Validation of a High-End Virtual Reality Simulator for Training Transurethral Resection of Bladder Tumors

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OBJECTIVE: The oncological outcome in patients with bladder cancer (BC) significantly correlates with the quality of transurethral resection of bladder tumors (TUR-BT). Virtual reality (VR) training simulators have been developed to improve surgical skills. We evaluated the advantages and limitations of the novel Uro Trainer (UT) (Karl Storz GmbH, Germany) with respect to training for TUR-BT.

DESIGN: Participants underwent VR training based on 4 different TUR-BT cases accompanied by self-assessment and evaluation questionnaires. Results were compared between experienced endourologists and novices, and furthermore, correlated with self-rated capabilities for content and construct validity. Student's *t* tests, Pearson's correlation, and chi-squared tests were performed for statistical evaluation.

SETTING: The study was performed at the tertiary care urological department of the Ludwig-Maximilians-University, Munich, Germany.

PARTICIPANTS: A total of 22 urological physicians, including residents and consultants, were included in the study.

RESULTS: There is a need to improve TUR-BT training as 27.3% of the participants had already experienced overtaxing situations during TUR-BT and only a few reported of high satisfaction with the classical "see one–do one" teaching mode. Construct validity was demonstrated, as consultants achieved significantly higher overall scores ($p < 0.001$) and safety ($p = 0.004$) and visualization ($p = 0.001$) subscores. Interestingly, the self-assessed capability to perform a TUR-BT correlated significantly ($p = 0.01$) with overall UT scores. Significant progress of self-rated abilities was shown for several parameters, including inspection ($p = 0.046$) and resection ($p = 0.026$). Although participants indicated improvements in several procedural skills and overall benefit of the VR training with the UT was rated 4.6 on a 5-point scale by consultants, limitations of the UT were demonstrated predominantly for tissue feedback and authenticity of different tissue layers.

CONCLUSIONS: The novel VR simulator showed a high face and construct validity, and therefore has a great potential to complement endourological training. (J Surg Ed 76:568–577. © 2018 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: Virtual reality, Simulation training, Urinary bladder neoplasms, Self-assessment, Urologic surgical procedures

COMPETENCIES: Practice-Based Learning and Improvement, Medical Knowledge

INTRODUCTION

Virtual reality (VR) simulators offer the opportunity to systematically acquire complex skills and therefore might precede or supplement real-life training. Studies on VR simulators for different surgical disciplines and applications were promising, demonstrating reduced time to finish surgical tasks, and furthermore, differentiating between different competence levels.[1] The urological setting seems to be predestined for VR training on account of its high complexity. VR training systems consequentially have been focused on robotic and endourological surgeries.[2-7] Transurethral resection of bladder tumor (TUR-BT) of non-muscle invasive bladder cancer (NMIBC)

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has long been erroneously considered a beginner's operation to familiarize residents with endourology and prepare them for seemingly complex operations like the transurethral resection of the prostate. However, several studies have proven this concept to be not only incorrect but also highly dangerous, as increased surgical experience was positively correlated with lower recurrence rates of non-muscle invasive bladder cancer.[8] These results were validated by 2 studies describing the presence of detrusor muscle as a surrogate quality marker to be higher in TUR-BT specimens from experienced urologists, and additionally proved surgeon experience as an independent predictor for BC recurrence.[9,10] Interestingly, a study investigating adverse events of TUR-BT showed that senior residents had a higher complication rate compared to novices, which was explained by the inordinate role of senior residents in more complex cases.[11] Accordingly, correct self-assessment of surgical capabilities and avoidance of intraoperative overtaxing situations must be the primary learning objective during residency. Trimodal therapy is a multimodal approach to muscle-invasive BC including a TUR-BT combined with radiotherapy and chemotherapy. A study investigating the outcome after trimodal therapy demonstrated a complete TUR-BT as a significant prognostic factor for improved survival.[12] Therefore, improving the surgical quality of TUR-BT might have an even greater impact on outcome parameters compared to technical innovations like en-bloc resection or optical coherence tomography.[13] Previous studies investigated different VR systems in training for the TUR-BT.[14,15] Although general feasibility and the opportunity to improve and supplement surgical training were demonstrated in the predecessor model of the Uro Trainer (UT) technical issues were predominantly identified as hindrances to immediate clinical implementation.[16] We, therefore, analyzed the latest model of the UT with respect to face, content and construct validity in a cohort of urological residents and consultants, and additionally evaluated both strengths and limitations of VR training.

