artificial joints, is degraded through oxidation. To overcome this issue, research on antioxidants has been conducted, resulting in the development of UHMWPE containing vitamin E, which has few side effects in the human body. UHMWPE containing vitamin E is resistant to oxidation, and has improved lubrication relative to traditional polyethylene. A clinical study of UHMWPE, involving 65 patients, was conducted in 2004.

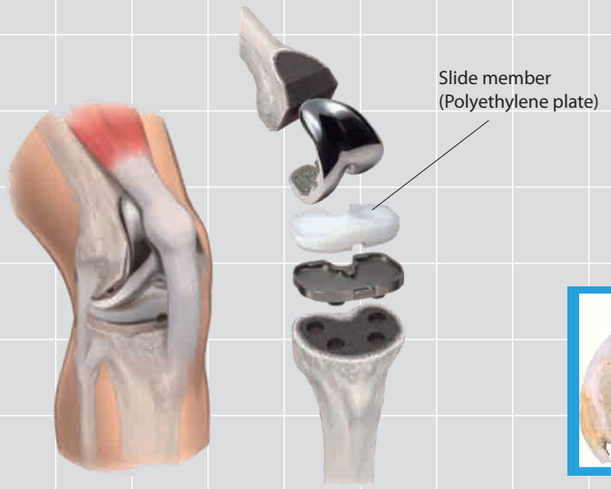
Results

It will take another 5-10 years to demonstrate that polyethylene containing vitamin E is actually resistant to oxidation. However, before UHMWPE can be commercialized, the antioxidant capability must be confirmed. To this end, a **trace amount of vitamin E contained in artificial joints** was precisely examined using SPring-8's highly brilliant infrared synchrotron radiation. This examination elucidated the relationship between the additive amount of vitamin E and antioxidant capability, leading to the commercialization of the artificial joints as early as 2010.

Moreover, a small-angle X-ray scattering (SAXS) technique at SPring-8 revealed that **age-related degradation of polyethylene can be analyzed by studying changes in the material's crystal structure**. This technique could also be applied to other products containing vitamin E, allowing an understanding of their age-related degradation and a demonstration of their long-term usefulness.

Replacement surgery with artificial knee joints

When a joint function fails due to diseases or injuries, the damaged joints can be surgically replaced with artificial joints in order to restore function and alleviate pain. In Japan, about 60% of artificial joints are applied to the knees; the incidence of surgical joint replacement is 4.3 per 10,000 people.

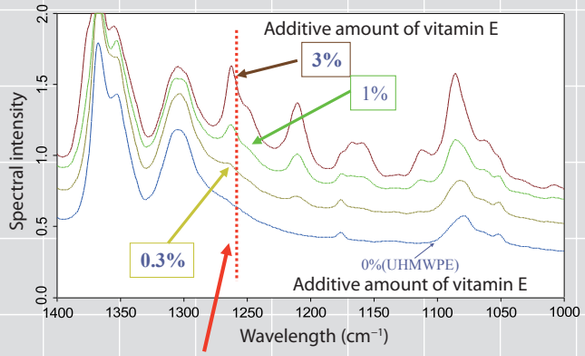


Age-related degradation of polyethylene plate

Analyses of the vitamin E concentration in artificial knee joints

Absorption spectra of vitamin E (dl-α-tocopherol) measured at the SPring-8's Infrared Materials Science (BL43IR) beamline.

Conventional measurement techniques for analyzing vitamin E as a trace ingredient cannot provide sufficient precision because they require thick samples. In contrast, SPring-8's infrared synchrotron radiation can precisely analyze samples sliced to a thickness of 500 μm. This study revealed that the addition of 0.3-0.5% of additive vitamin E is optimal; excess amounts adversely affect the mechanical performance of the joints.



The band at 1262 cm^{-1} varies in proportion to the vitamin E concentration.

X-ray scattering pattern of polyethylene used as a artificial knee joint

Small-angle X-ray scattering (SAXS) technique at SPring-8.

Measured SAXS data from an artificial joint used in the human body for 14 years. The scattering pattern can provide information about the crystal structure.