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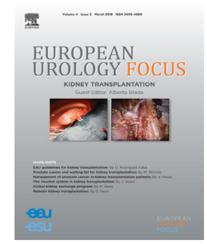

Education

Transurethral Resection of Bladder Tumors: Next-generation Virtual Reality Training for Surgeons

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Abstract

Background: The number of virtual reality (VR) simulators is increasing. The aim of this prospective trial was to determine the benefit of VR cystoscopy (UC) and transurethral bladder tumor resection (TURBT) training in students.
Design, setting, and participants: Medical students without endoscopic experience ($n = 51$, median age = 25 yr, median 4th academic year) were prospectively randomized into groups A and B. After an initial VR-UC and VR-TURBT task, group A ($n = 25$) underwent a video-based tutorial by a skilled expert. Group B ($n = 26$) was trained using a VR training program (Uro-Trainer). Following the training, every participant performed a final VR-UC and VR-TURBT task. Performance indicators were recorded via the simulator. Data was analyzed by Mann-Whitney U test.
Intervention: VR cystoscopy and TURBT.
Results and limitations: No baseline and post-training differences were found for VR-UC between groups. During baseline, VR-TURBT group A showed higher inspected bladder surface than group B (56% vs 73%, $p = 0.03$). Subgroup analysis detected differences related to sex before training (male: 31.2% decreased procedure time; 38.1% decreased resectoscope movement; $p = 0.02$). After training, significant differences in procedure time (3.9 min vs 2.7 min, $p = 0.007$), resectoscope movement (857 mm vs 529 mm, $p = 0.005$), and accidental bladder injury ($n = 3.0$ vs $n = 0.88$, $p = 0.003$) were found. Male participants showed reduced blood loss (males: 3.92 ml vs females: 10.12 ml; $p = 0.03$) after training.
Conclusions: Measuring endoscopic skills within a virtual environment can be done easily. Short training improved efficacy and safety of VR-TURBT. Nevertheless, transfer of improved VR performance into real world surgery needs further clarification.
Patient summary: We investigated how students without endoscopic experience profit from simulation-based training. The safe environment and repeated simulations can improve the surgical training. It may be possible to enhance patient's safety and the training of surgeons in long term.

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1. Introduction

Contemporary urological clinical instruction and training has been traditionally performed on patient-related "learning by doing" where trainees learn to perform operation procedures (see one, do one, teach one) using real patients [1,2]. Cystoscopy (UC) and transurethral resection of bladder tumors (TURBT) are basic endourological skills to be acquired, and these skills can also be acquired in a safe surrounding without jeopardizing patient safety by virtual reality (VR) simulation training [3–5].

Surgical simulation offers the opportunity to gain technical skills, such as instrument handling, navigation in a three-dimensional space via a two-dimensional monitor, and training of special surgical steps under controlled conditions. Therefore, it can shorten learning curves, especially for junior trainees, and reveal a beneficial impact on endoscopic skills [4]. Schout et al [2] performed a study to test if simulator-based training improved real-time UC. In their study cohort, the group that received training showed a significantly better performance in patients than the controls ($p \leq 0.003$).

TURBT simulation consists of step-by-step evaluation where an objective assessment of the surgical performance level could be obtained. Furthermore, in the real-time simulation, internal correction (eg, deep resection into the bladder wall, cut into the orifice) is carried out by the simulator. In addition, external specialist could give external correction. The face and content validity of the simulator was evaluated by Schout et al [3]. Mishra et al [5] performed a face and content validation study of the Uro-Trainer (Karl Storz GmbH, Tuttlingen, Germany). They showed with a novice and expert group that the simulator had satisfying usefulness but lacked some realistic domains. The current generation of the Uro-Trainer is much improved with regards to technical weak points in the simulation of virtual reality, thereby limiting previous studies.

The aim of this prospective trial was to determine the benefits of VR-UC and VR-TURBT training in students without endoscopic experience performed on the Uro-Trainer.