MATERIALS AND METHODS

Study Protocol of the VR Training with the UT

Both junior and senior residents (n = 15) and consultants (n = 7) from our urological department were included in the study. Participation was voluntary, and nonparticipation was not associated with any penalties or disadvantages. Importantly, performance scores and results of questionnaires were assessed anonymously in order to exclude false reporting or pressure from the staff conducting the study. Before the initiation of the study, participants were not exposed to VR simulators in our department. First, baseline parameters with respect to levels of education and experience were determined in order to assess the construct validity of the UT. Furthermore, the demand for improvements of endourological training in addition to specific intentions toward the VR system was monitored. The UT (Karl Storz GmbH, Germany) is an advancement of previous endourological VR models (Fig. 1).[16] A resectoscope, including virtual irrigation and drainage functions and foot pedals for coagulation and cutting current were included to train eye-to-hand coordination. The VR training itself included a mandatory theoretical and practical introduction into the function of the UT. In order to familiarize participants to the function of UT, they then had to undergo VR pretraining courses for inspection of the bladder, bleeding control, and resection of BT. The study protocol itself included 4 different BT cases with increasing difficulty with respect to the number of tumors and their respective location. Only participants who finished all 4 VR TUR-BT cases were included in our study. Different parameters, including percentage of the inspected bladder surface, amount of resected tumors, bleeding control, duration of the procedure, and safety issues, including avoidance of bladder perforation and protection of the ureteral orifices were evaluated. A PDD mode was included to identify pTis BC. The aim was to

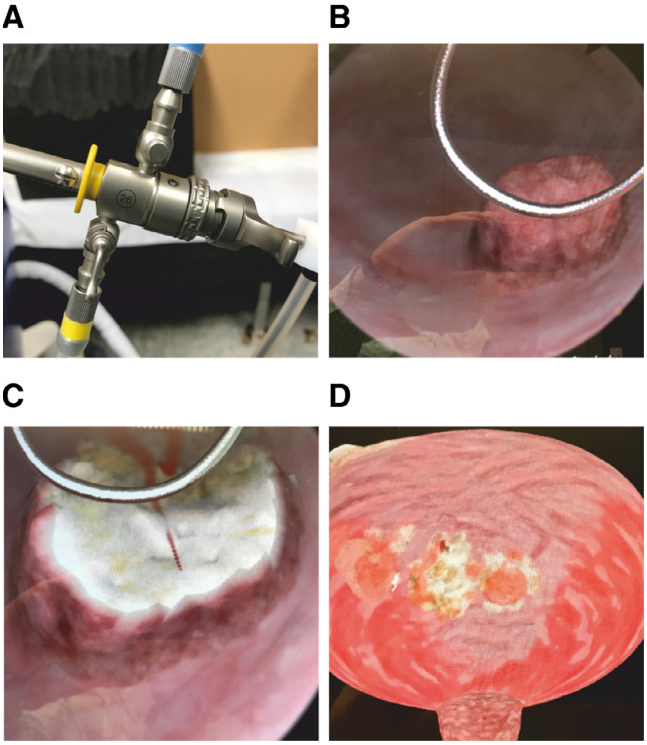

FIGURE 1. VR hardware, visualization and feedback. **(A)** Illustration of the resectoscope including irrigation and drainage function. **(B)** Solid bladder tumor during procedure. **(C)** Bleeding simulation during the TUR-BT. **(D)** Visual feedback showing areas of the bladder, which have not been inspected properly during TUR-BT.

