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Effectiveness of simulation models on technical skills among surgeons. A critical review

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Abstract. Based on simulation models the surgeons can train technical skills and improve their functional status of musculoskeletal state. Work in good ergonomic position could reduce and prevent musculoskeletal disorders. The aim of this review is to carry out critical analysis of research on simulation techniques analysing the effectiveness of simulators on technical skills among the surgeons. The search of the articles based on the databases EBSCO, Science Direct and Web of Science. The articles published in 2011–2016 years and not the literature reviews of simulator models in surgery were the selection criteria. Most often the simulator models have used for training of laparoscopic operations, choosing new instruments or introducing new methodologies. Some articles have paid more attention to ergonomic equipment layout in practice to prevent musculoskeletal disorders. It is important to use simulators in the university hospitals, where the young surgeons and medical students are practicing.

Key words: ergonomics, simulator, surgeon, skills.

INTRODUCTION

Many researches have shown that simulators are effective technical devices for training professional skills and test new tools, and good strategy to promote the effectiveness of students and young surgeons. When surgeons use the simulator for training it is needful to pay more attention on workplace ergonomics.

Technical skills means that the person who use simulator can practice more before practicing in patients. With simulator the surgeons can train psychomotor skills, camera navigation and objects transfer. Also, they can train for 2D to 3D perception, two hands coordination and needle suture as well as knots training, organ placing and total needling (Xiao et al., 2013). When professional skills have achieved, the simulator training enables to focus on the special aspects of a surgical procedure (Debes et al., 2012).

The simulators are good to test working on the new tool before buying and using it in operation. Often the instruments in one size used in laparoscopic surgery but the manner of using them varies according to the surgeon's hand size (Gonzalez et al., 2015).

Simulation method is a safe and accessible way to learn surgical procedures outside the operating room. Simulator training programs for surgical trainees have been developed using special simulation laboratories (Buckley et al., 2014). However, the simulation training can never replace practical training, but it does provide a cost-effective and safe environment for surgeons to train their laparoscopic skills (Xiao et al., 2014). Easily and low cost use of the simulator are two important qualities that could be considered by individual trainees in the training programs (Gromski & Matthes, 2011).

The most often problem of testing laparoscopic simulators is that the participants do not realize the importance of the ergonomic factors and till today there is no standard questionnaire and no consensus on how many participants should be included in a study (Jalink et al. (2015). The ergonomic factors are important for posture training, but seldom participants are thinking about them theoretically (Xiao et al., 2013). Work place ergonomics must consider monitor height between the operating surface and surgeon's eye-level height. The operating surface has set to 80% of elbow height, where the optical axis could be perpendicular to the target plane and box could tilt with angle of 20° (Van Veelen et al., 2002; Xiao et al., 2012).

The purpose of our study is to carry out critical analysis of research on simulation techniques to identify effectiveness of simulators on technical skills among the surgeons.

MATERIALS AND METHODS

We searched through the data basis of ScienceDirect, EBSCO and Web of Science to identify scientific papers related to 'ergonomics' and 'simulator' (Fig. 1).

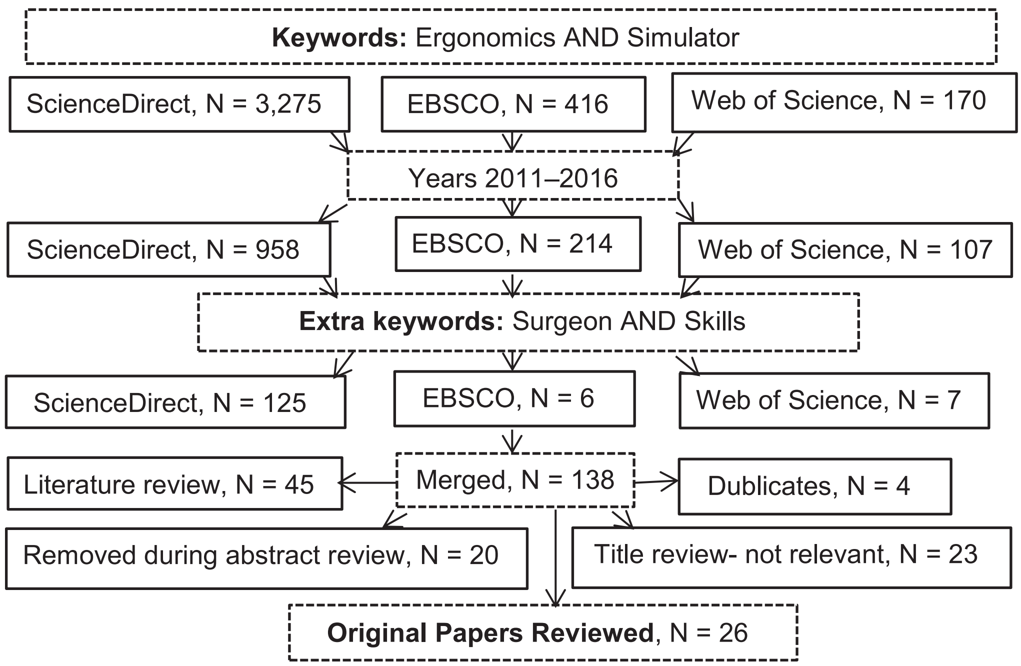

Figure 1. Review of studies flow chart.

