CHANGING CRYSTALLINITY OF POLYETHYLENE IN THE ACETABULAR CUPS OF WELLER HIP PROSTHESES

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We performed thermal analysis of polyethylene samples obtained from 73 new cups of the Weller hip prosthesis. There were marked individual differences in the degree of their crystallinity, ranging from 37.8% to 67.2% with a mean of 53%. Analysis of polyethylene from removed cups also showed differences in crystallinity in individual cups, with the mean value being higher in the removed implants than in the new ones. This difference in crystallinity between the groups was statistically significant. Marked individual differences in the degree of cup wear may result from these changes.

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Rapid wear of the polyethylene cup in a hip prosthesis is a frequent complication of total hip arthroplasty (Rose et al 1979; Isaac et al 1990; Weightman et al 1991). Progressive attrition of the bearing surface of the cup may lead to protrusion of the head of the prosthesis, reducing its movement, or to thinning of the wall of the cup which may result in fracture and fragmentation (Scherrer 1976; Salvati et al 1979; Weightman, Isherwood and Swanson 1979; Collins, Chetta and Nelson 1982; Thirupathi and Husted 1983; Stuck, Falahee and Brandon 1988; Otfinowski and Dutka 1991). Wear may liberate fine particles of polyethylene which will produce tissue reaction in the vicinity of the hip and osteolysis around the prosthesis leading to loosening (Revell et al 1978; Schmalzried et al 1992).

There are considerable differences in the rate of polyethylene wear which are not directly dependent on the duration of implantation of the prosthesis or on factors such as weight and the physical activity of the patient (Charnley and Cupic 1973; Charnley and Halley 1975; McKellop et al 1978; Rose et al 1979, 1980; Bankston et al 1993).

We have previously described 12 cases of extremely rapid mechanical wear of polyethylene cups associated with their spontaneous fracture and fragmentation (Otfinowski and Dutka 1991) (Fig. 1). Thermal analysis of the samples of polyethylene from these cups showed a statis-
tically significant increase in the degree of crystallinity compared with polyethylene from new cups (Otnowski, Dutka and Pawelec 1992); this may indicate a defect in the material used in the production of the failed implants. We therefore analysed the crystallinity in two series of samples obtained from new and retrieved cups to determine whether the internal crystalline structure of polyethylene in the new implants was the same in all samples and whether the degree of crystallinity was different in the retrieved material compared with the new.

MATERIAL AND METHODS

We analysed two groups of samples of high-density polyethylene ‘Chirulen’ DIN 58834 (Hoechst Ruhchemie AG, Oberhausen, Germany), each weighing 5 mg, obtained from the acetabular cups of Weller hip prostheses (Aesculap, Tuttlingen, Germany). The samples were taken from the non-weight-bearing, convex surface of the cups. The first group consisted of 73 samples of polyethylene obtained from new cups at the time of implantation of the prostheses; the second group comprised 20 samples obtained from cups which had to be removed because of loosening or fracture of the polyethylene. Table I shows the duration of implantation of the tested cups in this group.

The samples were tested in the Laboratory of Thermal Analysis of the Institute of Heavy Organic Synthesis in Kedzierzyn-Kozle, Poland, by scanning calorimetry-DSC (Hay 1992) using a microcalorimeter DSC-30 working in the thermoanalytical system Mettler TA-4000. The temperature and heat calibration of the instrument were checked with indium (99.999%, T_m = 156.6°C, H_m = 28.45 J/g). The degree of crystallinity was calculated in % (m/m) as follows:

\[ W_{c,h} = 100 \times \frac{\Delta H_i}{\Delta H_{i,c}} \]

where \( \Delta H_i \) is the heat of melting (J/g) of the analysed sample, and \( \Delta H_{i,c} \) the heat of melting of the pure crystalline phase; for polyethylene \( \Delta H_{i,c} = 290 \) J/g. The temperature of the sample corresponding to the peak on the DSC curve was accepted as the crystalline melting point. The data were tested for their statistical significance by Student’s \( t \)-test.

RESULTS

Thermal analysis of polyethylene samples obtained from new cups showed marked differences in the degree of crystallinity between individual samples (Fig. 2) ranging from 37.8% to 67.2% (mean 53%). Analysis of the samples
obtained from cups removed because of loosening or fracture also showed differences in crystallinity between individual samples ranging from 55.3% to 71.7% (mean 64.5%) (Table I). The mean degree of crystallinity in retrieved cups was increased compared with that in new cups (Fig. 3). The hypothesis of inequality of the means was verified by using Student’s t-test; the values were t = 9.02 and p = 0.00001, confirming a significant difference. In retrieved cups we observed an increased crystallinity, but were unable to show any relationship between the duration of implantation and the degree of crystallinity in this group.

DISCUSSION

We did not expect to find notable variations in the crystalline structure of polyethylene obtained from new, unused cups of the same type of prosthesis from the same manufacturer but our results showed large differences in crystallinity of the samples ranging from 37.8% to 67.2% (Fig. 2). The interpretation of such results is not easy because there are many physical and chemical factors which influence the final internal structure of polyethylene. Before surgical implantation the cup undergoes a complex process of production during which it attains its final shape. There is a two-phase model of organisation of the polymer chains with amorphic and crystalline phases both making up the internal structure of polyethylene. Inadequate control of polyethylene production during the processing stages may cause variation in the internal structure of the cup. Other factors associated with the final modelling and sterilisation may influence the ultimate internal spatial structure of the material and various chemical substances added during the process of polyethylene production may have an effect. Calcium stearate is added to polyethylene powder in the initial phase of production to protect the tools used in compressing the polyethylene blocks against corrosion. The manufacturers state that before 1987 the amount of this substance in polyethylene powder was 40 ppm, which was then reduced to 1 ppm (Aesculap, personal communication 1994). Most of the retrieved cups in our study which showed a higher degree of crystallinity were implanted in 1985 and 1986 when the content of calcium stearate in polyethylene powder was considerably higher, suggesting that this may be the cause of increased polyethylene crystallinity. In addition, ionising radiation which is used to sterilise the implants may alter the internal structure of polyethylene and the degree of its crystallinity (Roe et al 1981).

Irrespective of changes of crystallinity of the individual cups there may also be an effect on their mechanical properties. These are entirely dependent on the structure and crystallinity of the polymer (Boenig 1973; Hay 1992; Marciniak 1992). Changes in crystallinity will alter the response of polyethylene to forces such as tension, flexure, compression, shear, torsion and impact, and will also change its resistance to wear impact and its fracture energy (Boenig 1973). There are considerable individual differences in the wear rate of polyethylene cups, independent of the weight and physical activity of the patient, which are difficult to explain. We have previously shown that some polyethylene cups can wear rapidly and break with no apparent reason, and the possibility of defects in the material used in their manufacture has been raised. We have now demonstrated considerable variation in the crystalline structure of polyethylene in new cups and consider that this may be responsible for such large individual differences in the rate of wear.

Conclusions. Differences in the crystallinity of polyethylene have been identified in retrieved cups, whether damaged or not, and these may have already been present at the time of implantation. It is difficult to explain, however, the marked increase in crystallinity detected in all retrieved polyethylene cups. The implanted polyethylene may alter
its crystalline structure either by ageing or under the influence of biological factors. This could occur by reorganisation of the internal structure of the material and in the arrangement of the polymer chains with time, or by gradual ‘washout’ of the amorphous phase from the material with a relative increase in the crystalline phase of polyethylene.

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REFERENCES