TABLE 1. Baseline parameters and analysis of the demand for a virtual reality (VR) simulation in endourological training. Both detailed assessment of the level of education and endourological training in addition to deficiencies of classical endourological training and individual intentions toward a VR education were assessed

Variable	
Level of education	
Junior resident (year 1-3)	22.7% (5/22)
Senior resident (year 4-5)	45.5% (10/22)
Consultant	31.8% (7/22)
Level of experience	
Urethrocystoscopies (UC) performed	
0-50	13.6% (3/22)
50-100	31.8% (7/22)
>100	54.5% (12/22)
TUR-BT (assisted)	
0-50	59.1% (13/22)
50-100	31.8% (7/22)
>100	9.1% (2/22)
TUR-BT (independently)	
0-50	68.2% (15/22)
50-100	13.6% (3/22)
>100	18.2% (4/22)
Endourological education	
Feedback for TUR-BT is good/excellent	22.7% (5/22)
TUR-BT teaching system is good/excellent	13.6% (3/22)
Frequent overtaxing situations during TUR-BT	27.3% (6/22)
Virtual reality (VR) simulator	
A VR simulator can significantly improve TUR-BT training	72.7% (16/22)
Personal intention toward a VR simulator	
Self-assessment capabilities	36.4% (8/22)
Handling of the resectoscope	54.5% (12/22)
Operational speed	36.4% (8/22)
Bleeding control	31.8% (7/22)
Coverage of the whole bladder during UC	54.5% (12/22)
Correct resection depth	59.1% (13/22)
Reduction of insecurities to perform a TUR-BT completely and independently	59.1% (13/22)

complete all 4 TUR-BT cases, with a minimum of 95% of the total score for each case with a maximum of 5 attempts each. In order to obtain a continuous improvement process, detailed electronical feedback is given after each case. Identification of pTis, independent completion of a TUR-BT, inspection of the whole bladder surface, bleeding control, handling of the resectoscope, complete resection of the tumor mass, insecurities to perform a TUR-BT completely and independently , and self-assessment capability were analyzed before and after completion of the VR training. After the completion of all 4 cases, participants evaluated the realism of the UT regarding different key aspects, including the simulation of bleeding, different tissue layers, handling of the resectoscope, tissue feedback, illustration of pTis in the white light and PDD cystoscopy, and tumor configuration. Furthermore, individual improvements were self-assessed for key competencies required for the oncologically correct and safe completion of a TUR-BT at the end of the VR training. All questions had to be answered on a 5-point scale from 1 (basic skills/no agreement) to 5 (expert skills/full agreement) except for the expectations from the UT at the beginning (Table 1) and assessment of progress after the training (Fig. 4A). The Karl Storz GmbH (Tuttlingen, Germany) had no influence on the study protocol and analysis and interpretation of results.

Statistics

Mean scores for all 4 TUR-BT cases were compared between consultants and residents regarding the overall score, resection, bleeding control, safety, economy, and visualization using Student's t test. Overtaxing situations were defined as circumstances, where participants felt overstrained during TUR-BT, like excessive bleeding, difficult configuration or location of BC, pressure of time, or difficulties to determine the correct resection depth.

Self-assessed frequency of overtaxing situations during TUR-BT, and capability to independently perform a complete TUR-BT with average difficulty were correlated

with the overall score in Pearson's correlation, and results are shown in scatter plots. Differences between procedural and nonprocedural skills before and after the VR training and the realism evaluation of the UT were tested for significance with a 2-sided dependent Student's *t* test. Improvement parameters were compared between residents and consultants using the chi-squared test and results were shown as cross-tables. All statistical analyses were performed with SPSS 24. Additionally, several parameters for the evaluation of the face validity of the UT were compared between residents and consultants using a Student's t-test.

RESULTS

High Demand for a VR Simulator Training Based on Deficiencies in Classical Endourological Training

The composition of the included participants was well-balanced and representative, as very experienced endourologists, senior residents, and novices were included in order to increase the validity of our results. Of the participants, 13.6% rated the classical "see one—do one" teaching system as good or excellent, 27.3% frequently experienced intraoperative excessive