Our search strategy yielded 3,275 journal articles in ScienceDirect, 416 in EBSCO and 170 of them in Web of Science. We selected the articles in period 2011 to 2016. When to focus on clinical simulation method and skills' trainings we added the keywords ‘surgeon’ and ‘skills’. After that we removed from list the repeated articles and literature reviews.

Based on the abstract information, we removed the articles not focused on ergonomic aspects, simulator principles or simulator in use, clinical background or not published in English. For critical analysis we yielded 26 studies. The topics included in the results Table 1 and Table 2 are: study, aim, sample, skills’ training, number of sessions, duration of sessions and outcomes.

RESULTS AND DISCUSSION

Our review covers the following outcomes of the studies: ‘new simulator and testing of technical skills’ (n = 8; Table 1) and only ‘testing of technical skills’ (n = 18; Table 2).

There were 8 articles about testing ‘new simulator and technical skills’ (Table 1). Low cost was one principle to make the new model (Xiao et al., 2013; Xiao et al., 2014). The cost difference depends on the components have used. The cost of the simulation model in the study of Tunitsky-Bitton et al. (2016) was 180 $, in Xiao, et al. (2014) – it was 300 € – new Ergo-Lap Simulator was used, and in Burdall et al. (2016) study the cost was 900 £. In latter it was used Selective Laser Sintering printer to carry out 3D printing.

Most the simulators were constructed in the box, the exercises were covered and the camera was showing the results. The demo of video game was used in testing technical skills by Jalink et al. (2015). The video game is showing the results on an acceptable level, but usually it takes more time than a traditional simulator.

In the ‘new simulator and technical skills’ studies, all the used simulators showed acceptable results. Only the question arise, are these articles mutually comparable and statistically confident, when the participant numbers are quite different? For example, 82 surgeons were under the observation in the video game study (Herbert et al., 2015), and only 13 participants were included in the other study (Horeman et al., 2015)

There were 18 articles under the analysis about ‘testing of technical skills’ (Table 2). In addition some studies tested simulator effectiveness (Letouzey et al. 2014; Jalink et al. 2015) and some studies assessed the educational value (Botchorishvili et al. 2012; Enciso et al., 2016a, Enciso et al., 2016b, Enciso et al., 2016c).

Origin of the studies

From a total 18 studies of ‘technical skills’ testing’, five of them were conducted in Netherlands (Luursema et al., 2012; Xiao et al., 2012; Luursema et al., 2014; Groenier et al., 2015; Jalink et al., 2015), four in Spain (Sánchez-Margallo et al., 2014; Enciso et al., 2016a, Enciso et al., 2016b, Enciso et al., 2016c), three in France (Botchorishvili et al., 2012; Letouzey et al., 2014; Morineau et al., 2016), three in United States (Rinewalt et al., 2012; Thawani et al., 2016; Viriyasiripong et al., 2016), one in United Kingdom (Bharathan et al., 2013), and one in Denmark (Vedel et al., 2015) and Hungary (Lukovich et al., 2016).

