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COMPARISON OF FLEXIBLE URETEROSCOPES: DEFLECTION, IRRIGANT FLOW AND OPTICAL CHARACTERISTICS

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ABSTRACT

Purpose: We measured and compared the deflection, irrigation flow rates, distortion, resolution and light transmission of new generation flexible ureteroscopes.

Materials and Methods: Multiple characteristics of 5 flexible ureteroscopes (ACMI DUR-8 Elite™, Olympus URF-P3™, Storz 11278AU1™ [Flex-X], Wolf 7330.072™ and Wolf 7325.172™) commonly available in the market were measured and compared. Measured data included active deflection, irrigation flow rates and optical characteristics. Each ureteroscope was evaluated with an empty working channel and with various accessories. Optical characteristics, specifically resolution and distortion, were measured using test targets (Edmund Optics, Barrington, New Jersey). Light transmission was also measured from the ureteroscope tip at 50% and 100% intensity. All 5 flexible ureteroscopes were tested in a laboratory setting using a Storz OR 1™ system to capture the images.

Results: For all 5 ureteroscopes the angle of deflection was most impaired by a 365 μm laser fiber probe and least impaired by a 2.2Fr nitinol basket. Among all 5 ureteroscopes irrigation flow rate was most impaired with a 3.0Fr basket and least impaired with 200 μm laser fiber. The Wolf 7325.172 had the highest observed resolution of 25.39 lines per mm and the Wolf 7330.072 had the lowest distortion at 11.9%. The Karl Storz Flex-X and the ACMI DUR-8 Elite had the highest light output at 374 and 364 mV, respectively.

Conclusions: The various flexible ureteroscopes differ with regard to flow rates as well as degree of deflection with either an empty or an occupied working channel. The Wolf flexible ureteroscope with a slightly larger working channel and a fused quartz bundle provided for superior flow and better optical performance. However, the greatest amount of tip deflection and highest light output were found in the ACMI and Karl Storz flexible ureteroscopes.

KEY WORDS: ureteroscopy, surgical instruments, irrigation, fiber optics

After the first recorded application of a passive deflecting flexible ureteroscope by Marshall in 1964,[1] technical advances such as active deflection, incorporation of working/irrigation channels, development of secondary passive deflection, production of smaller endoscopes and development of improved optics have resulted in the evolution of flexible ureteroscopy to a point that it is now a staple in diagnosing and treating diverse upper urinary tract pathology ranging from urolithiasis to cancer.[2–4] The most recent design changes have centered around the development of endoscopes with active secondary deflection, as in the ACMI DUR-8 Elite, which has active deflection at 2 points along the distal shaft of the ureteroscope and extended active deflection greater than 240 degrees like the Storz Flex-X ureteroscope. Nevertheless, these cutting edge mechanical features are accompanied by greater instrument fragility, a higher purchase price and increased repair costs. Indeed, on average these endoscopes require repair after only 9 to 25 cases.[5] In this study 5 modern day ureteroscopes were compared with regard to respective angles of deflection, irrigation flow rates, optical resolution, optical distortion and light transmission in a laboratory setting.

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MATERIALS AND METHODS

Ureteroscope active upward and downward deflection, irrigation flow rates, optical resolution and distortion were measured for the 5 flexible ureteroscopes ACMI DUR-8 Elite, Karl Storz 11278AU1 (Flex-X), Wolf 7325.172 and 7330.072, and Olympus URF-P3. Each ureteroscope was tested for flow and deflection without and with several of the more commonly used ureteroscopic instruments in the ureteroscope's working channel such as 2.2 and 3.0Fr N-circle® nitinol tipless stone extractor baskets (Cook Urological Inc., Spencer, Indiana), 2.6Fr urological grasping forceps (Boston Scientific, Natick, Massachusetts), 1.9Fr electrohydraulic lithotriptor (EHL) probe (ACMI-Circon Corp., Stamford, Connecticut), and 200 μm laser and 365 μm holmium:YAG laser fibers (Convergent, Oakland, California).

Irrigation flow was measured by connecting the working channel inlet of each ureteroscope to an irrigation system set to a pressure of 100 mm Hg. For each ureteroscope the system was allowed to equilibrate for several minutes before flow measurements were recorded. Measurements of deflection were made by photocopying the ureteroscope when completely deflected and taking measurements using a protractor as described by Parkin et al.[6] Measurements for each instrument and each ureteroscope were taken 5 times. The intersection angle between the tangents to the active deflection segment and deflected tip was considered the deflection angle.[4]

Resolution and distortion were measured using an industry standard United States Air Force (USAF) Resolving Power 1951 test pattern (Edmund Industrial Optics, Stock Number NT36–275) and a Distortion Grid Target (Edmund Industrial Optics, Stock Number NT46–250), respectively. Both test targets were used and data were analyzed in accordance with the manufacturer's instructions. USAF 1951 Resolution target is compliant with United States government specification MIL-STD-150. Distortion Grid from Edmund Optics is produced with a serialized National Institute of Standards and Technology traceable certificate of accuracy per MIL-STD 45662-A. Resolution was defined per test target manufacturer definition (Edmund Industrial Optics) as an imaging system's ability to distinguish object detail. Test target USAF 1951 measures resolution in terms of line pairs per millimeter. USAF 1951 resolution targets use a repeating series of parallel bars sequentially decreasing in size that are separated into group and element numbers. System resolution (or cutoff frequency) is defined as the highest group and element at which the 3 bars are still distinct. The ureteroscope was held on top of the resolution slide and a light was allowed to shine through the other end. The ureteroscope was brought closer to the test target until the clearest and best resolution image was available. Since this is a qualitative test 3 individuals were asked to observe until blurring of the image was observed (element, group number).

