Supplementary Information I: Optical Fiber Evaluation

I. INTRODUCTION

INSIDE a needle for TransPerineal Laser Ablation (TPLA), an optical fiber is inserted to transfer the laser energy to the target site (i.e., the tumor of the prostate gland). Therefore, in a steerable TPLA needle, the optical fiber needs to follow a curved trajectory in tandem with the needle's curvature. Severe deflection of the optical fiber could potentially lead to power loss at the tip due to bending losses within the fiber. Laser light exiting the fiber core and entering the fiber cladding will be absorbed, resulting in a loss of power at the fiber tip [1]. Information on the power output during curved trajectories is crucial for integration of optical fibers in steerable needles, as well as for determining the correct power setting on the laser. The study in this supplementary information file experimentally investigates the impact of guiding an optical fiber along a curved trajectory on its power output.

II. MATERIALS AND METHODS

The experiment aimed to investigate the impact of fiber bending with distinct curvature on the power output. The experimental setup consisted of a single-use bare optical TPLA fiber (Asclepion Laser Technologies, GmbH, Jena, Germany) operating at 1064 nm, a diode laser system (SoracteLite, EchoLaser X4 system, Elesta S.p.A., Florence, Italy), a fiber trajectory block, a power sensor (PowerMax PM30, Coherent, Saxonburg, Pennsylvania, USA), and a laser power meter (FieldMaxII-TO, Coherent, Saxonburg, Pennsylvania, USA) (Fig. S.1). The fiber had a length of 2 m, a core diameter of 300 µm, a clad diameter of 330 µm, and a numerical aperture (NA) of 0.22. Measurements were performed at a fixed power of 3 W. A laser power meter behind the fiber trajectory block measured the output laser power of the fiber after it was bent along a curved trajectory in the fiber trajectory block.

The fiber trajectory block consisted of an aluminum plate containing 0.5-mm diameter, 0.5-mm deep semi-cylindrical tracks, and a transparent Perspex top attached to the aluminum plate using magnets. The curvature length of the tracks was kept constant at 77.8 mm for all trajectories, corresponding to a 270° bending angle for a bending radius of 16.5 mm. The bending radius varied between 500 mm and 16.5 mm (i.e., the minimum bending radius of the fiber equivalent to the clad diameter multiplied by 50). Accordingly, the bending angle varied between 8.9° and 270°. Furthermore, the fiber trajectory block