Table 1. 'New simulator and technical skills' testing' studies

Study	Debes et al. (2012)	Xiao et al. (2013)	Xiao et al. (2014)	Herbert et al. (2015)
Aim	To develop a standardized, graduated, and evidence based D-box.	To develop an inexpensive simulator to help surgeons to improve their skills under ergonomic conditions.	To verify the construct validity of 4 innovative tasks on the Ergo-Lap simulator for training basic laparoscopic skills.	To adapt the paediatric laparoscopic surgery simulator for paediatric single-port laparoscopy.
Sample	Medical and surgical interns (n = 20) and experienced surgeons (n = 10).	Medical students, surgeons, and experienced laparoscopic surgeons (n = 53).	Medical interns and junior surgical residents and laparoscopic specialists (n = 46).	Novices (n = 18), intermediates (n = 16) and experts (n = 7) participants (total = 41).
Simulator	D-box trainer.	Ergo-Lap simulator.	Ergo-Lap simulator.	Pediatric laparoscopic surgery simulator was modified to accommodate a SILS™ port.
Skill training	Peg transfer, sorting pegs, donkey stack, running gut, rubber plate, labyrinth.	Camera navigation and objects transfer; 2D to 3D perception; two hands coordination; pass needle suture and chenille wire through rings, ligation loop.	Transfer beads (coordination skills), transfer tubes (use of graspers), stretch band (both hands coordination), pass needle suture (bimanual coordination skills).	Peg transfer, pattern cut, ligating loop and intracorporeal suturing.
Number of sessions	6 tasks, 8 sessions.	Several tasks, 1 session.	Four tasks, 2 sessions.	4 tasks, 1 session.
Duration of sessions	30 to 60 min.	Not specified.	Different in every task and group (~150–1,200 s). Depended on participant skills.	Different in every task and group (~53.5 – 600 s).
Outcomes	Significant learning curves were obtainned for all construct valid parameters for tasks 4 and 5 and reached plateau levels between the 5 and 6 session.	Insignificant differences were found between the 2 groups. Only 50% of participants paid attention to the ergonomics factors.	Experienced group completed tasks faster than Novice group ($p < 0.001$) and did more errors in tasks.	Outcomes were significantly different between groups in all 4 tasks evaluated; There were no significant differences in outcomes between intermediates and experts for all tasks.

Table 1. Continues

Study	Horeman et al. (2015)	Burdall et al. (2016)	Maricic et al. (2016)	Tunitsky-Bitton et al. (2016)
Aim	To develop a trainer who can quantitatively measure task time, force and motion data.	To develop and trial a model of laparoscopic choledochal cyst excision.	To develop a model that could be used in simulation scenarios and brought experience and training as much as possible in practice.	Design a surgical model for training in laparoscopic vaginal cuff closure and to present evidence of its validity and reliability as an assessment and training tool.
Sample	Thirteen participants.	Senior paediatric surgical trainees (n = 20).	International faculty or paediatric surgeons (n = 39).	Gynaecology staff (n = 19) and trainees (n = 21).
Simulator	New box trainer.	3D printed laparoscopic choledochal surgery model.	A common rubber dummy, oesophagus and lungs model.	FLS box trainer.
Skill training	Laparoscopic multiport (MP), laparoscopic singleport (SP).	Active traction and division; dissection; internal visualization of the upper limit of the cyst and the duct level and transection of the cyst and hybrid anastomosis with porcine esophagus.	Thoracoscopic correction of Oesophageal atresia with tracheaoesophageal fistula (TEF/EA) repair training.	Laparoscopic suturing and specifically vaginal cuff closure. Needle loading, stitch placement, knot tying.
Number of sessions	3 tasks MP and 3 tasks SP, 1 session.	Four key steps, 1 session.	1 session.	3 tasks, 1 session.
Duration of sessions	Different in every task and group (MP – 61+/-16 s; SP – 122 +/-34).	20 min.	Different in groups (40 min vs 81 min).	Different in every task and groups (~8–250 s).
Outcomes	The task, maximum abdominal force, tissue manipulation force, and tilt angles of the left handle are significantly higher in SP.	The 10 delegates that trialled the simulation felt that the tactile likeness was good, was not too complex, and generally very useful.	Time in minutes and number of errors was significantly lower in the high experience group ($p < 0.0001$).	For the construct validity, the participants in the expert group received significantly higher scores in each of the 3 added items than did the trainees.

In total, eight 'new simulator and skills' testing' studies have taken under analysis. Three studies were conducted in Netherlands (Xiao et al., 2013; Xiao et al., 2014; Horeman et al., 2015), two in United Kingdom (Herbert et al. 2015; Burdall et al., 2016), one in United States (Tunitsky-Bitton et al., 2016), and one in Norway (Debes et al., 2012) and Argentine (Maricic et al., 2016).

Period and Duration

In Table 1 and 2 the studies with different duration for every task or group or session have shown (Debes et al., 2012; Luursema et al., 2012; Xiao et al., 2012; Groenier et al., 2015; Jalink et al., 2015; Burdall et al., 2016¸ Enciso et al., 2016a; Enciso et al., 2016c; Morineau et al., 2016) and in other studies were different duration in every task or group or session and depends on participant previous skills (Botchorishvili et al., 2012; Rinewalt et al., 2012; Bharathan et al., 2013; Letouzey et al., 2014; Xiao et al., 2014; Herbert et al., 2015; Horeman et al., 2015; Vedel et al., 2015; Enciso et al., 2016b; Lukovich et al., 2016; Maricic et al., 2016; Tunitsky-Bitton et al., 2016; Viriyasiripong et al., 2016) and some studies did not specify duration (Xiao et al., 2013; Luursema et al., 2014; Thawani et al., 2016). In some studies, the time of tasks have pointed out to achieve the best skills (Debes et al., 2012; Luursema et al., 2012; Groenier et al., 2015; Jalink et al., 2015; Burdall et al., 2016; Morineau et al., 2016). One study had no time limit (Sánchez-Margallo et al., 2014).

