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Bone-cement removal with the excimer laser in revision arthroplasty

M. Zimmer, R. Klöbl, G. DeToma, V. Jansson, H. J. Refior, B. Heimkes, and J.-H. Kühne

Orthopädische Klinik, Klinikum Großhadern, Marchioninistrasse 15, W-8000 München 70, Federal Republic of Germany

Summary. The excimer laser was thought to be an appropriate tool for the removal of bone cement without damaging the bone. However, due to its low ablation rate, its clinical use in total hip revision arthroplasty proved to be impossible. This experimental study was designed to evaluate the maximal ablation rate by adjusting the laser's parameters. Energy density, frequency, pulse duration, radiation area, quantity of pulses, and environmental conditions were varied in the experimental setup. Even with the best set of parameters the excimer laser was about ten times slower than, e.g., the carbon dioxide laser. The removal of 10 g bone cement takes about 1 h. Thus, complete cement removal by means of the excimer laser alone is not possible. However, selective application of the excimer laser in combination with other techniques could be discussed.

As the number of total hip replacements goes up, more and more revisions become necessary [1, 2]. Ritter and Campbell [7] showed that the condition of the femoral canal is crucial for the success of revision arthroplasty. This means that bone cement has to be removed completely with minimal damage to cortical or cancellous bone. Many different methods have been described [4, 5, 11–13], but no perfect solution has been found.

Srinivasan [9] proposed the use of the ultraviolet excimer laser because of its properties in photoablation. To date photoablation has been too slow for any practical use in orthopedics [14]. This study was designed to find the optimal configuration of the laser parameters to ensure maximum bone cement ablation.

Materials and methods

Bone cement (Palakos, Merk) formed with a plane surface was positioned perpendicular to the laser beam in a specially designed experimental setup (Fig. 1) which allowed working under water using ventilation or irrigation.

The excimer laser (MAX 10, Technolas) with a xenon chloride gas mixture was used to generate pulsed ultraviolet radiation (wavelength 308 nm, pulse duration 60 ns or 120 ns). Pulse energy, radiated area, pulse frequency, pulse duration, quantity of pulses, and environmental conditions were varied. The ablation rate was measured by three different methods: ablated weight, depth of the hole, and volume. The volume was calculated by the product of depth and electronically measured area of the hole.

Results

Using the smallest radiation area, energy density was varied by changing the pulse energy (Fig. 2). The resulting curve shows the typical shape expected for the mechanism of photoablation. The energy density has to be higher than the threshold of about 7 mJ/mm^2 to ensure minimal ablation. Saturation is reached by 120 mJ/mm^2. To accelerate the ablation, all efforts to increase the energy density over 120 mJ/mm^2 will not be economic.

Interestingly, rasing the pulse frequency leads to increased ablation per pulse (Fig. 3). However, with a higher pulse frequency more carbonization occurs and a higher ridge around the hole is formed, signs of increased thermal side effects.

Even with the highest energy density, no ablation could be measured under water without irrigation ($n = 10$). Working under water with irrigation after a defocusation of only 12 mm, no ablation could be detected, whilst working in air with a defocusation of 35 mm an ablation could be measured. The difference between in

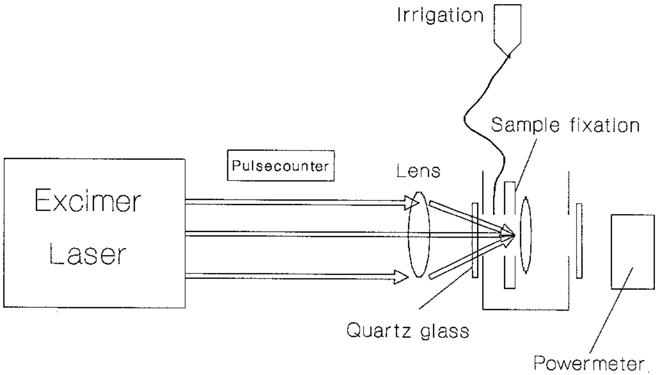

Fig. 1. The experimental setup. The bowl with the two quartz glass windows was removed for the experiments in air

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Correspondence to: Dr. M. Zimmer

