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ORIGINAL ARTICLE

Systematic evaluation of a holmium: yttrium-aluminum-garnet laser lithotripsy device with variable pulse peak power and pulse duration

Christopher Netsch*, Sophie Knipper, Christian Tiburtius, Andreas J. Gross

Department of Urology, Asklepios Hospital Barmbek, Hamburg, Germany

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Abstract *Objective:* The Holmium:yttrium-aluminum-garnet (Ho:YAG) laser is the standard lithotrite for ureteroscopy. This paper is to evaluate a Ho:YAG laser with a novel effect function *in vitro*, which allows a real-time variation of pulse duration and pulse peak power.
Methods: Two types of phantom calculi with four degrees of hardness were made for fragmentation and retropulsion experiments. Fragmentation was analysed at 5 (0.5 J/10 Hz), 10 (1 J/10 Hz), and 20 (2 J/10 Hz) W in non-floating phantom calculi, retropulsion in an ureteral model at 10 (1 J/10 Hz) and 20 (2 J/10 Hz) W using floating phantom calculi. The effect function was set to 25%, 50%, 75%, and 100% of the maximum possible effect function at each power setting. Primary outcomes: fragmentation (mm^3), the distance of retropulsion (cm); $\geq$5 measurements for each trial.
Results: An increase of the effect feature (25% *vs.* 100%), i.e., an increase of pulse peak power and decrease of pulse duration, improved Ho:YAG laser fragmentation. This effect was remarkable in soft stone composition, while there was a trend for improved fragmentation with an increase of the effect feature in hard stone composition. Retropulsion increased with increasing effect function, independently of stone composition. The major limitations of the study are the use of artificial stones and the *in vitro* setup.
Conclusion: Changes in pulse duration and pulse peak power may lead to improved stone fragmentation, most prominently in soft stones, but also lead to increased retropulsion. This new

* Corresponding author.
E-mail address: c.netsch@asklepios.com (C. Netsch).
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effect function may enhance Ho:YAG laser fragmentation when maximum power output is limited or retropulsion is excluded.

1. Introduction

Holmium:yttrium-aluminum-garnet (Ho:YAG) laser has been demonstrated to yield smaller fragments than lithoclast, pulsed dye laser, or electrohydraulic lithotripsy, fragmenting all compositions of urinary calculi with low risk of injury to the urothelium [1–6]. Fragmentation efficiency and retropulsion during Ho:YAG laser lithotripsy depend on power settings, pulse duration, fibre type, and stone composition [7–12]. The pulse duration is usually fixed between 250 and 350 μs in most of the Ho:YAG lasers available, while in some Ho:YAG devices pulse duration can be set freely between 150 and 800 μs [13] or set at 350 or 750 μs [8–11]. Wezel et al. [11] demonstrated an improvement of fragmentation efficiency by reducing the pulse duration from 700 to 350 μs in Ho:YAG laser lithotripsy. We systematically evaluated a new commercially available Ho:YAG laser device with a novel effect function *in vitro*, which allows a real-time variation of pulse duration and pulse peak power, on fragmentation efficiency and retropulsion of phantom calculi.

2. Methods

The Ho:YAG laser has a wave-length of 2.1 μm, a maximum power output of 30 W, a pulse energy ranging from 0.5 to 3.5 J and a pulse rate ranging from 1 to 20 Hz (Sphinx jr.®, Lisa Laser, Katlenburg, Germany), respectively. It possesses a novel effect feature (range: 0–100%), which allows a simultaneous real-time variation of pulse duration (range: 700–900 μs) and pulse peak power (range: 4.6–18 kW). Once the settings are made, a real-time oscillogram at the display of the laser informs at glance about pulse energy, pulse rate, pulse peak power and pulse duration. A 365 μm optical core bare-ended, re-usable laser fibre (PercuFib®, Lisa Laser) was used for the experiments.

According to Wezel et al. [11], artificial stones with four different degrees of hardness (DH) were produced: Dr Kühns® dental stone (DH 1, concentration 3:1 [*w*/*v* in H_2O] in water, Ernst Hinrichs, Germany) and Plaster of Paris (DH 2, concentration 2:1 [*w*/*v* in H_2O]) were used to simulate soft stone composition, while Laborit® (DH 3, concentration 10:3 [*w*/*v* in H_2O], Ernst Hinrichs) and Fujirock® type 4 dental stone (DH 4, concentration 5:1 [*w*/*v* in H_2O], GC Europe, Belgium) were used as hard stone composition. For testing fragmentation efficiency, standardized cone-shaped stones were poured according to Wezel et al. [11]. Test tubes with a standardized volume of 1.5 mL were used to produce standardized cones for testing retropulsion (Fig. 1). The treatment of the artificial stones before and after the lithotripsy and retropulsion experiments (including measurements of the volume of the craters after lithotripsy experiments) was done according to Wezel et al. [11].

Fragmentation efficiency was compared at 5 (0.5 J/10 Hz), 10 (1 J/10 Hz), and 20 (2 J/10 Hz) W using variable adjustments of maximum pulse peak power and pulse duration by choosing four different settings of the effect feature (25%, 50%, 75%, and 100%) applied to the four different stone compositions. According to Wezel et al. [11], the lithotripsy experiments were done in a water basin with the cone-shaped stones inside. 1000 J were applied in contact mode (hand-assisted) at each calculus on a surface area of 5 mm × 5 mm. Stones were fixed at their bottom to exclude retropulsion [11].

In a second step, designed to analyze retropulsion, an ureteral model according to Finley et al. [10] was used. Retropulsion was tested at 10 (1 J/10 Hz) and 20 (2 J/10 Hz) W using variable adjustments of maximum pulse peak power and pulse duration by choosing four different settings of the effect feature (25%, 50%, 75%, and 100%) applied to the four different stone compositions, respectively. The experimental set-up was according to Finley et al. [10] as follows: the phantom stones were placed inside an 8-cm clear polymer tube (inner diameter 12 mm), open on each end, and inscribed with distance markings. The tube was secured to the base of a water basin [10]. As Finley et al. [10] described, a stone phantom was placed into the tube at a starting point marked as zero for each trial. After each pulse, the stone was pushed

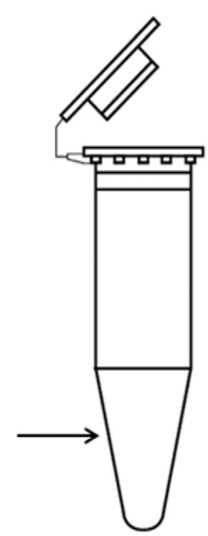

Figure 1 Test tubes with a standardized volume of 1.5 mL (black arrow) were used to produce standardized cones for testing retropulsion.