Simulation

In total eight 'new simulator and skills' testing studies' have taken under the analysis (Table 1). The box trainer for laparoscopy was constructed to train laparoscopic skills. Ergo-Lap simulator was used in two studies (Xiao et al., 2013; Xiao et al., 2014) and Herbert, G.L. et al. (2015) study was the existing simulator modification. The simulator was printed out with 3D printer (Burdall et al., 2016) and a common rubber dummy was used and constructed simulation model was placed in it (Maricic et al., 2016).

In the 'technical skills' testing studies' the different conditions and technical equipment have used. The box trainer have used in different studies: Surgical Science's LapSim simulator was used in four studies (Luursema et al., 2012; Luursema et al., 2014; Groenier et al., 2015; Vedel et al., 2015). LAPMentor virtual reality simulator was used in four studies (Bharathan et al., 2013; Enciso et al., 2016a; Enciso et al., 2016b; Enciso et al., 2016c) and a Covidien box trainer was used in two studies (Xiao et al., 2012; Lukovich et al., 2016). Also, the simulator room (Morineau et al., 2016), Nintendo Wii U game console plus Underground game (Jalink et al., 2015) and validated video-trainer suturing model (Botchorishvili et al., 2012) have introduced.

Outcomes

Xiao et al. (2012) have paid an attention on ergonomics. In the ergonomic simulation setting the proper distance of the monitor has included, the optical axis was perpendicular to the target plane, the operating surface was set as 80% of elbow height, and box trainer was tilt as an angle of 20°. Xiao et al. (2012) was doing the experiment with optimal and non-optimal ergonomic simulation setting.

Table 2. 'Technical skills' testing' studies

Study	Botchorishvili et al. (2012)	Luursema et al. (2012)	Rinewalt et al. (2012)	Xiao et al. (2012)
Aim	To evaluate prospectively the educational value and responsiveness of a large series of residents.	To add knowledge of the relation between the development and visuospatial ability of laparoscopic skills.	To measure the amount of improvements over time by residents at different levels of training.	To investigate the influence of ergonomic factors on task performance during laparoscopic training with a box trainer.
Sample	Residents (n = 191).	Students (n = 24).	Surgery residents (n = 20).	Twenty subjects.
Simulator	Validated video-trainer suturing model similar to that used in the MISTELS skill set.	Surgical Science's LapSim.	Laparoscopic box trainers.	A Covidien box trainer.
Skill training	Suture with each hand and porcine nephrectomy.	Grasping and instrument navigation.	Bead drop and rope drill, precision cutting and endo-loop, checker-board, endostitch, intracorporeal suture/ knot tying.	Optimal ergonomic simulation setting (A) and non-optimal ergonomic simulation setting (B). Tasks were suturing.
Number of sessions	Not specified.	2 tasks, 4 sessions, 8 weeks.	5 tasks, 1 session.	2 tasks, 1 session.
Duration of sessions	Different in every day and hand (~114.7–299 s).	30 min.	Different in every task (5–10 min).	Timing score were defined based on the completion time and a cut-off time of 900 seconds.
Outcomes	Significant improvement in time and technical scores for both laparoscopic suturing and porcine nephrectomy was noted.	Correlations for all performance measures over all sessions showed the motion efficiency to correlate highly with both damage and duration.	Scores improved in all the categories ($p < 0.05$) except for the bead drop/rope drill, which improved on objectively measured tasks only.	The mean score of G1A was significantly higher than G2B. Both groups performed better under condition A than under B.

Table 2. Continues

Study	Bharathan et al. (2013)	Letouzey et al. (2014)	Sánchez-Margallo et al. (2014)	Groenier et al. (2015)
Aim	To validate a virtual reality simulator for the training and assessment of laparoscopic tubal surgery.	To evaluate the value of a box trainer simulator in laparoscopy training.	To assess the usefulness of the evaluation system of surgical skills based on motion analysis of laparoscopic instruments.	To examine the influence of cognitive and psychomotor ability on the training duration and learning rate.
Sample	Gynaecologists (n = 34).	Residents and gynecology (n = 12).	Surgeons (n = 6).	Novices (n = 98).
Simulator	LAP Mentor VR laparoscopic simulator.	da Vinci1 surgical robot.	SIMULAP.	Surgical Science's LapSim v.3.0.10.
Skill training	Salpingectomy and salpingotomy.	Timing of the hands, movement through space, cutting in a defined plane and suture of synthetic material.	Synthetic fabric cutting task, organic tissue dissection task, organic tissue suturing task.	Hand-eye coordination.
Number of sessions	2 tasks, 1 session.	4 tasks, 1 session.	3 tasks, 1 session.	6 sessions.
Duration of sessions	Different in every task and group (~170–313 s).	Different in every task and sessions (60–300s).	No time limit.	30 min.
Outcomes	Both tasks revealed significant differences among 3 group times and total number of movements.	Technical performance was significantly higher after the training.	Regarding the dissection activity, experienced surgeons need less time ($p = 0.006$) and less length with both instruments ($p = 0.006$ for dissector and $p = 0.01$ for scissors).	Participants with better psychomotor ability, shows better results across all sessions on all outcome measures.

