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Shock wave therapy for femoral head necrosis—Pressure measurements inside the femoral head

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ABSTRACT

There is a persisting need for effective therapies of femoral head necrosis, a common bone disease. Promising clinical results have been stated for the treatment with extracorporeal shock waves (ESW). However, the effective remaining pressure in the target region inside the femoral head has never been determined. Aim of this study was to investigate whether ESW are able to propagate through bone without an excessive loss of pressure. The remaining ESW pressure generated by an electromagnetic device after passing a certain intraosseous distance within the femoral head was measured. Standardized holes were drilled in porcine femora and the absorption in relation to reference measurements in degassed water was determined. The results showed continuous attenuation of shock waves in bone. After a clinical relevant intraosseous distance of 10 mm an ESW pressure of ~50% remained.

In conclusion, ESW have the potential to reach necrotic regions with therapeutic pressure levels and to effectively treat femoral head necrosis.

1. Introduction

Osteonecrosis of the femoral head is a common disease which can lead to the collapse of the femoral head. The reason for necrosis is mostly an impaired microcirculation with a broad variety of underlying causes like trauma, alcoholism, steroid treatment or systemic diseases (Lieberman et al., 2003; Aldridge and Urbaniak, 2004). Current treatment practices vary between non-operative treatment, joint-preserving procedures and total hip replacement (McGrory et al., 2007). There is a preponderance among young patients (Mont and Hungerford, 1995) which intensifies the need for an effective, minimal invasive procedure to avoid joint replacement (Mont et al., 2007).

ESW, originally invented in the early 1980s to destroy kidney stones, are used in orthopaedic surgery to treat insertional tendinopathies like lateral humeral epicondylitis, calcifying tendinitis of the shoulder, plantar fasciitis (Thiel, 2001) and more recently for delayed unions or non-unions of bone (Rompe et al., 2001; Schaden et al., 2001). Positive effects of ESW on bone and vascular endothelial growth factor (VEGF) were demonstrated *in vitro* (Wang et al., 2004; Aicher et al., 2006) and *in vivo* (Delius et al., 1995; Maier et al., 2002; Chen et al., 2004). An upregulation of VEGF following ESW treatment in necrotic femoral heads was shown in rabbits (Ma et al., 2007) and a clinical trial displayed promising results of ESW treatment (Wang et al., 2005). However, it has not been shown what amount of pressure and energy of ESW reaches the femoral head to induce the previously described biological responses or whether there is any transmission of shock waves through bone at all.

Aim of this study was to investigate whether ESW treatment is able to effectively reach the necrotic zone of femoral heads with sufficient pressure values. ESW pressure was therefore measured online when propagating through porcine femoral heads with varying bone distances and energy flux densities.

2. Methods

2.1. Bone specimens

Femora from adult pigs (body weight ~100 kg) ($n=6$) were obtained from a local slaughterhouse after storage for 24 h at 6 °C. All soft tissues were accurately removed and the specimens were frozen at −20 °C. Before measurement the bones were thawed in water at 37.5 °C. The femoral head was positioned perpendicular to the shock wave device.

2.2. Shock wave source

Shock waves were administered with an electromagnetic shock wave device (EPOS, Dornier MedTech GmbH, Wessling, Germany). The shock wave device was coupled via a membrane to a water bath, which was filled with degassed water, containing the femoral bone (Fig. 1). The water bath was used to replace soft tissue

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which is normally surrounding the femoral head. Shock wave focusing was controlled by two laser pointers adjusted in two planes.

2.3. Pressure measurement

The pressure (p) produced by the shock waves was measured using a PCB-probe with a rigid brass shaft and a planar 8 mm sensory head. Inside the PCB-probe a piezocrystal is compressed by the shock wave pressure and the electrical signal is recorded by an oscilloscope (Le Croy Corp., Chestnut Ridge, NY, USA). Data were transmitted to a laptop and calculated by the standard calculation software (Microcal Origin 7.0).