2. Material and methods

2.1. Participants and simulator

Between April 2016 and October 2016, medical students of the University of Tuebingen (n = 51, median age = 25 yr, median 4th yr of training) without endoscopic experience participated voluntarily for the study. The study was approved by the institutional ethical review board (No. 323/2016B02). A written informed consent was obtained from all the participants. The commercially available Uro-Trainer is a VR simulation training system for diagnostic and therapeutic interventions. It allows training in basic skills like hand-eye coordination, visual perception and haptic force feedback, as well as surgical procedures like TURBT and transurethral resection of the prostate (TURP). It contains customary resectoscopes (active and passive) with different resection features, with three virtual optics and inlet and outlet valves for fluid handling. Different learning scenarios with normal bladder surface and diverse bladder pathologies, such as flat and papillary tumors in various locations, offer the trainee the opportunity to perform UC and TURBT procedures. All movements of the resectoscope, (defined as movements in any axes of the resectoscope) including tip as well as the properly visualized or resected bladder area, blood loss, unsealed vessels, or accidental bladder injuries are recorded via the simulator and provide objective feedback. The current generation of the Uro-Trainer (Karl Storz GmbH, Germany) shows key improvements in comparison to the previously shown weak points in face and content validity studies [3,5]. The simulator used in this study is advanced in realism domains, with improved visualization of the bladder and the pathologies, and in constructive domains, with enhanced kinesthetic feedback, tissue and depth feel.

Kinesthetic feedback has been defined as advanced vibration patterns that convey information with predefined haptic waveforms.

2.2. Training

Each participant got a short standardized practical introduction into the handling of Uro-Trainer. Each student performed an initial VR-UC and VR-TURBT, which was recorded as a baseline task. Next, all students were prospectively block randomized into two groups (A and B). Group A (n = 25) underwent a video-based tutorial by a skilled expert. Group B (n = 26) was trained using the next-generation VR training program (Uro-Trainer). Subsequently, each participant performed a final VR-UC and VR-TURBT task, which was recorded (detailed flow chart, Fig. 1). The performance was done separately by each student without audience or assistance. Performance indicators of VR-UC and VR-TURBT efficacy (procedure time, resectoscope movement, inspected bladder surface, tumor resection rate) and safety (blood loss, unsealed vessels, accidental bladder injury) were recorded via the simulator.

2.3. Statistical analysis

Primary endpoint of the study was the reduction in the surgical procedure length between groups.

A sample size of 50 (25 per group) was necessary to detect at least 60 s of pair-difference between pre- and post-training simulation, using a pre-training mean of 5 min (standard deviation = 2.0). Because of the lack of previous report, we used a pilot pre-sampling of 10 participants to evaluate baseline characteristics of the cohort.

Discrete variables were compared with the chi-square test and presented as numbers and percentages. Data was analyzed by the nonparametric Mann-Whitney U test. Statistical significance was regarded as $p < 0.05$. Statistical analyses were performed using JMP (SAS Inc., Cary, USA).

3. Results

3.1. Study baseline characteristics

Group characteristics are shown in Table 1. There were no significant differences between groups A and B. First, the participants performed an initial baseline VR-UC. No baseline differences were found between both groups for VR-UC in terms of procedure time, cystoscope movement, and collision with the bladder wall. No baseline differences (procedure time, resectoscope movement, tumor resection, blood loss, unsealed vessels, and accidental bladder injuries) were found for VR-TURBT, with exception of a significant difference in inspected bladder surface (A: 56% vs B: 73%, p = 0.03).