Table 2. Continues

Study	Jalink et al. (2015)	Luursema et al. (2014)	Vedel et al. (2015)	Enciso et al. (2016a)
Aim	To face validity of the game.	To develop the method for generating intermediate performance variables and investigate the development of laparoscopic skills.	To examine does medical students can facilitate laparoscopic procedural tasks to residents using a virtual reality simulator.	To evaluate a structured training model for laparoscopic gynaecologic surgery skills.
Sample	Surgeons (n = 77).	Beginner group (n = 16) and experienced group (n = 9).	Residents (n = 51).	Novice gynaecologists (n = 21).
Simulator	Nintendo Wii U game console plus Underground game.	LapSim laparoscopic simulator.	LapSim from Surgical Science.	LAPMentor virtual reality simulator.
Skill training	It is supposed to train eye-hand coordination, depth perception, inverse movements, and bimanual operation.	Suturing, camera navigation and coordination, precision and speed skills, handling intestines, fine dissection task.	Camera navigation, coordination, lifting and grasping, cutting, clip applying, fine dissection, tubal occlusion, salpingostomy, and salpingectomy.	Eye-hand coordination, hand-hand coordination, cutting tissue, dissection and intracorporeal suturing.
Number of sessions	1 session.	5 sessions.	Unlimited attempts.	5 tasks, tasks were repeated until they achieved a predetermined proficiency level.
Duration of sessions	5–15 min.	Not specified.	Different in every task and group (~200–230 min).	7 hours.
Outcomes	The majority of the participants (93.1%) said that The Underground game is a useful tool for learning basic laparoscopic skills.	Damage performance differentiated the most between groups and proficiency values; Motion performance variables differentiated the least.	The first group spent significantly longer time training basic modules (p = 0.001) but significantly fewer attempts to pass the upgraded salpingectomy module.	After the receiving training the participants performed all the tasks faster, using fewer movements.

Table 2. Continues

Study	Enciso et al. (2016b)	Enciso et al. (2016c)	Lukovich et al. (2016)	Morineau et al. (2016)
Aim	To validate a structured training model for efficient development of urological laparoscopic surgical skills.	To assess a laparoscopic training model for general surgery residents.	To compare the acquired skills in using straight vs. curved instruments in a laparoscopic training box and underline their importance in the laparoscopic curriculum.	To test framework qualitatively, as a methodological tool for identifying task management deficiencies.
Sample	Urology residents (n = 16).	Residents (n = 12).	Five-year medical students (n = 20).	Nurses (n = 13).
Simulator	LAPMentor virtual reality simulator.	LAPMentor virtual simulator.	The Single Incision Laparoscopic Surgery port by Covidien.	Simulation room.
Skill training	Balanced combination of simulation and animal training. Eye-hand coordination, hand-hand coordination, transference of objects.	Eye-hand coordination, hand-hand coordination, the transfer of objects, placing clips and cutting.	Peg transfer, curved peg transfer, loops and string.	A case of respiratory failure and cardiac arrest.
Number of sessions	3 tasks, 2 sessions-before and after the course.	4 exercises, session number are not specified.	3 tasks, 7 sessions.	2 tasks, 4 sessions.
Duration of sessions	Different in every task and sessions (~65.69–253.15 s).	7 hours.	Different in every task and sessions (~94–367 s).	10 min.
Outcomes	After the course, the participants exhibited a faster performance and the number of movements was significantly reduced in all of the tasks.	After the course, the participants performed all the tasks faster, increasing the speed of movements.	All the participants achieved significantly shorter task completion time on the last day; Group-S reached significantly higher task completion time with curved instruments.	The framework opens perspectives for designing ergonomic work situations and training caregivers.

