Contemporary retrograde intrarenal surgery: Scopes and Lasers

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Abstract
Flexible instrumentation is the mainstay of minimal invasive stone surgery and this led to the invention of smaller and safer instruments which performed remarkable good to a variety of procedures. Further developments like digital technology and single use ureteroscopes which along with similar technological advances in lasers transformed flexible surgery in a tool of paramount importance in the intrarenal surgery of various clinical entities. We review the literature concerning the advances in the field of scopes and lasers for retrograde intrarenal surgery in an effort to find the optimal combination, if any, that potentially produces the best surgical outcomes.

Introduction
Since 1929 and the first ureteroscopy ever reported by Young H., many things have changed concerning this important procedure for the treatment of a wide variety of urological procedures. Technological advances transformed the first completely rigid ureteroscope (with rod lens system), to a smaller again rigid scope but with a working channel this time and further to the first “semi” rigid scope, containing fiber-optics. But it was not until the late 1980s that an unmet need for a flexible and actively deflectable ureteroscope has been fulfilled.

Key words
Flexible, ureteroscope, intrarenal surgery, lasers

One of the first reports of the use of this novel technology in the management of human lithiasis came from Kavoussi et al., where 4 different scopes were used producing remarkable ergonomics in more than 84% of the intrarenal movements performed. Flexible instrumentation is the mainstay of minimal invasive stone surgery and for that smaller and more safe instruments had to be invented, and this need was indeed met in the 90s where 7.5F scopes with 3.6F working channel where put into trial and performed remarkable good. The most novel marvel in the development line of flexible ureteroscopes is the annexation of digital technology that

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permitted the development of single use scopes. Their technological improvement consisted of better resolution and color representation and of course a significantly larger image size when compared to the standard flexible device.6 These devices allowed better understanding and management of intrarenal pathology providing better stone free rates and reducing morbidity of stone surgery but all these came with the cost of various disadvantages that will be outlined in this review.

Material and Methods

We conducted a thorough literature review for articles written in English, indexed in Pubmed, between 1990 and 2018. The key words utilized in this search consisted of ureteroscopes, flexible, retrograde intrarenal surgery, laser and lithiasis. We reviewed all papers and we report only the bigger and better organized ones.

Scopes

The basic components of a flexible ureteroscope are pretty similar to the semi rigid ones and consist of the optical system and the working channel with an extra deflection mechanism found only in flexible scopes. The development of flexible fiber optics is the “heart” for the development of flexible ureteroscopes. Technical improvements in the splitting of the light bundle permitted better ergonomics and light emission within the working field of view.9 On the other hand the deflection mechanism is the “hands and feet” of the instrument, permitting complex maneuverability in the upper urinary tract. This movement is performed with the aid of wires running down the length of the scope until the tip of it. Moving the designed lever provides movement to the abovementioned wires that produce movement to the tip of the scope. This movement can be active and passive deflection whereas the most modern ones provide also active secondary deflection (controlled from a separate lever) that facilitate easier access to difficult anatomic positions of the kidney.6 All available scopes can produce deflection of 270° in both angles which is more than 175°, reported to be the maximum angle between ureter and lower calyx.10 Another important technical detail of the ureteroscopes that can potentially affect the outcomes of the procedure is the outer diameter. It is well proven that the fail rate of advancement of the instrument is directly affected by its outer diameter with the diameter of 7.5 F reported to be the “ideal” one with a failure rate of 0.9%.11

The majority of flexible ureteroscopies are still performed with the aid of “conventional” multi use scopes available in the market. Table 1 shows the basic technical characteristics of the above mentioned ureteroscopes. The basic manufacturers that share the market are Karl-Storz, Olympus and Wolf.7,8 All manufacturers possess fiberoptic and digital products each one with their advantages and disadvantages. Comparison studies of these models are extremely useful in deciding the more suitable scope for each surgeon and possibly for each patient. In one of this studies, Flex XC, URF V and Cobra scopes were evaluated during 90 procedures. Authors found that the deflection loss when using ancillary instrument was similar between all 3 scopes whereas there were no statistically significant differences regarding maneuverability and insertion, but this was not the case for visibility where the Cobra model was outperformed (p=0.02).12 Nevertheless the bigger problem of these instruments remains their durability. Flexible scopes are expensive instruments and possibly differences in their durability could make the difference in the final decision. Randomized prospective studies currently available in the literature fail to prove any statistical advantage between the available endoscopes even though small differences do exist.13,14 The median number of procedures as well