3.2. Training effect

After VR-UC training, group B showed lower, but not significantly lower, cystoscope movement (235 mm vs

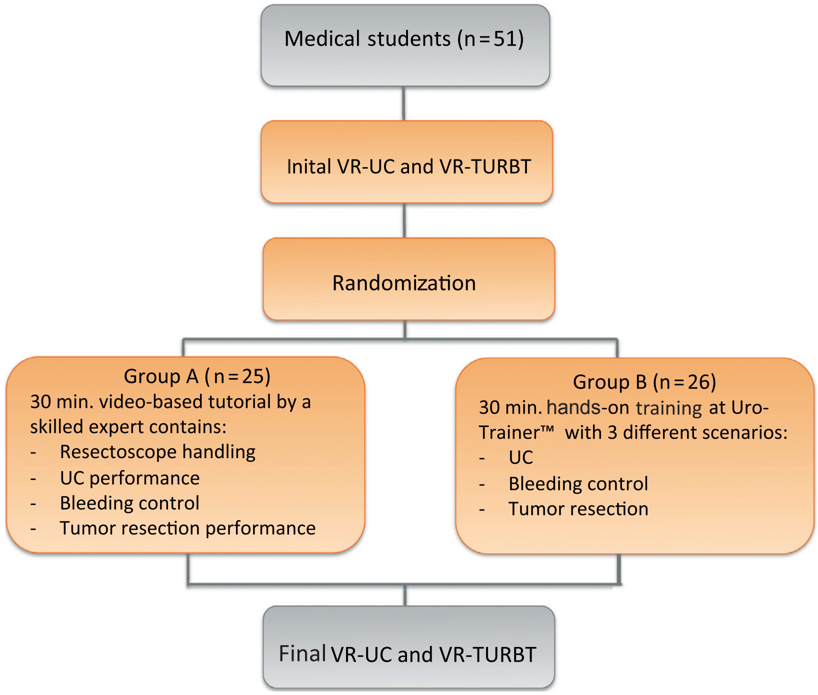

Fig. 1 – Flow chart of participant allocation to the trial.
UC = urethrocystoscopy; VR = virtual reality.

Table 1 – Demographics.

Students characteristics	Total cohort (n = 50)*	Group A (n = 25)	Group B (n = 25)*	p value
Sex (female/male)	25/25	13/12	12/13	0.78
Median semester (range)	7.5 (5–12)	8 (5–11)	7 (6–12)	0.65
Median age, years (range)	25 (20–31)	25 (20–31)	25 (21–31)	0.53
Handedness (right/left)	46/4	22/3	24/1	0.3
	Total cohort (n = 47)**	Group A (n = 25)	Group B (n = 22)**	p value
Previous work experience (no/yes)	20/27	13/12	7/15	0.16
Median previous work experience, yr (range)	1 (0–8)	0 (0–8)	1.25 (0–6)	0.3
Previous work experience (no/medical/other)	20/20/7	13/10/2	7/10/5	0.23
Video gaming ORS (1 [never] to 7 [very often]), median (range)	2 (1–7)	2 (1–7)	2 (1–7)	0.72

The whole study includes 51 participants: Group A, n = 25 and Group B, n = 26.
* 1 data set is missed.
** 1 data set is missed/3 forms were incorrectly filled out.

209 mm, p = 0.05) during the VR-UC (Table 2), whereas group A had an averaged procedure length of 3.9 min and group B of 2.7 min (p = 0.007).

In addition, another indicator for TURBT efficacy, a low resectoscope movement during procedure, was significantly better (A: 857 vs B: 529 mm, p = 0.005) after training. Regarding safety aspects, group B showed a significant reduction of accidental bladder injury (A: 3 vs B: 0.88, p = 0.003; Table 2).

We also assessed the training benefit defined as the difference between post- and pre-training results. Both the training strategies showed an improvement of all performance indicators; however, group B showed a higher positive impact on surgical procedure length (–2.06 min vs −0.72 min; p = 0.04; Table 2).

However, overall subgroup analysis detected differences related to sex before training [(male: 31.2% decreased procedure time and 38.1% decreased resectoscope movement; p = 0.02) and after training (male: 61. 5% decreased blood loss; p = 0.03).

4. Discussion

In this prospective trial, we evaluated the benefit of VR-UC and VR-TURBT training in students without any endoscopic experience performed on Uro-Trainer. One group underwent

Table 2 – Training parameters.

