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Performance analysis of the RandomPOD wear test system

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ABSTRACT

The type of relative motion between the bearing surfaces of prosthetic joints is known to strongly influence their wear behaviour. The previously validated 16-station wear simulator of the pin-on-disc type, called RandomPOD, was used to study the wear of a conventional, gamma-sterilized ultra-high molecular weight polyethylene (UHMWPE). The counterface was polished CoCr and the lubricant was diluted calf serum. Two test conditions were compared, random motion/random load and circular translation/static load. With random motion, the accumulated change of the direction of sliding was 2.8 times higher than that with circular translation. The test duration with both test conditions was 880 h. Random motion/random load resulted in a mean wear factor 23% higher than that produced with circular translation/static load. The difference was statistically significant. The wear mechanisms however were similar and in agreement with clinical observations. As earlier studies have shown that the type of load is of secondary importance, the present study confirms the earlier findings that the type of relative motion is tribologically of fundamental importance. In particular, the complex, yet biomechanically realistic non-cyclic motion, represented by the random track, resulted in a wear factor significantly higher than that produced by a fixed slide track shape.

1. Introduction

The type and rate of wear of prosthetic joints strongly depend on the type of relative motion between the articulating surfaces [1]. Laboratory wear tests for orthopaedic biomaterials have shown that the way in which the direction of sliding changes is of fundamental importance [2,3]. Circular translation [4] has been shown to produce the highest wear rate together with realistic wear mechanisms [5]. Many different activities take place daily, and the relative motions in a certain activity, say, level walking, do not remain unchanged. Until recently, mainly fixed slide track patterns have been used in wear testing, which undoubtedly differs from the clinical situation [6]. Therefore, there is a growing interest in orthopaedic tribology research to use more diverse motion input in wear simulation studies [7].

A new wear test method and device of a pin-on-disc type, called RandomPOD, was recently described and validated [8]. With a certain type of biomechanically realistic random motion between the pin and the disc, the wear factor of conventional, non-irradiated ultra-high molecular weight polyethylene (UHMWPE) was almost twice that with circular translation. The basic idea in the RandomPOD is that the biaxial random motion includes a wide variety of track features with a view to producing wear that is as realistic as possible. The principle of random motion and random load is unique and it differs fundamentally from all earlier methods used in this field.

The main differences between the validation paper [8] and the present study are that this time, the UHMWPE pins were gamma-sterilized, the tests were longer, and the lubricant temperature was lower. Moreover, the sliding velocity of circular translation was halved so that it was equal to the average velocity of random motion. The distribution of the random travel was presented for the first time. The hypothesis was that with the clinically most used bearing material, gamma-sterilized UHMWPE, the mean wear factor with random motion exceeds that obtained with a fixed, multidirectional motion.

2. Methods

The 16-station RandomPOD design (Fig. 1) has servo-electric x-y motion and proportional-pneumatic loading. The motions and the load are computer-controlled. The range of both motions is 10 mm, and the maximum load is 150 N per station. The random motion was programmed so that the slide track of the pin always remained inside a circle of 10 mm diameter (Figs. 2 and 3). The sliding velocity varied from zero to 31.4 mm/s so that the average value was 15.7 mm/s. The acceleration varied from zero to 300 mm/s^2. The radius of curvature of the track varied from zero to infinity. The occasional reversals were smooth, as in a

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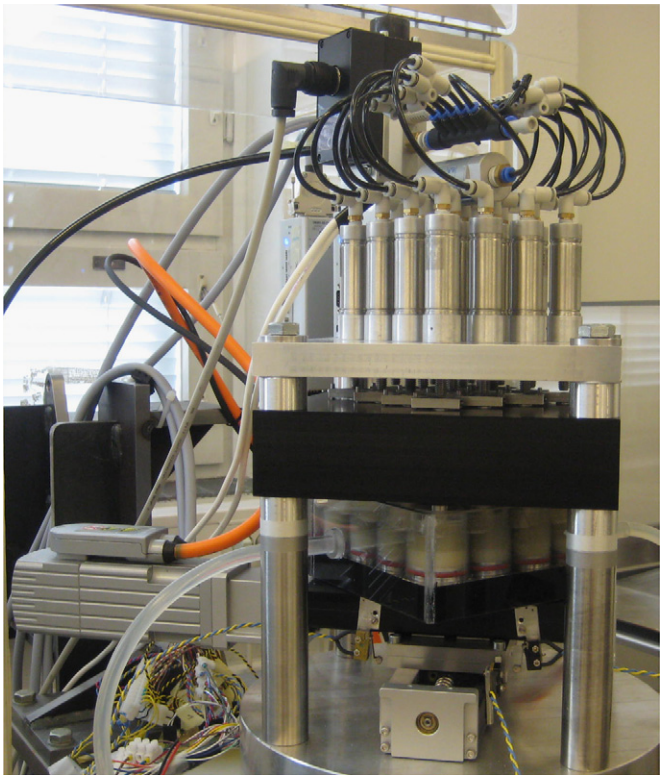

Fig. 1. RandomPOD wear test device with 16 test stations. Note servo-electric x–y-table for translation of discs, and proportional-pneumatic, vertical loading of pins. Test chambers are surrounded by circulating cooling water.