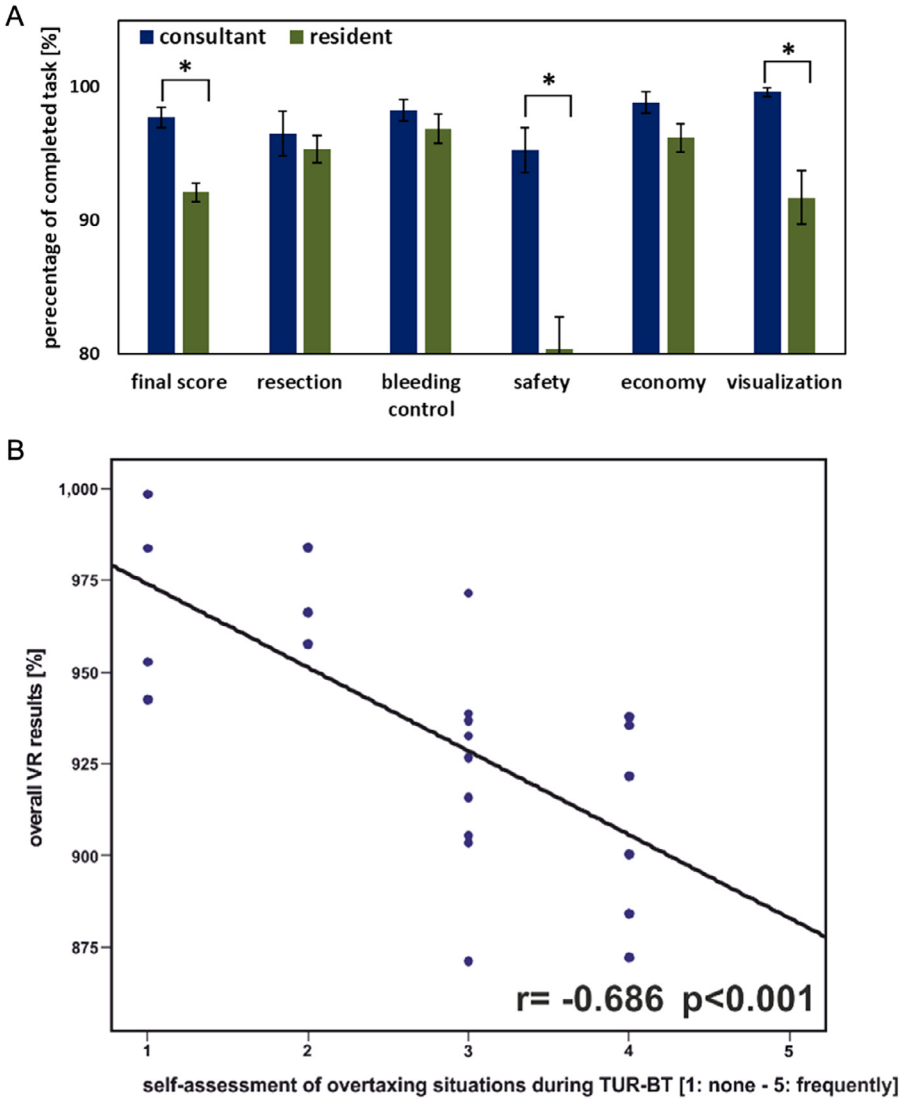

FIGURE 2. The VR simulator has a high construct and content validity and demonstrates specific training deficits. **(A)** Mean scores of all four TUR-BT cases were assessed for every participant regarding overall score, extent of resection of the BT, safety, economy, bleeding control and visualization of the bladder surface. In order to assess the construct validity of the VR simulator, we compared results between consultants and residents with an independent Student's *t* test. Error bars are shown as standard deviation of the mean. Significant results are marked with an asterisk in the graphic. **(B, C)** To further validate the UT, we correlated self-assessment of overtaxing situations and self-assessment of the capability to independently perform a TUR-BT with overall results in ⊖ Pearson's correlation. p values values ≤0.05 were considered significant.

