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Physical Joint Simulators

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Physical Joint Simulators have been part of the preclinical assessment of artificial joints for at least 40 years, although it is fair to say that their complexity has changed remarkably over time. Initially, these tended to be simple pendulum machines, whereas nowadays, full three-dimensional force and motion simulators help to evaluate hips, knees, ankles, fingers, shoulders and spines. It is easy to take the results from these simulators for granted and accept the data they produce without questioning in detail the design principles involved in how they were obtained.

It is with this in mind that the present Special Issue was conceived. As joint editors of this Special Issue, we wanted to open the different designs of physical joint simulator to scientific scrutiny and subject the measurements to objective assessment so that researchers could make rational decisions regarding comparative performances of different prostheses, taking account of the actual simulators used.

Inevitably, total wear and wear rate are the most commonly measured outcomes, but to enable studies of lubrication, friction too has been evaluated in some simulators. The details behind how friction has been measured and the reliability that we can attach to these measurements need to be explored in order to identify the current areas of concern and ways of overcoming these.

Loading and motion patterns have also been shown to be important to wear and in particular the imposition of realistic accidental loads (trips and stumbles) to provide more meaningful simulations which are likely to provide better predictions of joint life. It is this realisation, that failure is possibly enhanced by unusual loads caused by stumbling or impacts, that have led to simulators which incorporate more realistic load/motion cycles.

Our first paper (Medley) looks at the philosophy of physical joint simulators and asks whether they can help hip joint manufacturers to avoid clinical problems with new products. Professor Medley proposed a fourstep system to clarify risks and concluded that in the case of his second example, the DePuy ASR implant system, hip wear simulator testing did provide data in the academic literature that indicated some risk of clinical wear problems prior to market release. His interesting paper highlights ways in which physical joint simulator data can be analysed to become an important part of pre-clinical decision-making.

But can simulators tell us more about the scientific basis of the wear process by offering a better understanding of the lubrication mechanisms and the friction?

Friction is rarely easy to measure because the requirements of measurement influence the measurements themselves. For this reason, the next three papers address frictional measurement in joint function simulators.

Unsworth presents much of the thinking behind the Durham hip/knee friction simulator which has been used now for a great number of years. Generally speaking, in most joints, the frictional torques are low, thus with applied loads of the order of thousands of Newton (N), real care has to be exercised in order to avoid these influencing the frictional torques being measured. Very little has been written on ensuring that the measured frictional torques are not affected by the applied loads, many of which are eccentric to the measuring axis and therefore can appear to be part of the frictional measurement.

In many papers on simulators, these issues are not even mentioned. Friction is also the subject of the next two papers: the first by Saikko and the next by Haider et al. In both cases, the authors attempt to measure the frictional torques during real-time wear tests. Saikko uses a single dimension torque transducer, while Haider et al. use a six-degree-of-freedom transducer to measure the frictional torques in three orthogonal planes.

Without a doubt, accurate frictional measurement can help identify lubrication mechanisms present in joints, and this can be really important to the design of the joint and how well it lasts, particularly if fluid-film lubrication can be designed into the contacts. This would separate the articular surfaces and vastly reduce wear.

Next, the work of Ali et al., investigates different types of simulator testing the same hip prostheses. In particular, a SimSol electro-mechanical simulator was compared with a pneumatic simulator and the electromechanical simulator was seen to produce higher wear rates and penetration depths than the pneumatic version.

However, when abduction/adduction was introduced to the gait cycle, it in turn had no effect on wear rates. This in itself is a very useful revelation but the differences in wear rates obtained using different designs of machines raise alarm bells for comparisons across different designs of simulator. This article also considers different kinematic inputs and shows the effects on wear, which is also reflected in the next paper by De Villiers and Shelton. They present work on hard-on-hard (CoCrMo with AgCrN coating) and hard-on-soft (CoCrMo with CrN coating on vitamin E highly cross-linked polyethylene).

Gravimetric wear rates, as well as silver and cobalt release into the lubricating fluid, were used to measure wear. Silver and cobalt were both found in the lubricant even when no particles were detectable.

Neville et al. show the important effects of corrosion on the total material loss in artificial hip joints, although this can be generalised to other prostheses.

Corrosion measurements were incorporated into realtime hip simulator wear experiments and showed the marked effects of corrosion. Static corrosion (where a joint is simply sitting in a body, not articulating) can contribute a significant amount to the total wear depending on the application. Clearly, this aspect of material removal must be taken seriously in any meaningful assessment of wear.

The early papers in this issue have all been based on hip joint simulators, although knee joints are being replaced in similar numbers making knee simulation another important area of study. Lowry et al., used a crouching simulator based on the Oxford knee simulator to study wear in artificial knees. Combining motion capture, laser scanning and computer modelling, they determined the contact areas of the knee bearing surfaces.

Brockett et al., on the other hand, investigated the influence of simulation input conditions such as the magnitude of the kinematic amplitudes and waveforms, as well as the directions of motion and position of the centre of rotation of the knee. They analysed a fixed bearing total knee replacement by combining an experimental and computational approach. Both moderately cross-linked polyethylene and conventional ultra-high molecular weight (UHMW) polyethylene were used.

Changes in centre of rotation and kinematics affected the wear, but especially the direction of the anterior–posterior translation which changed the contact points and hence wear.

To complete our section on lower limb simulators, Natsakis et al. review the design developments and methodologies of various foot/ankle simulators before outlining the details of the kinematics of the hind-foot, ankle and subtalar joints following total ankle arthroplasty. Moving to the upper limb, we have the Durham finger simulator described by Joyce. Finger simulators had their origins in pendulum machines but have been developed to represent much more realistic loading and motion, and the currently reported machine has been used by Joyce to evaluate a wide range of artificial finger joints. The important design features have been explored and joint failures in the simulator have been comparable with those from clinical practice.

Then follow two papers on shoulder simulators.

Langohr et al. review shoulder simulators and describe a MATCO orbital bearing simulator adapted for reverse shoulder configuration joint testing, whereas Smith et al. have designed, built and evaluated a fivestation shoulder simulator which has been evaluated using five JRI reverse VAIOS 42mm diameter prostheses.

Our final paper connects the lower and upper limbs via the spine. Hyde et al. give us an insight into the complex world of spinal arthroplasty and spinal simulators. Part of this work confirms results seen in experiments on other joints, that is, that wear rate is inversely proportional to serum concentration in the lubricant. Thus, it is not only important to simulate accurate physical forces and motions but also the entire environment requires careful and accurate simulation.

It has been a real pleasure for us to see this Special Issue come to fruition. We have both had a longstanding interest in joint simulation and we have discussed producing such a Special Issue on many occasions. So it is with great pleasure that we thank all our contributors to this edition and hope that it stimulates further work in pre-clinical testing with newer and better designs of simulators which improve our understanding of artificial joints and how they function. This should then lead to avoidance of unnecessary clinical failures, resulting in longer lasting, pain-free procedures.