Table 2. Continues

Study	Thawani et al. (2016)	Viriyasiripong et al. (2016)
Aim	To evaluate resident performance and assessed the effect of simulation training on performance in the operating room.	To analyse head motion during laparoscopic skill tasks.
Sample	First – (n = 3) and second – (n = 3) year residents.	Surgeons (n = 19).
Simulator	NeuroTouch VRH simulation.	EDGE laparoscopic simulator plus MUSE headband.
Skill training	Drill shown outside of right nasal passage. The endoscope within the right nasal corridor. Opening right sphenoid ostium. Blood accumulating on the endoscopic camera, based on excessive contact with the nasal mucosa.	Peg transfer and suturing task.
Number of sessions	2 sessions.	2 tasks, 1 session.
Duration of sessions	Not specified.	Different in every task and group (~107–279 s).
Outcomes	Simulation training was associated with an increase of performance scores in the operating room averaged over all measures ($p = 0.0045$).	Average acceleration analysis showed statistically significant differences between the groups on both vertical and horizontal axis in the laparoscopic suturing task.

Similar methods have used but different participants have observed in the Enciso et al. (2016a; 2016b; 2016c) studies. The eye-hand coordination, hand-hand coordination, and transference of objects registering time and movement metrics have trained with the virtual reality simulator. The participants passed theoretical session (one hour) and a hands-on session on simulator (7 h) and on animal model (13 h). After the training course the participants performed all the tasks faster. Animals who were in the Enciso et al. (2016a; 2016b; 2016c) studies were anesthetized and attended by veterinarians to assess their welfare.

Thawani et al. (2016) stressed on limitations which include a small number of subjects and bias adjudication − although the identifying of trained and untrained subjects was blinded. In further studies the using of proposed methods may better describe the relationship between simulated training and operative performance in endoscopic neurosurgery.

Sometimes the participants did not play the full and final version of the simulator's game, was also highlighted as the limitation of the simulators' studies (Luursema et al., 2014; Jalink et al., 2015).

Maricic et al. (2016) have used the questionnaire to evaluate the simulator ergonomics, the anatomical features and functionality of the simulation model. The study of Xiao and co-authors (2012) clearly demonstrated how the optimal ergonomic simulation setting and posture of a surgeon leads to better task performance. Some studies have included one or more questions about simulator ergonomics into the questionnaire (Botchorishvili et al., 2012; Bharathan et al., 2013; Jalink et al., 2015; Vedel et al., 2015; Lukovich et al., 2016). Two studies were talking about what was effective for practicing basic laparoscopic skills in an ergonomic manner (Xiao et al., 2013 and Xiao et al., 2014).

In Maricic et al. study (2016) showed that the new model regarding anatomical and functional characteristics as useful specific advanced training method was widely accepted among participants.

The Fig. 2 demonstrate theoretical framework for clinical task management skills (Morineau et al., 2016).

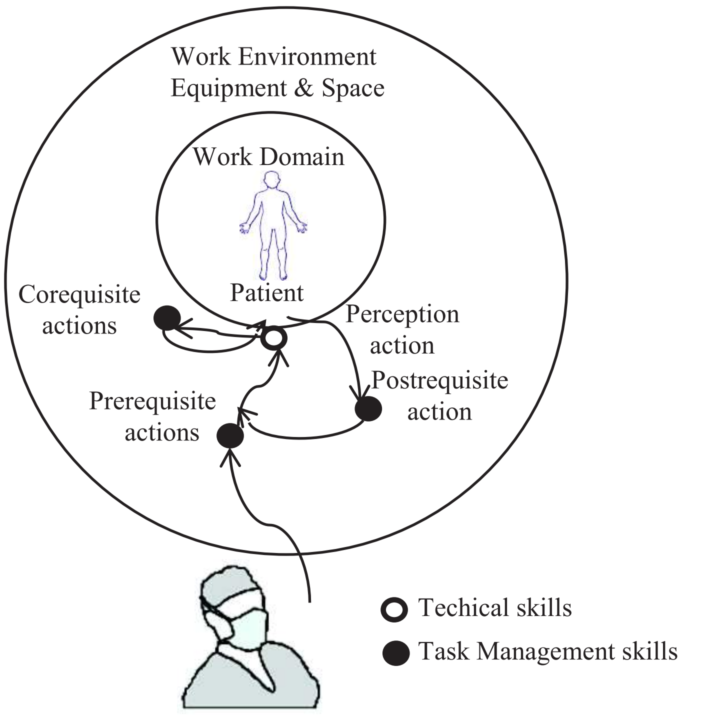

Figure 2. A framework for clinical task management skills (Morineau et al., 2016).

The Fig. 2 summarise the objective of the observed studies to develop the task management skills by proposing a framework focusing on task management deficiencies qualitatively. So far, it is not possible to use this framework as an 'on hand' tool for evaluating care performance in the course of educational process. However, it open some significant perspectives to improve understanding of performance deficiencies during care delivery inside heterogeneous medical teams.