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Basic characteristics of available reusable flexible ureteroscopes7,8</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Olympus URF-P6</td>
</tr>
<tr>
<td>Shaft Size</td>
<td>7.95</td>
</tr>
<tr>
<td>Tip size</td>
<td>6.9</td>
</tr>
<tr>
<td>Field of view</td>
<td>90</td>
</tr>
<tr>
<td>Working length</td>
<td>67</td>
</tr>
<tr>
<td>Working channel</td>
<td>3.6</td>
</tr>
<tr>
<td>Active deflection</td>
<td>275/275</td>
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Contemporary retrograde intrarenal surgery: Scopes and Lasers, p. 45-51
as the factors that affect the longevity of the scopes were the objectives of another well designed prospective study: After a total of 198 procedures, the median number was 27 procedures whereas the damage to the distal part of the shaft and shaft coating were the most frequent damages that sent the scopes for repair. Finally, it seems that deflection impairment was maximum when a 365μm laser fiber was utilized and minimum with a 2.2 F nitinol basket whereas irrigation flow is mostly influenced by a 3.0 F nitinol basket and least influenced by a 200 μm laser fiber.

The limitations of fiber-optic scopes and the need for an optimal image, set the goal for the development of new technologies in flexible ureteroscopy. Fiber-optic fibers are easily broken either from the advancement of the instrument through the urinary tract or from the deflection of the scope when trying to reach a difficult calyx. Some studies report a very narrow repair window (15.3 passes result in the damage of more than 20 fibers), which practically interprets in loss of image quality even though the scope remains somewhat usable. Furthermore, it seems that a repaired scope demonstrates a shorter period of life when compared to a new one. Advancement in digital technology and development of imaging chips made possible the manufacturing of digital scopes. Both charge coupled devices (CCDs) and complementary metal oxide semiconductors (CMOS) function by converting photons into electrons. These chips are positioned on the scopes so the need for a camera head, that most of the time is heavy and difficult to manipulate, is eliminated. The reduction in weight and cords provide better ergonomics and reduces collision during difficult movements. Last but not least the image provided by the digital technology is superior when compared to the classic “honeycomb” pattern that fiber optic technology produce. On the other hand, digital ureteroscopes have their own disadvantages: larger tips (may incommode entry in a difficult or narrow calyx), potential difficult orientation (due to lack of camera attached to the scope) and of course cost (nearly 3 times bigger for the digital scopes). There are several studies, already published in the literature comparing flexible with their fiber-optic counterpart with interesting outcomes. In one of these, digital scope was related to favorable image quality and ease of movement whereas its performance in visualization of the entire collecting system was remarkable better in contrast to fiberoptic scope. The most important remark of this study as well as others is the difficulty of the digital scopes to reach challenging calyx. The outcomes of the in vitro PETRA study revealed that digital scopes are possibly less successful in accessing a sharp angled calyx and have lesser end tip deflection compared to the fiber-optic ones and authors propose in this situation the utilization of the latter scope.

The real breakthrough in flexible ureteroscopy is possibly at hand. The drawbacks and unfavorable features of the first ever reported single use ureteroscopy have been surpassed and now there is a shift towards this technology by surgeons and manufacturers. There are several single use ureteroscopes currently available or under development most of which provide a high-quality image. The available instruments along with their basic characteristics are shown in Table 2. One of the basic advantages of these devices is the cost, since single use scopes are cost effective especially for big loads of surgeries compared to the cost of reusable ones (purchase and maintenance can cost as high as 100.000 US dollars). The second more important is contamination issue since there are reports of high contamination of the reusable scope despite the adequate sterilization. Other advantages include better ergonomics, decreased weight, better connectivity and easier carriage in remote places where specialized procedures can now be performed. Due to these advantages, several authors put the avail-

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**Table 2: Basic characteristics of single use flexible ureteroscopes**