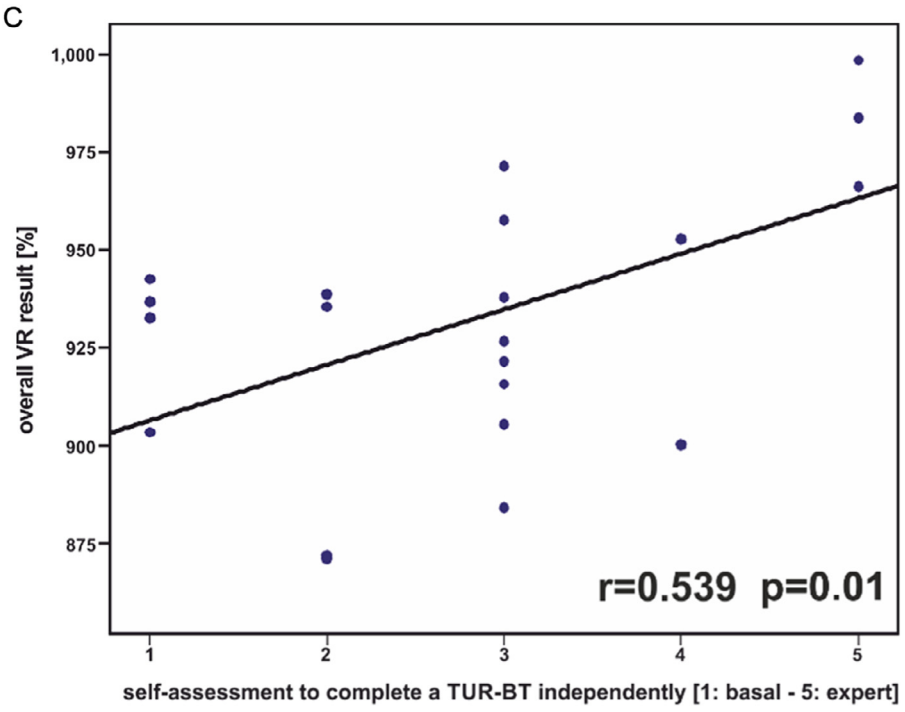

FIGURE 2. Continued

demands and 22.7% showed high/excellent satisfaction with the performance feedback for TUR-BT. Expectations toward the implementation of a VR simulator were high with 72.7% being optimistic that a VR system can improve endourological education. Reducing insecurities to perform a TUR-BT completely and independently (59.1%), finding the correct resection depth (59.1%), increasing the percentage of the inspected bladder surface (54.5%), and improving the handling of the resectoscope (54.5%) were major learning objectives (Table 1). In conclusion, current endourological training concepts are yet imperfect, and VR systems might potentially contribute to improvements.

UT Scores Correlated With Both Real-Life Endourological Experience and Self-Assessed Surgical Skills Indicating a High Construct Validity

Consultants performed significantly better compared to residents with respect to mean overall score (97.7% vs 92.1%; $p < 0.001$) and the subcategories of safety (95.3% vs 80.4%; $p = 0.004$) and visualization (99.6% vs 91.2%; $p = 0.001$) (Fig. 2A). The self-rated frequency of overtaxing situations negatively correlated with the overall UT performance ($r = -0.686$; $p < 0.001$) (Fig. 2B). Furthermore, self-assessment of the capability to independently perform a TUR-BT positively correlated with the mean overall score of the UT training ($r = 0.539$; $p = 0.01$) (Fig. 2C). Taken together, VR scores significantly correlated with not only the level of surgical experience, but also self-rated skills, underlining the validity of results monitored by the UT.

Self-Rated Surgical Capabilities Significantly Increased During UT Training

Having shown that self-assessment is a valid tool to study endourological competencies, we now compared different parameters essential to perform a high-quality TUR-BT before and after VR training on a 5-point scale. The subjective capacity to complete a TUR-BT (2.9-3.7; $p = 0.003$), evaluate the whole bladder surface (4.2-4.4; $p = 0.046$), properly handle the resectoscope (3.5-4.1; $p = 0.005$), and completely resect all tumors (3.5-4.0; $p = 0.026$) significantly increased. Furthermore, self-assessment skills significantly improved (3.7-4.1; $p = 0.046$), and insecurities to perform a TUR-BT completely and independently reduced (3.5-2.8; $p = 0.015$) (Fig. 3A-C). In summary, there was significant progress in 6 out of 8 parameters during the UT training.

UT Demonstrated an Overall High Face Validity With Few Parameters Showing Limitations

After the completion of the study protocol, participants were asked to evaluate which skills improved after using the UT. Handling of the resectoscope