	Before training			After training			Training benefit (Difference post-pre training)		
Cystoscopy	Group A (n = 25)	Group B (n = 26)	p value	Group A (n = 25)	Group B (n = 26)	p value	Group A (n = 25)	Group B (n = 26)	p value
Procedure time (min, SD)	3.54 (±2.44)	3.12 (±2.36)	0.47	1.35 (±0.53)	1.16 (±0.47)	0.1	−2.19 (±2.25)	−1.95 (±2.11)	0.74
Collisions with bladder wall (n, SD)	6.48 (±5.19)	6.23 (±6.62)	0.4	4.48 (±3.18)	4.54 (±2.16)	0.38	−2.0 (±5.37)	−1.69 (±6.1)	0.51
Cystoscope movement (mm, SD)	576.56 (±410.88)	436.46 (±337.45)	0.17	235.48 (±75.49)	209.73 (±92.41)	0.05	−341.08 (±393.7)	226.73 (±291.74)	0.35
TURBT									
Procedure time (min, SD)	4.48 (±1.99)	4.80 (±2.58)	0.81	3.86 (±1.8)	2.74 (±1.04)	0.007*	−0.72 (±2.02)	−2.06 (±2.44)	0.04*
Resectoscope movement, (mm, SD)	1084.28 (±498.81)	1009.38 (±558.87)	0.51	857.48 (±455.01)	529.85 (±174.58)	0.005*	−226.8 (±452.25)	−479.54 (±545.03)	0.11
Resection tumor 1 (%, SD)	83.13 (±29.69)	83.81 (±32.02)	0.14	99.0 (±0.76)	95.15 (±19.43)	0.77	+15.88 (±29.37)	+11.35 (±38.73)	0.08
Resection tumor 2 (%, SD)	95.44 (±5.08)	91.69 (±21.65)	0.53	93.03 (±19.96)	98.0 (±3.56)	0.17	−2.36 (±19.8)	+6.31 (±21.06)	0.92
Inspected bladder surface (%, SD)	56.48 (±26.51)	73.15 (±21.59)	0.03*	75.88 (±29.46)	85.12 (±24.43)	0.38	+19.4 (±33.32)	+11.96 (±26.58)	0.76
Blood loss (ml, SD)	20.52 (±13.91)	19.92 (±15.11)	0.69	8.76 (±12.34)	5.08 (±7.92)	0.16	−11.76 (±14.27)	−14.85 (±16.13)	0.51
Unsealed vessels (n, SD)	0.92 (±1.04)	0.65 (±0.85)	0.38	0.24 (±0.44)	0.31 (±0.55)	0.76	−0.68 (±1.11)	−0.35 (−0.94)	0.37
Accidental bladder injury (n, SD)	6.0 (±3.97)	4.23 (±3.69)	0.07	3.0 (±2.90)	0.88 (±1.11)	0.003*	−3.0 (±4.51)	−3.35 (±3.53)	0.49

SD = standard deviation; TURBT = transurethral bladder tumor resection.
Group A = video-based tutorial by a skilled expert.
Group B = virtual reality training program (Uro-Trainer, Karl Storz GmbH, Germany).
* Statistical significance was regarded as $p < 0.05$.

a video-based tutorial by a skilled expert, similar to a traditional apprenticeship training model, and the other group was trained using a next-generation VR training program. VR-simulation training had a significant improvement on surgical procedure length ($p = 0.007$), resectoscope movement during procedure ($p = 0.005$), and accidental bladder injuries ($p = 0.003$). These results showed that VR training improved efficacy and safety of VR-TURBT compared to traditional teaching methods. This can be explained by an interactive, computer-simulated experience of the bladder anatomy, and an integrated haptic interface. This may allow a better understanding of lower urinary tract anatomy and an enhanced resectoscope handling after practical training. Nevertheless, no significant reduction of bleeding was noted, most probably due to an increased resection of tumor mass after training. VR-simulation training offers the opportunity to gain endourological skills and to practice repetitive special surgical steps under controlled conditions without patient discomfort or risk [4,6]. Prior work has documented that surgical simulators and pelvic training models are useful tools for residents and advanced physicians for the training of surgical skills [7]. Former meta-analysis approved that VR-simulation training can reduce the time to complete a task, increase the accuracy, and decrease errors compared with no training. Therefore, VR training can supplement standard surgical training and teaching [8,9].