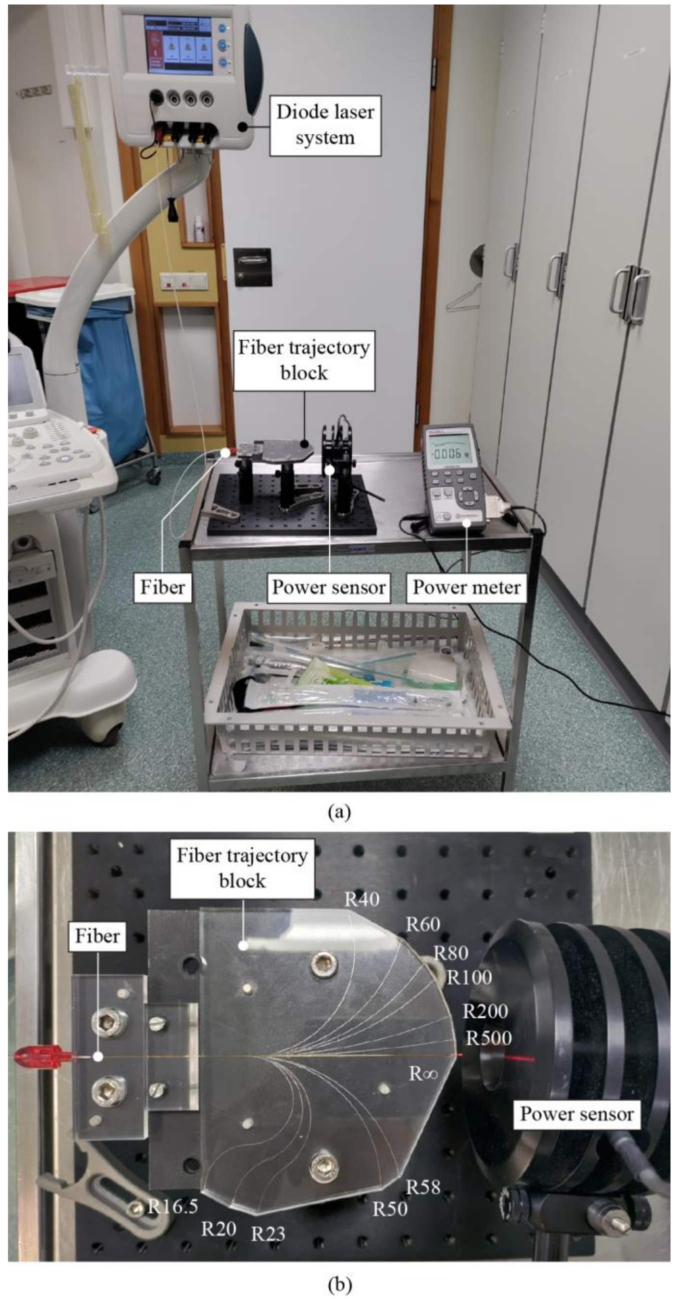

Fig. S.1. (a) Experimental setup for evaluating the impact of fiber bending on the power output. (b) Top view of the laser fiber in the straight trajectory of the fiber trajectory block, indicating the different bending radii of the corresponding trajectories.

This supplementary information file is part of the manuscript titled "Discrete Bevel-Tip Steering in a Wasp-Inspired Needle for Transperineal Laser Ablation."

TABLE S.I

MEASURED POWER OUTPUTS PER BENDING CONFIGURATION. d_{ratio} = DEFLECTION-TO-INSERTION RATIO.

Bending radius (mm)	**Bending angle (°)**	d_{ratio} **(no unit)**	**Power output 1 (W)**	**Power output 2 (W)**
∞*	0*	0	3.08	2.75
500	8.9	0.078	3.10	2.75
200	22.3	0.19	3.10	2.85
100	44.6	0.41	3.18	2.81
80	55.7	0.52	3.19	2.85
60	74.3	0.75	3.21	2.81
58	76.8	0.79	3.01	2.99
50	90.0	1	3.03	2.99
40	111.4	>1	3.19	3.01
23	193.7	>1	2.95	2.98
20	222.8	>1	2.87	3.02
16.5	270	>1	2.75	3.01

*∞ mm bending radius and 0° bending angle is equal to a forward trajectory (i.e., no steering).

also contained a straight trajectory with an infinite bending radius and a 0° bending angle as a control measure.

During a single measurement, the fiber was inserted into a track of the fiber trajectory block. Subsequently, the diode laser system was turned on at a power of 3 W (Fig. S.2). To determine the output power of the fiber passing through the track of the fiber trajectory block, a power sensor and laser power meter were placed at the distal tip of the fiber. Each fiber trajectory of the fiber trajectory block was measured twice, resulting in 24 measurements in total. The same optical fiber was used for each measurement.

III. RESULTS

The power output experiments showed that bending the optical fiber over trajectories with a bending radius of 500 to 16.5 mm only minimally impacted the power output, as shown in Table S.I. The measured output signal ranged between 2.75 W and 3.21 W, with a mean of 2.98 W and a standard deviation of 0.14 W. The greatest difference between input and output power of 0.25 W was measured for the smallest bending radius (i.e., 16.5 mm), the greatest bending radius (i.e., 500 mm), and the straight trajectory (i.e., bending radius = ∞ mm). The successful bending of the optical fiber with low power losses implies that optical fibers can safely be used in steerable needles with a bending radius of up to 16.5 mm.

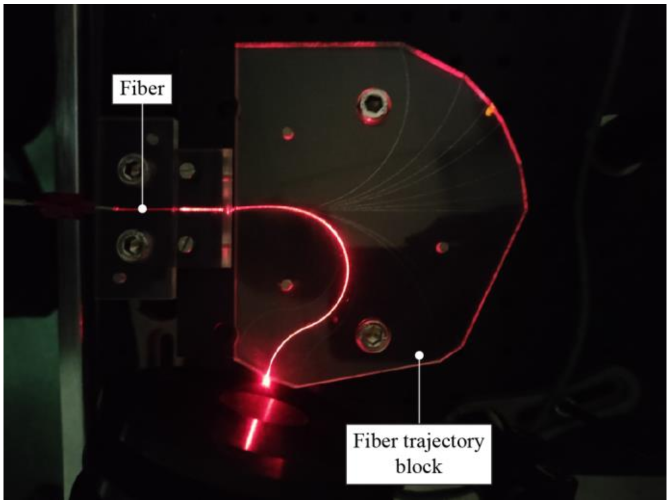

Fig. S.2. Top view of the laser fiber in a curved trajectory of the fiber trajectory block when the diode laser system was turned on at a power of 3 W.

REFERENCES

[1] A. C. Mues, J. M. Teichman, and B. E. Knudsen, “Evaluation of 24 holmium: YAG laser optical fibers for flexible ureteroscopy,” *The Journal of urology*, vol. 182, no. 1, pp. 348-354, 2009.