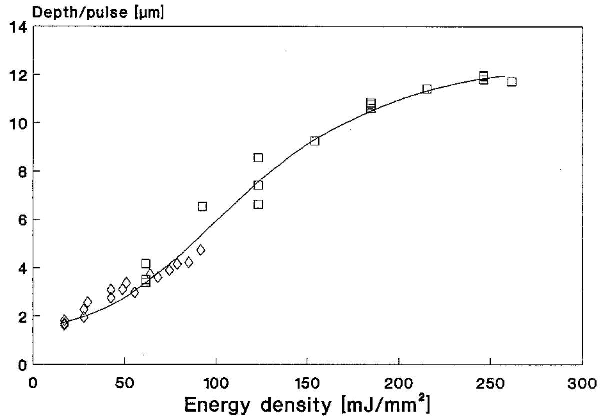

Fig. 2. Ablation of bone cement depending on the energy density. The parameter of the ablation is the depth of the hole per pulse. The *rhomboids* show the 60-ns laser pulses, the *squares* the 120-ns laser pulses

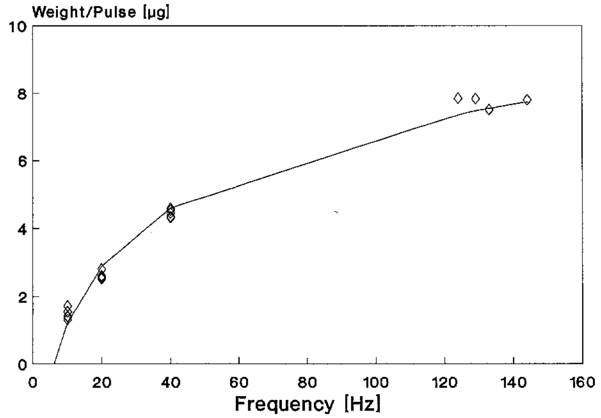

Fig. 3. Ablation of bone cement depending on the pulse frequency. The parameter of the ablation is the weight per pulse

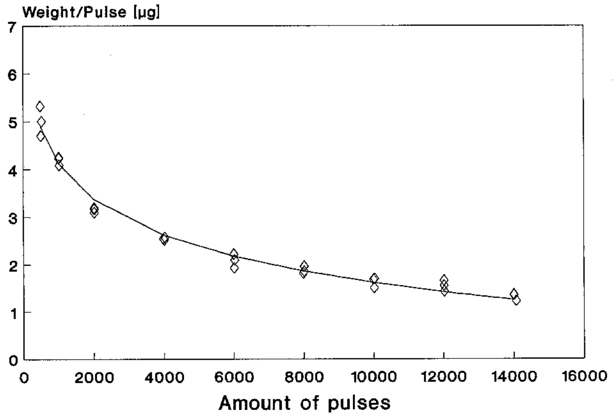

Fig. 4. Ablation of bone cement depending on the number of applied pulses. The parameter of the ablation is the weight per pulse

air and under water in the energy-dependent experiments was statistically significant ($P < 0.001$, $n = 45$) in the U test by Wilcoxon, Mann, and Whitney. However, in air there also seemed to be a significant positive effect of ventilation or suction ($P < 0.005$, $n = 30$).

Increasing the amount of pulses resulted in a statistically significant decrease in the amount of ablation per pulse of about 70% (Fig. 4). This is partly an effect of defocusation with a measured increased radiation area of 20%, and partly an observed loss of energy at the laser output of less than 20%. Nevertheless, it remains a significant loss of ablation rate, which is only a function of the number of applied pulses.

Working under optimal conditions of all tested parameters, the maximum rate of ablation of bone cement by the xenon chloride laser is approximately 10 g bone cement per hour.

Discussion

The results of this study show that with the only excimer laser approved for medical use in Germany, the ablation rate could not be sufficiently accelerated for all the bone cement in a hip revision operation to be removed in adequate time. However, in practice, some bone cement can be removed mechanically. The important part is the boundary between bone and bone cement. Its properties make the excimer laser easy to control and it has minimal thermal side effects. It could therefore be used to cut pieces of bone cement free, which are then removed mechanically.

Due to its high photon energy, the excimer laser induces fluroescence radiation, which can be used to control the laser beam electronically by spectral distinction between bone and bone cement [15].

Like the other lasers (e.g., infrared lasers) used for bone cement removal, the excimer laser produces toxic derivatives during ablation, which have to be removed by suction in order to protect patient and medical staff [3, 8].

Compared with the carbon-dioxide laser [6], which seems at the moment to be the best alternative, the excimer laser is slower by about a factor of 10. However, the excimer laser has much less thermal side effects than a carbon dioxide laser used in quasi-continuous mode. So far, there has been no sufficient proof that the remaining bone is not severely damaged by any of the lasers.

In comparison to alternative methods, mechanical procedures are usually fast, but sometimes extensive operative steps like an osteotomy of the femur become necessary.

Therefore, optical methods for bone cement removal seem to provide additional support in complicated clinical cases. Future studies should focus on the side effects and on the development of special devices to work selectively at the bone cement interface.

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