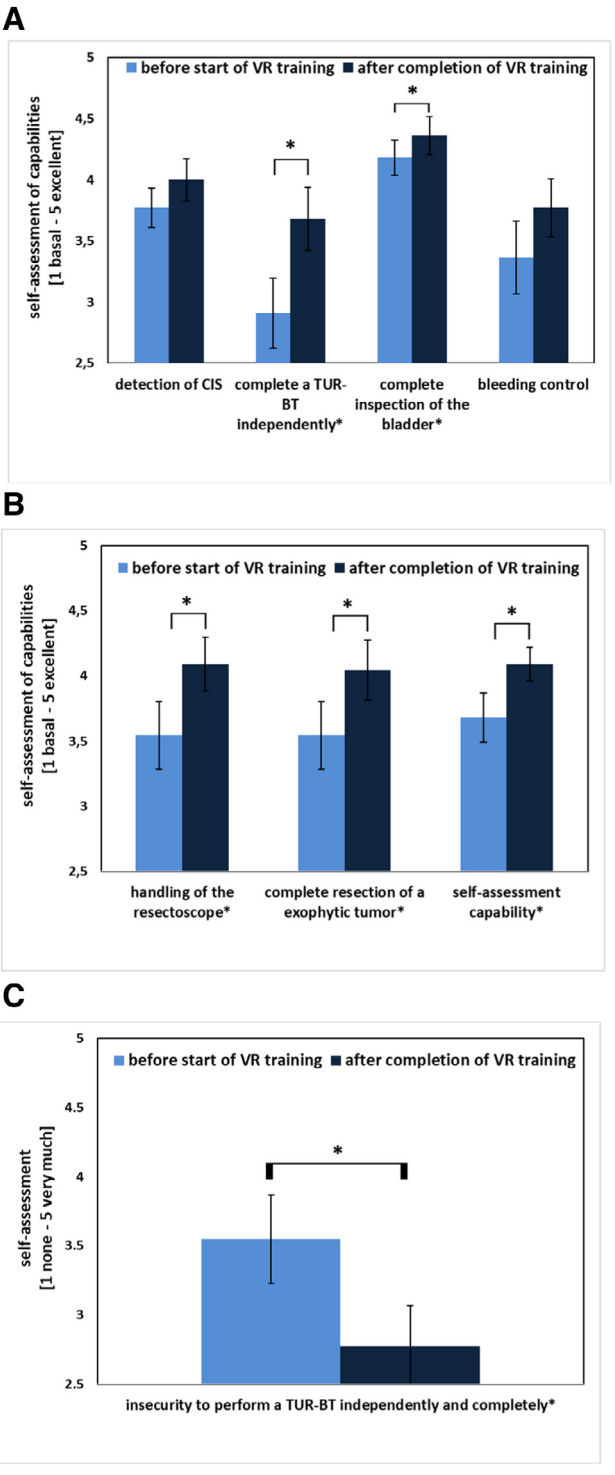

FIGURE 3. Self-assessed procedural and nonprocedural skills increase during VR training. **(A-C)** Different key capabilities important to professionally perform a TUR-BT regarding safety, oncological and psychological aspects. Scores were self-rated on a 5-point scale from 1 (no skills) to 5 (expert skills). Results were tested for differences with a dependent 2-sided Student's *t* test and error bars were demonstrated as standard errors of the mean. p values $p \leq 0.05$ were considered significant and were marked with an asterisk.

(68.2%), reduction of insecurities to perform a TUR-BT completely and independently (59.1%), and complete evaluation of the whole bladder surface (54.5%) were the 3 leading parameters with no statistical significant differences between consultants and residents (Fig. 4A). Importantly, only 2 participants (9.1%) indicated no improvement at all. Different aspects relevant to a TUR-BT simulation were rated on a 5-point scale for realism, and the results were then compared between consultants and residents. Except for handling of the resectoscope (4.8 vs 3.5, $p = 0.005$), there were no differences in other parameters between groups. Notably, tissue feedback and differentiation of the tissue layers were the only items rated below 3 by both consultants (1.8 and 2.2, respectively) and residents (2.3 and 2.5, respectively) (Fig. 4B). In conclusion, the UT shows a high face validity with few drawbacks which can be improved in the next generations of VR endourological trainers.