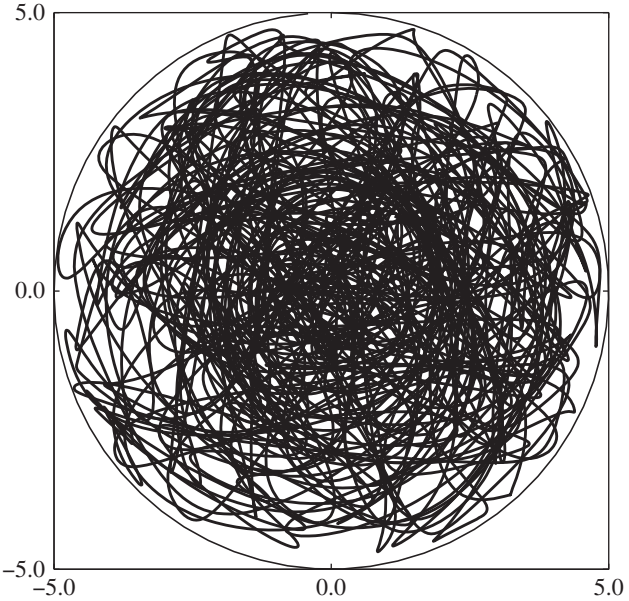

Fig. 2. Example of random track after 2 min of sliding. Track never crosses boundary circle of 10 mm diameter.

reciprocator driven by a crank. The random load varied from zero to 142 N with an average close to 71 N. The load set value was a smoothened 5 Hz random step signal. The maximum load change rate of the set value signal was limited to 300 N/s. In the random track, the accumulated change of direction of sliding (absolute value of computed increment summed) was 2.8 times that of the circular track with the same sliding distance. In circular translation, the pin translated along a circular track of 10 mm diameter

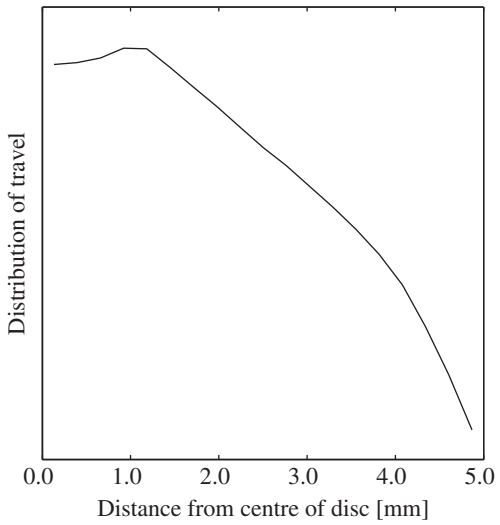

Fig. 3. Distribution of random travel on disc. A total of 360 000 points were computed, time interval being 0.01 s, corresponding to 60 min of sliding. In computation, disc was divided into 0.1 mm wide concentric rings, and total length of travel on each ring was divided by area of ring.

relative to the disc with constant sliding velocity of 15.7 mm/s, and so the direction of sliding relative to the pin changed at a constant rate, π/s. This was half of that used in the validation study [8] in order to have a sliding velocity equal to the average sliding velocity of the random motion. With circular translation, a constant value of load, 71 N, was applied.

The pins (diameter 9.0 mm, length 12 mm) were conventional GUR 1020 UHMWPE (ISO 5834-1/-2). They were gamma-irradiated by 25–40 kGy in nitrogen, a method used in the sterilisation of prosthetic components. The discs were polished CoCrMo wrought alloy (ISO 5832-12) with a surface roughness R_a value of 0.01 μm. The contact was flat-on-flat (area 63.6 mm^2). The lubricant was HyClone Alpha Calf Fraction serum SH30212.03, diluted 1:1 with Milli-Q-grade distilled water. The total protein concentration of the lubricant was 20 mg/ml. The RandomPOD has a separate lubricant chamber for each test station, containing 18 ml of lubricant.

A new temperature control system was added to the device. The lubricant chambers were surrounded by circulating cooling water. The control system kept the lubricant temperature at 20 ± 0.5 °C with a view to retarding the detrimental denaturation and degradation of serum.

The test duration was 36 days, and the total sliding distance was ca. 50 km. The accumulated change of direction of sliding was $1.6 \times 10^{9\circ}$ with random motion and $0.57 \times 10^{9\circ}$ with circular translation. The test was stopped every 6 days for the weighing of the pins. In this way, 6 points were obtained for the determination of the wear rate using linear regression. From this, the wear factor was calculated using the numerically integrated product of the instantaneous load and sliding increment [8], and the density of UHMWPE. Two consecutive 36 day tests were run, first with random motion/random load and then with circular translation/static load. The same pins were used in both tests. The wear factors were compared with a *t*-test. In each reassembly, the position and location of the specimens were randomized (Table 1), and the lubricant chambers were filled with fresh serum.

In addition, two shorter tests of 6 day duration were done with the same specimens to check the following. First, whether the wear factor in the circular translation/static load mode using the 15.7 mm/s sliding velocity differs from that produced by the device with the sliding velocity of 31.4 mm/s used in the earlier study [8]. Second, with random motion/random load, after the