<table>
<thead>
<tr>
<th></th>
<th>LithoVue</th>
<th>Flexor-Vue</th>
<th>Semi-Flex</th>
<th>Neo-Flex</th>
<th>Uscope</th>
<th>YC-FR-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>277.5</td>
<td>NA</td>
<td>NA</td>
<td>Na</td>
<td>147</td>
<td>95</td>
</tr>
<tr>
<td>Working Length</td>
<td>955</td>
<td>NA</td>
<td>NA</td>
<td>Na</td>
<td>650</td>
<td>630</td>
</tr>
<tr>
<td>Outer Diameter</td>
<td>9.5</td>
<td>16</td>
<td>8.3</td>
<td>9</td>
<td>9.5</td>
<td>8</td>
</tr>
<tr>
<td>Deflection</td>
<td>280/280</td>
<td>180/0</td>
<td>270/270</td>
<td>280/280</td>
<td>175/175</td>
<td>190/0</td>
</tr>
<tr>
<td>Working Channel</td>
<td>3.6</td>
<td>9</td>
<td>3.4</td>
<td>3.6</td>
<td>3.6</td>
<td>4.2</td>
</tr>
<tr>
<td>Imaging</td>
<td>Digital</td>
<td>Fiberoptic</td>
<td>Fiberoptic</td>
<td>Digital</td>
<td>Fiberoptic</td>
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</tr>
</tbody>
</table>
able scopes to the test and reported data in order to prove if the substitution of the reusable with the single use scope in our everyday clinical practice is justified. Since it is extremely difficult to come to a conclusion about the ideal single use scope, with each one having its advantages and disadvantages the attention was overlined in the comparison of single use and reusable scopes. Tom et al reported superior deflection of YC-FR-A scope against to its rivalries. In contrast, a more recent in vitro study, reported the exact opposite, with the NeoFlex in the first position in terms of deflection, followed by LithoVue whereas the YC-FR-A scope found to have the smallest cumulative deflection. Testing the scopes under real life situations, LithoVue performed remarkably well, maintaining its original deflection in 29 out of 40 patients even in challenging anatomical positions.30

Other important factors that may influence stone surgery significantly, is irrigation and imaging. The first increases its significance since it influences also the second. Taking into account the latest reports, single use scopes are comparable and sometimes superior to reusable models in respect to irrigation flow rates and this conclusion is maintained even when instruments are inserted into the working channel with LithoVue maintain the best irrigation flow from its rivalries when a 1.9F basket or a 200μm laser fiber were utilized. As for the imaging, LithoVue was found to have a greater field of view and superior imaging when compared to Flex XC and Cobra whereas the second was found to be superior in term of depth of view. In another study YC-FR-A demonstrated inferior outcomes when compared to NeoFlex in terms of resolution, with the opposite results for image distortion. No differences were found for color representation, field and depth of view between these two scopes.38

As for the major factor, cost, that can potentially overshadow all the rest, the available data are inconclusive. Many studies have proved the superiority of single use scopes and their cost-effectiveness (with savings from hundreds to thousands) but of course the latter are directly influenced by the initial price of the scope and by the load of cases per center. On the other hand, a much more precise assessment of the cost, taking into consideration factors like resources (micro-costing) failed to prove any statistical significant difference between single use and re-usable scopes. Another important aspect was reported in a relatively recent study: reusable flexible ureteroscope is cost-effective in high-load centers whereas the opposite apply for low volume centers that may benefit from single use technology. All the above were summarized in a recent systematic review of 11 studies and 466 patients that compared three commercially available flexible scopes (LithoVue, Polyscope and Semiflex) along with reusable ones in terms of clinical outcomes. The study assesses the technical characteristics of each scope and point out the differences along with their advantages and disadvantages. Furthermore, when reusable and single use ureteroscopes were compared for their clinical effectiveness, the outcomes were revealing: no statistically significant differences were found in terms of stone free rate, stone size, procedure time and complication rates. In summary, all the available data converge to one conclusion: single use scopes provide an equivalent alternative to their reusable counterpart with no major differences in terms of mechanical and irrigation capabilities, imaging and clinical effectiveness.

