Introduction: Primary stability is long established as a determinant of the long-term performance of total hip prostheses. Initial mechanical stability is the prerequisite for an extensive biological integration of the implant (osseointegration). Pre-clinical in vitro tests ought to evaluate the implant behavior in vivo and thus, to predict their long term clinical outcome. These tests often reduce the loading of the hip region to the resultant joint contact force, producing implant micromotions of the order of 10-20 μm. However, the complex in vivo loading of the hip region (due to muscle activity) gives rise to initial implant movements of up to 100 μm. Therefore, the aim of this study was to qualitatively and quantitatively describe the influence of various loading conditions on the primary stability of a clinically successful hip endoprosthesis.

Methods: Based on in vivo hip contact force measurements and gait data of 4 patients with THA, a validated musculo-skeletal computer model was employed to determine the distribution of muscle and joint forces of the lower limb. From this model, simplified load cases of the proximal femur region including both muscles (max. 5) and weight bearing were extracted. A mechanical test set-up, consisting of a servo-hydraulic testing machine (Instron) to apply the bodyweight and four servo-electrical actuators to simulate muscle forces, was realized. Three groups, each consisting of six synthetic femurs (Sawbones), were implanted with cementless prostheses (CLS, Spotorno). The femurs were transcortically instrumented at six locations (levels 2-5, Fig. 1) with linear variable displacement transducers (LVDT) to measure the 3D interface movements. In addition, the axial (distal) displacement of the prosthesis shoulder (level 1) and the rotational movement of the shoulder (level 2, LVDT 2) were recorded. The femur was first distally mounted on a ball bearing and simultaneously loaded by muscle forces (tensor fascia lata, abductor, vastus lat. and med.) and partial weight bearing were extracted. A loading that considers the muscle forces, albeit at a less critical level, leads to considerably higher movements (Groups II and III). For comparison with conventional primary stability tests, the femur was proximally unconstrained and distally fixed with polymethylmethacrylate (PMMA) in the stair climbing position and loaded only by the equivalent hip contact force (group I). In all cases, the applied dynamic load (1000 cycles, 0.25 Hz) represented 50% of the peak resultant force (walking: 1062 N, stair climbing: 1174 N).

Results: The total movements after 1000 cycles was in group I always lower than 10 μm. The implant principally moved in the lateral direction and no significant distal migration occurred (Fig. 2, top). In comparison, group II showed substantially higher movements of up to 50 μm with a clear distally oriented component and a pronounced posterior-anterior (rotational) elastic movement at level 2 (Fig. 2, middle). The movements in group III were lower than those in group II. In addition, the torsional component was comparatively low (Fig. 2, bottom).

Discussion: Even though the load level and number of cycles were relatively low compared to the in vivo situation, the study demonstrates a clear difference between the load cases. Pre-clinical in vitro testing which employs hip contact force only tends to cant the implant into the femur and subsequently leads to lower interface micromotions (Group I). These tests underestimate the relative movements of hip endoprostheses compared to the clinical situation. Loading that considers the muscle forces, albeit at a less critical level, leads to considerably higher movements (Groups II and III). Stair climbing, in producing the highest implant movements, confirmed its status as the most critical activity for THA patients. Therefore, pre-clinical tests should consider stair climbing and the active role of muscles in the assessment of initial implant stability, otherwise micromovements may be underestimated. The physiologic-like loading in vitro produced micromotions comparable with those seen radiographically in patients following THA. The analyses suggest an influence of muscle activity on the initial stability of total hip endoprostheses with a potential implication for rehabilitation. However, in vivo clinical data is required to further confirm the interaction between activity and implant stability.

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