Transurethral surgery is an important part of urology and requires a lot of technical skills and know-how by the surgeon. A large part of the procedural learning curve, especially technical skills, can be acquired using simulators for training [10]. It is well known that many procedures must be performed until an acceptable plateau in outcome factors, such as operation time, complication rate, or blood loss, is reached [11,12]. During VR-simulation training, it is possible to determine the individual learning curve of each trainee and to supervise an effective learning process [4]. Kruck et al [4] showed as well that repetitive simulation training achieves better results in bladder visualization and tumor resection. A Dutch survey reveals that residents in urology would prefer to learn on simulators prior to real patient-related surgeries despite approved traditional apprenticeship-models [1]. The VR-simulator availability is restricted due to the high acquisition costs. Therefore, only some hospitals and universities can offer these training methods [4,10].

The importance of the simulator training is continuously gaining importance.

However, these surgical training inside residence programs encounter difficulties in corresponding surgical skilling with progressive responsibilities for residents and this in turn would considerably limit surgical residents learning [13]. Recent studies have shown that 38% of general surgery residents are not confident in their ability to practice independently upon completion of the standard 5-yr residency programs [14].

To this regard, simulation surgical programs could face this problem by giving more skills to residents or novice surgeons.

Many training simulator are present in the global market; however, no direct comparison is present when considering TURBT. Based on this consideration, our results should be externally validated before its inclusion in an accredited and official program to a wider community. Local skills labs or mobile equipment sponsored by medical associations could help to get the cost down. Simulators can be effectively used as a part of a multimodal training curriculum [15]. Furthermore, they can be used to make regions and hospital groups more attractive to future surgeons. In any case, the employee acceptance rate of the implementation of such a skills-training program is high. Design characteristics that increase its acceptability are structured scheduling the use of peer teaching and high-fidelity models [1]. In the event of any innovation, the risk of potential pitfalls should be discussed. In repeated use of predefined scenarios of the simulation-based training, the trainee becomes an expert at using simulators. However, an expert level will only be achieved by successfully handling the natural human variations, unconventional solutions, and any kind of complications. A false security could take place in training surgeons. At the end, the work with real patients under experienced supervision is irreplaceable [2].

We would also point out that simulation training should be validated involving practical training beyond students [13]. In fact, Somani et al [16] recently reported that surgical training is continuously changing and simulation has to be integrated into a comprehensive curriculum. To this regard, findings of VR trainer should be validated using practical training before translating results into clinical use.

As a limitation, one may state that all students participated voluntarily in our study. It can be assumed that all students interested in endoscopic simulation-based training may result in a selection bias. Despite the prospective nature of the trial, it is limited by the small size ($n = 51$) and lack of inclusion of senior surgeons. Second, performance measurement within a clinical setting could have been evaluated with bladder phantoms. Finally, the lack of vibration alerting, defined as simple vibration patterns that notify users of an event, could represent a bias during the simulation training performance.

5. Conclusions

VR training improved efficacy and safety of VR-TURBT compared to traditional teaching methods and is a desirable tool in the education of surgical skills. Furthermore, objective patient- and training-independent measurements identified individual differences in computer-controlled endoscopic performance. Nevertheless, transfer of improved VR performance into real-world surgery needs further clarification. We suggest that simulation-based training is very useful to push the surgical learning curve of future urologists.

Author contributions: Jens Bedke had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Neumann, Mayer, Bedke, Kruck.
Acquisition of data: Neumann, Mayer, Russo, Deininger, Harland, Da Costa, Hennenlotter.
Analysis and interpretation of data: Neumann, Russo, Kruck, Bedke.
Drafting of the manuscript: Neumann, Bedke, Kruck.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: Neumann, Kruck.
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Supervision: Kruck, Amend, Rausch, Bedke.
Other (specify): None.

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Research involving human participants and/or animals

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The local ethic committee approved the study (No. 323/2016B02).

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