Detection of Sound Vibrations for Monitoring Aseptic and Septic Loosening of Total Hip Stems

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INTRODUCTION:
Aseptic loosening of endoprosthetic implants is the main reason for surgical revision. Up to date, precise diagnosis of the implant fixation is vitally important for the early detection of loosening. This cannot sufficiently be assured by current imaging methods like radiographs or scintigrams. In order to optimize detection of implant loosening, vibrometry was introduced in total hip replacement (THR), using accelerometers and an excitation shaker. One of the disadvantages of this technique for patients appeared in the pressure pain at the knee initiated by the shaker. These circumstances require a new excitation approach to detect sound vibrations and therefore monitoring both aseptic and septic loosening of total hip stems.

MATERIALS AND METHODS:
The novel excitation method includes small oscillators with an attached magnetic sphere placed inside the endoprosthetic implant, e.g. in the proximal part of the femoral hip stem (Fig. 1). Due to magnetic induction, the magnetic spheres can be excited to impinge inside the implant using an external magnetic field impulse of a coil outside the human body. Accordingly, the impingement of the oscillator at the implant wall can be described as source for transmission of the sound vibrations. Hence, the sound vibrations can be detected by vibration sensors either attached outside the human body or integrated in the endoprosthetic implant with telemetry unit. The difference of the transmitted oscillations enables diagnosis of aseptic and septic implant loosening.

For the experimental application in porcine legs a hexahedral prototype (Ti6Al4V) was developed (Fig. 2). An oscillator was inserted in the prototype composed of two magnetic discs (NdFeB), two steel spheres and a flat steel spring to impinge on two sides of the implant. The prototype was designed in a way to achieve a clearly visible osseointegration in latter animal experiments. To measure the sound vibration, the prototype was implanted in a porcine foreleg (ulna) (Fig. 2) in a bore hole and furthermore press fitted using an impaction hammer. A piezoelectric vibration sensor for broadband measurements between 0.5 Hz and 28 kHz (Metra, Radebeul, Germany) with a high sensitivity due to higher frequencies compared to complete loosening. According to dampening coefficient decreases with increasing loosening phase. This detecting implant loosening by examining sound vibrations. The system for the diagnosis of implant loosening is required. The presented vibrometry was introduced in total hip replacement (THR), using accelerometers and an excitation shaker. One of the disadvantages of this technique for patients appeared in the pressure pain at the knee initiated by the shaker. These circumstances require a new excitation approach to detect sound vibrations and therefore monitoring both aseptic and septic loosening of total hip stems.

RESULTS:
Two characteristic progressions of the sound vibrations as time signal, initiated by the oscillator and recorded by the vibration sensor are shown in Fig. 3 (left) exemplarily for the press fitted and the loosened implant prototype. The signal shows one impingement of the oscillator on each implant wall. Tests with the prototype in a pressfit situation resulted in the highest obtained dampening coefficients (mean value ± standard deviation), comparing impingement 1 with 49.4 ± 1.7 and impingement 2 with 36.3 ± 2.1 which was 82.5 % (impingement 1) and 70 % higher (impingement 2) than the overall lowest obtained velocity of 6.9 ± 0.1 (impingement 1) and 10.0 ± 0.1 (impingement 2) for the loosened prototype (Fig. 3, right). The frequency spectrum of the oscillation signal shows higher frequencies in case of the press fitted prototype. The mean frequency was determined to be 13.0 kHz ± 0.1 kHz for the prototype press fitted in the porcine ulna, while 3.1 kHz ± 0.1 kHz could be found for the loosened implant.

DISCUSSION:
With respect to the worldwide demand on endoprostheses, a new system for the diagnosis of implant loosening is required. The presented results show the usability of the described non-invasive method for detecting implant loosening by examining sound vibrations. The dampening coefficient decreases with increasing loosening phase. This can be explained by the higher stiffness of the implant-bone interface due to higher frequencies compared to complete loosening. According to the influence of soft tissue inducing shifts in the frequency spectrum, integrated structure-borne sound sensors with telemetry unit have to be considered in further tests. The robustness of the oscillators yields a high advantage due to the simplicity of the assembly. This novel excitation method guarantees functionality during intraoperative impaction and sterilization of the endoprosthetic implant.

SIGNIFICANCE:
The implementation of the presented sensor system in endoprosthetic implants could facilitate highly precise detection and diagnosis of early loosening status. Due to its high simplicity it could be suitable for out patient monitoring of the implant fixation.