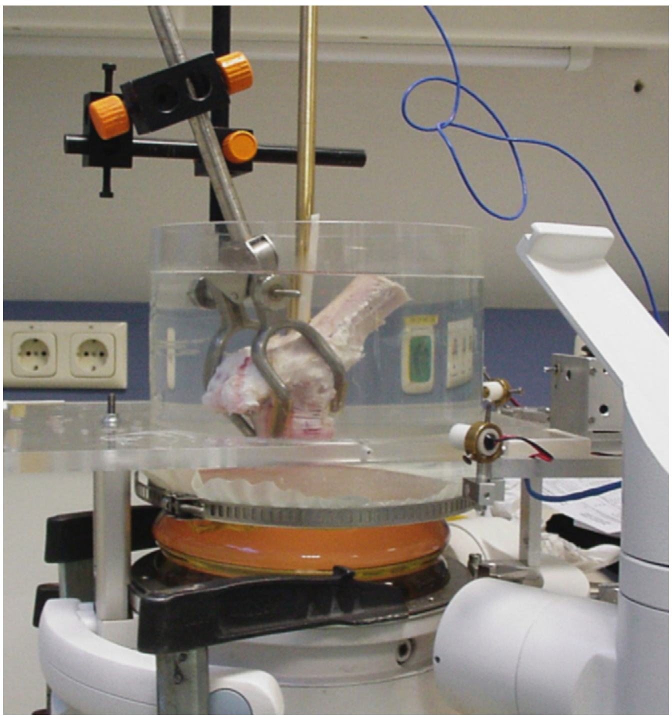

Fig. 1. Pressure measurement: bone with PCB-probe in degased water, shock wave coming from beneath.

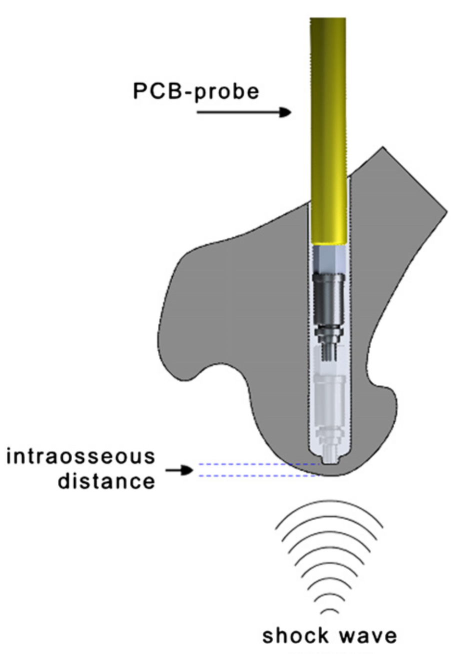

Fig. 2. Probe inserted in the canal after drilling.

Fig. 3. Probe inserted in the canal, final position.

2.4. Experimental setup

For the reference pressure measurement (P_R) the PCB-probe was installed in degassed water alone, reference measurements were performed before each intraosseous measurement. For the intraosseous pressure measurement (P_B) a canal (11 mm diameter) was drilled stepwise (2 mm) into the femoral head starting at the lateral subtrochanteric region, according to the clinical setting of a core decompression (Figs. 2 and 3). To guarantee a plane coupling of the bone to the inserted PCB-probe with the sensory head, a secondary drilling with a planar 8 mm drill bit guided by an 11 mm guide sleeve was added. Depending on the size of the bone an intraosseous drilling distance between 14 and 16 mm could be reached. After each procedure the drilling canal was vented in the water bath before the probe was inserted. The femoral bone was installed within the water bath above the shock wave source (Fig. 1). The PCB-probe which was inserted into the drilling canal was parallel to the focus axis of the shock wave device. Then 15 impulses of ESW were applied at a certain voltage and intraosseous pressure measurements were performed. Voltage magnitudes of 8–14 kV (in 1 kV steps) were used and pressure measurements were performed for each voltage. The results were directly related to reference measurement carried out before each intraosseous pressure measurement.

The absorption (α) of pressure was calculated as $\alpha = 1 - P_B/P_R$.

Results were represented as the mean $\pm$ SD for 14 measured values regarding a confidence interval of 95%. Statistical analysis was performed by using Student's t-test.

3. Results

3.1. Reference measurements

The reference pressure measurement curve showed a voltage dependent increase of pressure with small standard deviations over the whole voltage range (Fig. 4). During one experiment the pressure amplitude evoked by a certain voltage declined, which was due to the decreasing water quality evoked by a growing number of microbubbles. Therefore, the reference measurement taken before each bone measurement was performed.

3.2. Intraosseous measurements

The intraosseous pressure measurements were carried out in relation to the voltage of the shock wave device and to the intraosseous distance. In concordance with the results from the reference measurements the pressure amplitude of intraosseous measurements increased with increasing voltage. Concerning the intraosseous distance the shock wave had to pass; there was a