The most of studies showed significant differences between the groups – after the simulator training the participants demonstrated faster performance (Botchorishvili et al., 2012; Luursema et al., 2012; Rinewalt et al., 2012; Xiao et al., 2012; Bharathan et al., 2013; Letouzey et al., 2014; Luursema et al., 2014; Sánchez-Margallo et al., 2014; Groenier et al., 2015; Vedel et al., 2015; Enciso et al., 2016a; Enciso et al., 2016b; Enciso et al., 2016c; Lukovich et al., 2016; Thawani et al., 2016¸ Viriyasiripong et al., 2016). That shows necessity for simulation training.

Based on yielded 26 studies, we can say that simulators are effective for training of technical skill and help to pay attention on functional status of musculoskeletal system among surgeons.

CONCLUSIONS

Our critical review focused on an effectiveness of training on technical skills with different simulators among the surgeons. The main topics were testing of new simulator with training of technical skill and only training of technical skills with existing simulator. To find more studies about the measurements of the effects of the simulator training on functional status of musculoskeletal system the other search programs could be in use. In majority studies the authors who tested the simulators have achieved positive results of surgeons' technical skills, but they used different exercises. Two hands coordination, needle suture, 2D to 3D perception, knots training, organ placing and total needling were the most often used exercises.

Based on this critical review we can conclude that simulators are important method for students and young surgeons to train technical skills effectively. In further studies the researchers should pay more attention to work place ergonomics, position and musculoskeletal system status.

REFERENCES

Bharathan, R., Vali, S., Setchell, T., Miskry, T., Darzi, A. & Aggarwal, R. 2013. Psychomotor skills and cognitive load training on a virtual reality laparoscopic simulator for tubal surgery is effective. *European Journal of Obstetrics & Gynecology and Reproductive Biology* **169**(2), 347–352.

Botchorishvili, R., Rabischong, B., Larraín, D., Khoo, C.K., Gaia, G., Jardon, K., Pouly, J.L., Jaffeux, P., Aublet-Cuvelier, B., Canis, M. & Mage, G. 2012. Educational value of an intensive and structured interval practice laparoscopic training course for residents in obstetrics and gynecology: a four-year prospective, multi-institutional recruitment study. *Journal of surgical education* **69**(2), 173–179.

Buckley, C.E., Kavanagh, D.O., Traynor, O. & Neary, P.C. 2014. Is the skillset obtained in surgical simulation transferable to the operating theatre? The *American Journal of Surgery* **207**(1), 146–157.

Burdall, O.C., Makin, E., Davenport, M. & Ade-Ajayi, N. 2016. 3D printing to simulate laparoscopic choledochal surgery. *Journal of pediatric surgery* **51**(5), 828–831.

Debes, A.J., Aggarwal, R., Balasundaram, I. & Jacobsen, M.B. 2012. Construction of an evidence-based, graduated training curriculum for D-box, a webcam-based laparoscopic basic skills trainer box. *The American Journal of Surgery* **203**(6), 768–775.

Enciso, S., Díaz-Güemes, I., Pérez-Medina, T., Zapardiel, I., de Santiago, J., Usón, J. & Sánchez-Margallo, F.M. 2016a. Validation of a structured intensive laparoscopic course for basic and advanced gynecologic skills training. *International Journal of Gynecology & Obstetrics* **133**(2), 241–244.

Enciso, S., Díaz-Güemes, I., Serrano, Á., Bachiller, J., Rioja, J., Usón, J. & Sánchez–Margallo, F.M. 2016b. Initial validation of a training program focused on laparoscopic radical nephrectomy. *Actas Urológicas Españolas (English Edition)* **40**(4), 237–244.

Enciso, S., Díaz-Güemes, I., Usón, J. & Sánchez-Margallo, F.M. 2016c. Validation of a Model of Intensive Training in Digestive Laparoscopic Surgery. *Cirugía Española (English Edition)* **94**(2), 70–76.

Gonzalez, A.G., Salgado, D.R. & Moruno, L.G. 2015. Optimisation of a laparoscopic tool handle dimension based on ergonomic analysis. International *Journal of Industrial Ergonomics* **48**, 16–24.

Groenier, M., Groenier, K.H., Miedema, H.A. & Broeders, I.A. 2015. Perceptual Speed and Psychomotor Ability Predict Laparoscopic Skill Acquisition on a Simulator. *Journal of surgical education* **72**(6), 1224–1232.

Gromski, M.A. & Matthes, K. 2011. Simulation in advanced endoscopy: state of the art and the next generation. *Techniques in Gastrointestinal Endoscopy* **13**(3), 203–208.

Herbert, G.L., Cundy, T.P., Singh, P., Retrosi, G., Sodergren, M.H., Azzie, G. & Darzi, A. 2015. Validation of a pediatric single-port laparoscopic surgery simulator. *Journal of pediatric surgery* **50**(10), 1762–1766.