Lasers

The holmium: YAG laser is currently the gold standard laser for ureteroscopic lithotripsy. The laser crystalline matrix is a YAG crystal containing also chromium, thulium
The holmium: YAG laser operates in the near-infrared portion of the electromagnetic spectrum at 2100 nm. This technical aspect is that makes this device suitable and safe for intracorporeal lithotripsy since energy is absorbed by waters and does not infiltrate tissue more than 1 mm. The stone disintegration takes place primarily through a photothermal mechanism resulting mainly in vaporization of stone molecules. This device has numerous advantages which has transformed it to the gold standard device for intracorporeal lithotripsy. These include: efficacy in most types of stones, less fragment “push back” due to weaker waves produced, more than satisfactory stone free rates and most important wider safety margins. Furthermore, the energy can be transmitted via conventional, low hydroxyl silica optical fibers which are strong, they provide optimal thermal and mechanical properties (including bending, corrosion resistance etc.), they are cost-efficient and they are biocompatible. Finally, research has accomplished to advance holmium laser technology to new standards: from low power (20w) desktop modules, to larger (30-120W) output powers that provide lesser operation space or high disintegrate abilities utilizing correct values. Even though, holmium lasers stand as the main solution for laser lithotripsy, several alternatives do exist in the market. These potential rivalries have been developed in order to surpass some of the basic limitations of the holmium technology. Even though safety is issues with Holmium laser are not frequent, they do exist, and this is due to the photo-thermal laser-tissue interaction that this laser produces. The frequency-doubled, double pulse YAG (FREDDY) laser produces a short pulse (1μs) and emits energy at 532 and 1064 nm, characteristics that provide a better safety profile, avoiding tissue energy damage to the urothelium due to absorption of the wave from the elastic tissues. Nevertheless this laser has the disadvantage of the inability to fragment harder stones. Even though there are no big studies directly comparing this laser to the gold standard holmium, the available data implies that for stones medium to soft composite FREDDY laser can provide a safe and efficient alternative for urological stone management. Improved laser ablation was the main goal for the next type of laser, Erbium:YAG laser which special characteristics of 2.9 nm wavelength, increased stone and water absorption, theoretically provides an improved stone fragmentation profile. However this laser, requires special optical fibers in order to transfer its energy, which despite the fact that there are commercially available, they are not cost-effective. The most recent development in the laser technology stands for fibre lasers. In these lasers a conventional optical fibre is utilized as the medium instead of a bulk solid-state crystal, whereas the light originates within the core of a small optical fibre and it is emitted with the aid of a separate laser source such a diode laser. The energy is then emitted through a second conventional fibre. Important advancements have been recently made, in order to surpass the main limitation of these lasers, the power: novel thulium fibre lasers operate at 1940 nm of wavelength yielding promising results in stone fragmentation. However, the basic advantage of this technology is the high intensity due to the origin of the light (which is situated inside the small fibre) which again is providing a more uniform and symmetrical beam than the one produced by the Holmium:YAG laser. Another potential advantage of these lasers is the operation at pulse rates more than 2.000 Hz which may, for now, not advantageous or necessary but still can theoretically provide more flexibility in dusting mode and potentially produce smaller fragments and increased stone free rates. Either way the most important aspect of these technologies is the outcomes they manage to accomplish and so a direct comparison between them would be of great importance. Recent studies reporting their preliminary data conclude that thulium fibre laser produces 5-10 times higher stone vaporization rates when compared to Holmium laser whereas Thulium seems to be advantageous in a 1.5-4-fold manner in terms of stone ablation speed. The comparison between the two technologies holmium YAG: laser and the thulium fibre laser is inevitable and it is shown in Table 3.
Τα εύκαμπτα εργαλεία είναι ο βασικός πυλώνας της ελάχιστης επεμβατικής χειρουργικής του νεφρού και αυτό οδήγησε στην εφεύρεση μικρότερων και ασφαλέστερων οργάνων, τα οποία παρουσίασαν αξιοσημείωτα καλά αποτελέσματα σε μια ποικιλία ουρολογικών παθήσεων του νεφρού. Περαιτέρω εξελίξεις στην τεχνολογία των εύκαμπτων ουρητηροσκοπίων αποτέλεσαν η εφαρμογή ψηφιακής τεχνολογίας και η ανάπτυξη ουρητηροσκοπίων μιας χρήσης, μαζί με παρόμοιες τεχνολογικές εξελίξεις στα λέιζερ, τα οποία μεταμόρφωσαν την εύκαμπτη ουρητηροσκόπηση σε ένα εργαλείο πρωταρχικής σημασίας στην ενδονεφρική χειρουργική, διαφόρων ουρολογικών νεφρικών παθήσεων. Το παρόν αποτελεί μια ανασκόπηση της βιβλιογραφίας σχετικά με τις εξελίξεις στον τομέα των ουρητηροσκοπίων και των λέιζερ για την παλίνδρομη ενδονεφρική χειρουργική σε μια προσπάθεια να βρούμε τον βέλτιστο συνδυασμό, αν υπάρχει, που δυνητικά παράγει τα καλύτερα χειρουργικά αποτελέσματα.

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