INTRODUCTION:
In current total hip arthroplasty, modularity between the head-neck connection of the femoral stem is well established. More recently, implants with an additional modular connection between the neck and stem have become more popular. The ability to adjust the head centre relative to the stem axis intraoperatively, by connecting the neck in different positions, guarantees high versatility during surgery.

The mechanical loading conditions of the neck-stem connection fundamentally differ from the well-established head-neck connection. Fretting caused by micro-motion between the modular components may lead to particle and ion release to the surrounding tissue. Titanium-containing particles may cause the release of cytokines that are associated with periprosthetic bone loss. Additionally, such particles may get trapped between the articulating surfaces of the artificial joint resulting in third-body wear. Modularity is often associated with corrosion effects and is seen as a weak link with a possible source of complications.

The aim of this study was to analyse and compare the corrosion effects and to evaluate the particle and ion release of the modular neck hip implants currently used.

METHODS:
Five different implant designs (Fig. 1) were investigated in an experimental set up (n=3). In-vivo loading conditions were simulated by applying sinusoidal loads between 0.3 kN and 2.3 kN for 10x10^6 cycles. The stems were orientated in 10° adduction and in 9° flexion resulting in bending and torsional loading of the stem and stem-modular neck connection. A small simulation chamber, filled with serum, surrounded the modular connection. The long-term titanium release was analysed using HR-ICP-MS at intervals of 0.1x10^6 cycles. In order to detect not only ions but also particles in the serum, the samples were first digested with high purity nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). Finally, the modular connections were carefully disconnected and inspected for corrosion processes and signs of fretting.

An analysis of variance (ANOVA) was used to prove whether there were differences between the prostheses in total titanium release. Pearson’s correlation test was performed to deal with geometrically related influences on total titanium release. Student’s t-test was used to detect possible influences of the taper shape. Regression analysis was performed to demonstrate a progression in titanium release over time.

RESULTS:
The total titanium release of all systems varied between 12 and 44 µg at the end of the test (Fig. 2). No significant differences in total titanium release were found between the tested implants (p=0.66). Neither the mean cone angle (p=0.45), the cone angle difference (p=0.30) nor the shape of the taper (p=0.44) had a significant influence on the total titanium release. Based on an almost significant (p=0.06) negative correlation coefficient of r=−0.86, the total surface roughness indeed seemed to have an effect. A significant linear progression in titanium release over time was found for the Eco-Modular® implant (p<0.01, r=0.98), the SPS-Modular® implant (p<0.01, r=0.99) and the Bio-Ball® implant (p=0.04, r=0.90). No linear correlation was found for the Varicon® implant (p=0.30, r=0.59) and the Metha® implant (p=0.19, r=0.70). SEM revealed moderate signs of fretting in all tested connections. No severe corrosion effects were detected in any of the implants investigated.

DISCUSSION:
The literature unequivocally demonstrates that design- and material-related parameters influence micro-motion and fretting of implant connections. However, no differences in total titanium release were found for the implant designs tested here.

Compared to other studies the titanium release of all systems investigated in this study is low. The implants showed different patterns with respect to progression in titanium release over time (Fig. 2). For the Symbios SPS®, Endopoint Eco-Modular® and Merete Bio-Ball® implants the titanium release proceeds in a linear manner. However, the Aesculap Metha® and Falcon Varicon® systems showed a titanium release which increased during the first 2x10^6 cycles and subsequently remained stable. This progression may be related to an adaption of the surface geometries of both counterparts leading to decreased micro-motion and resulting in a more stable connection. Contrary, the measured steady-state titanium concentrations may also be related to a limited fluid transfer between the crevice of the modular connection and the surrounding fluid. In this case the local concentration of free oxygen may drop and this will result in an increased concentration of free metal ions in the crevice. The excess of metal ions then attracts chloride ions to form metal chlorides. These metal chlorides will react with water to form metal hydroxide and hydrochloride acid, lowering the pH and resulting in a hydrochloric acid solution with a very low pH in the crevice. Finally, mechanically assisted crevice corrosion (as a combination of fretting and crevice corrosion) may attack the alloy and lead to implant failure. However, neither mechanically assisted crevice corrosion nor other severe corrosion effects could be identified by final SEM analysis.

The results of this study are promising and can support limited clinical use of these implants. Very low concentrations of titanium release were found. No differences between the different designs in total titanium release were seen. Compared to in vivo and other in vitro studies extremely low concentrations of titanium release were seen. The measured titanium concentrations are believed to be within a clinically non-critical range. The safety of the modular neck-stem connection still needs to be proven in clinical studies.