DISCUSSION

As only a few participants in this study rated the current endourological teaching system as good or very good; therefore, improvements need to be made to the current surgical training.[17-19] This is underlined by the high frequency of intraoperative overtaxing situations in our cohort, which is an explicit high-risk situation to be avoided. A possible strategy to tackle these issues is to improve constructive feedback mechanisms, which are a central part of the learning process. Considering the most common expectations from a VR simulator, like better handling of the resectoscope and coverage of the whole bladder surface during urethrocystoscopy, these issues can be improved by VR simulator training, which formed the strength and the basis of our study.[20] Construct validity characterizes the ability to discriminate between novel and expert users, whereas content validity describes the coverage of all aspects important to simulate the reality. Both are predispositions for the implementation of a VR simulator into clinical training curriculums. Expert endourologists performed significantly better with respect to the overall score in addition to key subcategories. Furthermore, the self-rated frequency of overtaxing situations and the capability to complete a TUR-BT independently were also significantly correlated with overall VR results. Taken together, the UT, therefore, showed both high construct and content validity. All UT mean values ranged above 80%, showing a potentially low discrimination between good and very good participants. Self-assessed competencies significantly improved after the completion of

the UT training in several categories. Notably, progress was also seen in the subcategories of handling of the resectoscope, complete inspection of the bladder, and reduction of insecurities to perform a TUR-BT completely and independently, which were leading parameters on the expectations from the VR training. Strengthening our results, self-assessment was demonstrated as a reliable tool comparable to expert-assessment in several studies on surgical skills training.[21-23] When participants were asked about specific abilities that improved after the VR training schedule, more than 50% indicated handling of the resectoscope, inspection of the whole bladder, and reduction of insecurities to perform a TUR-BT completely and independently.

An advantage inherent to VR simulators in contrast to classical training might be the immediate detailed and objective feedback after each case, which also includes information about the part of the bladder surface which was not inspected, volume of blood loss, missed amount of tumor mass, and cuts into ureteral orifices or perivesical fat. Importantly, only 9.1% indicated no improvement at all, underlining the overall high acceptance of the UT. Interestingly, there was no significant difference with respect to subjective progress between consultants and residents, concluding that the UT might be equally useful for both novices and experts.

Realism of the UT was rated good or excellent for most categories, with no significant differences between

A

Improvement parameters	Total	Level of education		p
		consultant	resident	
self-assessment capability	5 (22.7%)	2 (40.0%)	3 (17.6%)	0.294
handling of the resectoscope	15 (68.2%)	3 (60%)	12 (70.6%)	0.655
operational speed	8 (36.4%)	2 (40%)	6 (35.3%)	0.848
bleeding control	6 (27.3%)	2 (40%)	4 (23.5%)	0.467
inspection during UC	12 (54.5%)	4 (80%)	8 (47.1%)	0.193
correct depth of resection	5 (22.7%)	1 (20.0%)	4 (23.5%)	0.869
Insecurity to perform a TUR-BT independently and completely	13 (59.1%)	2 (40%)	11 (64.7%)	0.323
No improvement	2 (9.1%)	1 (20%)	1 (5.9%)	0.334

FIGURE 4. Impact of VR training on endourological skills and evaluation of the UT. **(A)** After completion of all VR simulation modules, participants were asked for specific areas where they experienced a personal improvement. Results were compared between consultants and residents with a Pearson's chi-squared test and demonstrated as absolute numbers and percentages of the respective subgroups. (**B)** In order to evaluate the UT and furthermore identify improvement possibilities, participants were asked to evaluate important parameters on a 5-point scale between 1 (no benefit/not realistic) to 5 (maximum benefit/very realistic). Results were compared between consultants and residents with an independent Student's *t* test and error bars are shown as standard error of the mean. p values ≤ 0.05 were considered significant and were marked with an asterisk.