Distortion was defined as an optical error (aberration) in the lens that causes a difference in the magnification of the object at different points in the image (spherical/barrel distortion). It is calculated per test target manufacturer instructions (Edmund Industrial Optics) as % distortion = (actual distance –predicted distance)/predicted distance × 100). The ureteroscope was placed 3 mm away from the distortion grid and an image was captured from the flat screen monitor. All pictures of distortion were taken during the same session and measured twice on 2 different days. Images were then measured digitally using Image-Pro Plus® software. To take consistent measurements of distortion and resolution, all ureteroscopes were tested using a digital Storz Image 1™ camera and the Storz flat screen monitor. A 4 megapixel Olympus® C-4000 digital camera was placed on a tripod and pictures were taken of the image which appeared on the screen.

For the light transmission part of the study, the ureteroscope manufacturer's specific light source and light cables were used. Figure 1 shows the integrating sphere which was used to integrate ureteroscope light output. The inside of the sphere is precisely coated with a highly reflective white material to reflect and focus all light frequencies equally. A narrow hole allows the tip of the ureteroscope to enter while eliminating any external lighting that could impact the measurement. The tip of the ureteroscope was placed in this 6 inch integrating sphere (SphereOptics Hoffman LLC, Contoocook, New Hampshire) in a dark room, and light transmission was then measured at 50% and 100% intensity as indicated on the respective company's light source control. Output of the standard integrating sphere was converted to an electrical signal using a silicon photovoltaic detector with 1 mm^2 detector surface area. This electrical signal (voltage) was then quantified with an oscilloscope (Tektronix TDS 2024, Richardson, Texas).

RESULTS

Mechanical assessment. Tables 1 and 2 demonstrate how several different instruments affect deflection among the 5 tested flexible ureteroscopes. Deflection was most impaired with a 365 μm laser fiber. With this fiber the DUR-8 Elite showed a decrease in downward deflection by 46% and a decrease in upward deflection by 39.5%. Likewise the Storz Flex-X showed a decrease in downward deflection by 27% and a decrease in upward deflection by 32%. In addition, the Wolf 7325.172 and 7330.072 ureteroscopes and Olympus URF-P3 had a decreased down/up deflection of 38.8%/35.9%, 33.3%/28.1% and 34.1%/43.9%, respectively (tables 1 and 2). Deflection was least impaired with the 2.2Fr basket (table 2). The ACMI DUR-8 Elite decreased by 5% for downward deflection and 14.4% for upward deflection. The Storz Flex-X downward deflection decreased by 2.4% and upward deflection decreased by 10% compared with an empty working channel. The angles of deflection for the Wolf 7325.172, Wolf 7330.027 and Olympus URF-P3 decreased by 9%/11%, 5.4%/11.5% and 5.1%/3.1% (down/up), respectively.

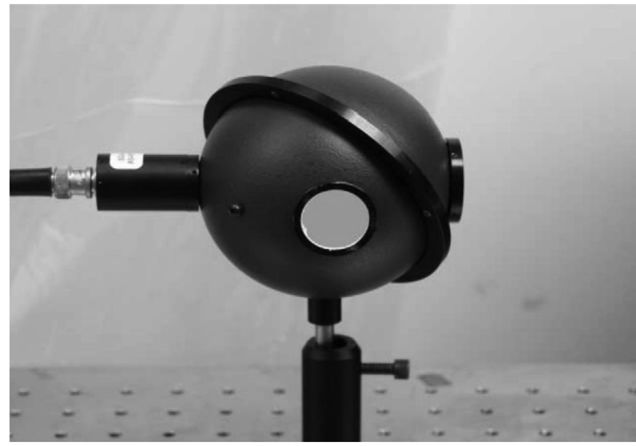

FIG. 1. Integrating sphere measures light transmission

Table 3 shows the irrigation flow rates with various accessories. In contrast to deflection, irrigation flow rate was most reduced in all 5 ureteroscopes with passage of a 3.0Fr nitinol basket, which was the largest diameter working element tested. The DUR-8 Elite showed a 94% decrease in irrigation and the Storz Flex-X showed a 95% decrease. The Wolf 7330.072 and Wolf 7325.172 showed a 70.5% and 94.3% decrease, respectively. Lastly the Olympus URF-P3 showed a 92.3% decrease in flow. Irrigation was least impaired with the 200 μm laser probe resulting in decreases of 44.5%, 49%, 28%, 47% and 45%, respectively.

Optical characteristics. The Wolf 7330.172 and 7330.072 had the best resolution and least distortion. The Wolf 7325.172, Wolf 7330.072, ACMI DUR-8 Elite, Olympus URF-P3 and the Storz Flex-X had resolution values of 25.39, 22.62, 11.30, 12.70 and 9.54 line pairs per mm, respectively. For comparison we tested a 12 mm rigid laparoscope and it had a resolution of 32.0 line pairs per mm.

In terms of distortion the Olympus URF-P3 and Wolf 7330.072 had the lowest distortion values with 11.9% and 13.6%, respectively. These were followed by the Wolf 7325.172, the DUR-8 Elite and the Storz Flex-X with distortion values of 18.4%, 34.2% and 38.1%, respectively.

Light transmission. Light transmission data are shown in table 4. The greatest light output at 50% and 100% intensity was with the Storz Flex-X at 347 and 374 mV, respectively. The Olympus light source has a unique brightness feature, and the ureteroscope was tested with and without this feature activated (table 4). At 100% intensity the Olympus URF-P3 transmitted 326 and 352 mV with and without the brightness feature activated.