Horeman, T., Sun, S., Tuijthof, G.J., Jansen, F.W., Meijerink, J.W. & Dankelman, J. 2015. Design of a box trainer for objective assessment of technical skills in single-port surgery. *Journal of surgical education* **72**(4), 606–617.

Jalink, M.B., Goris, J., Heineman, E., Pierie, J.P.E. & Henk, O. 2015. Face validity of a Wii U video game for training basic laparoscopic skills. *The American Journal of Surgery* **209**(6), 1102–1106.

Letouzey, V., Huberlant, S., Faillie, J.L., Prudhomme, M., Mares, P. & de Tayrac, R. 2014. Evaluation of a laparoscopic training program with or without robotic assistance. *European Journal of Obstetrics & Gynecology and Reproductive Biology* **181**, 321–327.

Lukovich, P., Sionov, V.B. & Kakucs, T. 2016. Training With Curved Laparoscopic Instruments in Single-Port Setting Improves Performance Using Straight Instruments: A Prospective Randomized Simulation Study. *Journal of surgical education* **73**(2), 348–354.

Luursema, J.M., Rovers, M.M., Groenier, M. & van Goor, H. 2014. Performance variables and professional experience in simulated laparoscopy: a two-group learning curve study. *Journal of surgical education* **71**(4), 568–573.

Luursema, J.M., Verwey, W.B. & Burie, R. 2012. Visuospatial ability factors and performance variables in laparoscopic simulator training. *Learning and individual differences* **22**(5), 632–638.

Maricic, M.A., Bailez, M.M. & Rodriguez, S.P. 2016. Validation of an inanimate low cost model for training minimal invasive surgery (MIS) of esophageal atresia with tracheoesophageal fistula (AE/TEF) repair. *Journal of pediatric surgery* **51**(9), 1429–1435.

Morineau, T., Chapelain, P. & Quinio, P. 2016. Task management skills and their deficiencies during care delivery in simulated medical emergency situation: A classification. *Intensive and Critical Care Nursing* **34**, 34–42.

Rinewalt, D., Du, H. & Velasco, J.M. 2012. Evaluation of a novel laparoscopic simulation laboratory curriculum. *Surgery* **152**(4), 550–556.

Sánchez-Margallo, J.A., Sánchez-Margallo, F.M., Carrasco, J.B.P., García, I.O., Aguilera, E.J.G. & del Pozo, J.M. 2014. Usefulness of an optical tracking system in laparoscopic surgery for motor skills assessment. Cirugía Española (English Edition) **92**(6), 421–428.

Thawani, J.P., Ramayya, A.G., Abdullah, K.G., Hudgins, E., Vaughan, K., Piazza, M. ... & Grady, M.S. 2016. Resident simulation training in endoscopic endonasal surgery utilizing haptic feedback technology. *Journal of Clinical Neuroscience* **34**, 112–116.

Tunitsky-Bitton, E., Propst, K. & Muffly, T. 2016. Development and validation of a laparoscopic hysterectomy cuff closure simulation model for surgical training. *American journal of obstetrics and gynecology* **214**(3), 392–e1.

Van Veelen, M.A., Kazemier, G., Koopman, J., Goossens, R.H., Miejer, D.W. 2002. Assessment of the ergonomically optimal operating surface height for laparo- scopic surgery. *Journal of Laparoendoscopic & Advanced Surgical Techniques* **12**(1), 47–52.

Vedel, C., Bjerrum, F., Mahmood, B., Sorensen, J.L. & Strandbygaard, J. 2015. Medical students as facilitators for laparoscopic simulator training. *Journal of surgical education* **72**(3), 446–451.

Viriyasiripong, S., Lopez, A., Mandava, S.H., Lai, W.R., Mitchell, G.C., Boonjindasup, A. ... & Lee, B.R. 2016. Accelerometer Measurement of Head Movement During Laparoscopic Surgery as a Tool to Evaluate Skill Development of Surgeons. *Journal of surgical education* **73**(4), 589–594.

Xiao, D.J., Jakimowicz, J.J., Albayrak, A. & Goossens, R.H.M. 2012. Ergonomic factors on task performance in laparoscopic surgery training. *Applied ergonomics* **43**(3), 548–553.

Xiao, D., Albayrak, A., Jakimowicz, J.J. & Goossens, R.H. 2013. A newly designed portable ergonomic laparoscopic skills Ergo-Lap simulator. *Minimally Invasive Therapy & Allied Technologies* **22**(6), 337–345.

Xiao, D., Jakimowicz, J.J., Albayrak, A., Buzink, S.N., Botden, S.M. & Goossens, R.H. 2014. Face, content, and construct validity of a novel portable ergonomic simulator for basic laparoscopic skills. *Journal of surgical education* **71**(1), 65–72.