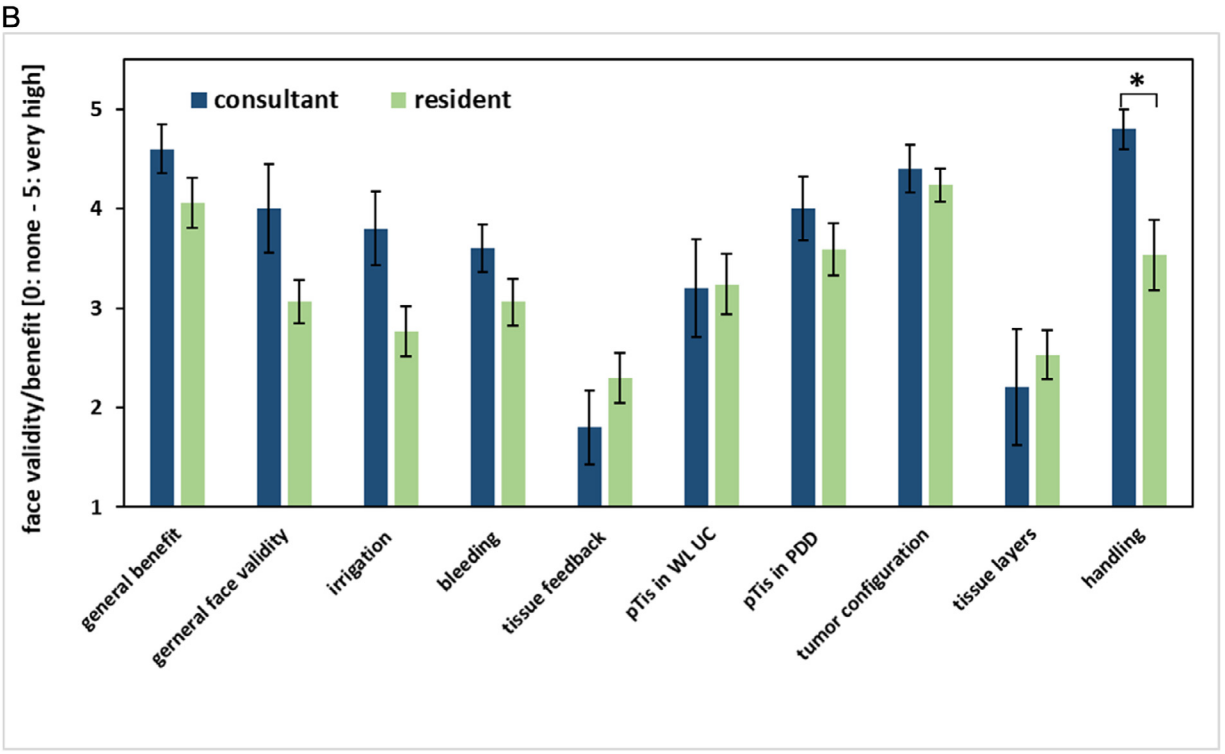

FIGURE 4. Continued

experienced users and beginners except with respect to handling of the resectoscope, indicating a high face validity of the UT. Evaluation of the feedback and correct display of the different tissue layers was limited. Finding the right tissue layer during TUR-BT is important, as both perforation of the bladder and absence of detrusor muscle in the specimen on the other side must be avoided. Our results and those of previous studies identified resection depth as a major challenge for an endourological beginner, prioritizing UT update for these items. [24] Comparing our results with previous studies investigating the efficacy of VR simulators for improving TUR-BT skills, the novel UT seems to perform better when compared to the predecessor model.[15,16] Furthermore, the UT simulates bleeding, which is a clear advantage in contrast to physical simulators.[14]

Besides the objective feedback, a major advantage of all VR simulators, might be the setting where novices and experienced users have the opportunity to train surgical competencies without the pressure of limited time or direct consequences of mistakes. As the technical possibilities to simulate real-life surgery are continuously increasing, it seems to be only a matter of time until virtual VR simulators become an integral part of surgical training. However, at the moment, VR simulators are still associated with high acquisition costs, which could be mitigated by leasing systems. As flat learning curves and a high complication rate also cause relevant costs, future studies will have to evaluate the economic efficacy of VR simulators.[25-27] Furthermore, alternative validation methods regarding surgical simulation have recently been discussed and might change the way VR systems are rated in the future.[28] In the meantime, other improvement opportunities like surgical checklists or video-based feedback might be used as cheap and easily implementable training supplements.[29-31] Although our study revealed face, content, and construct validity of the novel UT, we did not investigate the impact of using the UT on quality indices like real-life operation time or frequency of detrusor muscle in the tissue samples for criterion validity, which also limits our conclusions. However, obtaining these data might be difficult, as endourological BT cases vary significantly with respect to level of complexity. Furthermore, the optimal frequency, intensity, and time point of using the UT is still unclear.

CONCLUSION

The current surgical teaching concept of "see one—do one" is outdated and detrimental for the patient. The novel UT has shown to have a high face, content, and

construct validity in this study, and therefore, might be a valuable supplement in endourological training.

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