



# Is actual surgical experience reflected in virtual reality simulation surgery for a femoral neck fracture?

Yasuhiro Homma<sup>1</sup> · Atsuhiko Mogami<sup>2</sup> · Tomonori Baba<sup>1</sup> · Kiyohito Naito<sup>1</sup> · Taiji Watari<sup>1</sup> · Osamu Obayashi<sup>2</sup> · Kazuo Kaneko<sup>1</sup>

Received: 9 March 2019 / Accepted: 6 June 2019 / Published online: 11 June 2019  
© Springer-Verlag France SAS, part of Springer Nature 2019

## Abstract

**Introduction** A virtual reality simulator developed for orthopaedic and trauma surgical training has been introduced. However, it is unclear whether the experiences of actual surgery are reflected in virtual reality simulation surgery (VRSS) using a simulator. The aim of this study is to investigate whether the results in VRSS differ between a trauma expert and a trauma novice.

**Methods** In Group A (expert), there are ten orthopaedic trauma surgeons and in Group B (novice) ten residents within 2 years after medical school graduation. VRSS for a femoral neck fracture using Hansson hook-pins (Test 1) and Hansson twin hook plate (Test 2) was performed. The parameters evaluated were total procedure time (s), fluoroscopy time (s), number of times X-ray was used (defined by the number of times the foot pedal was used), number of retries in guide placement, and final implant position.

**Results** In Test 1, the averages of four parameters (distance to posterior cortex ( $p=0.009$ ), distal pin distance above lesser trochanter ( $p=0.015$ ), distal pin hook angular error ( $p=0.004$ ), and distal pin tip distance to centre (lateral) ( $p=0.015$ )) were significantly different between Groups A and B. In Test 2, no parameters in a mean were significantly different between groups, but seven parameters in a variance (guide wire distance to joint surface ( $p=0.0191$ ), twin hook length outside barrel ( $p=0.011$ ), twin hook tip distance to centre (lateral) ( $p=0.042$ ), twin hook distance to centre of lateral cortex (lateral) ( $p=0.016$ ), plate end alignment error (lateral) ( $p=0.027$ ), guide wire angle with lateral cortex (front) ( $p=0.024$ ), and 3.2-mm drill outside cortex ( $p=0.000$ )) were significantly different between groups. In Test 1, Group B showed significantly longer fluoroscopy time than Group A ( $p=0.044$ ). In Test 2, Group B showed significantly fewer instances of X-ray use than Group A ( $p=0.046$ ).

**Conclusions** Our study showed that the experiences of actual surgery are reflected in the result of VRSS using the simulator.

**Keywords** Virtual reality · Simulation surgery · Femoral neck fracture

## Abbreviation

VRSS Virtual reality simulation surgery

## Introduction

Surgical education is one of the most important factors for patient safety. Various education methods have been developed and practiced [1–3]. In the surgical field, in particular, more effective operative training methods are desired because of the increasing complexity of surgical procedures, increasing limitations on work hours [4–6], and changing social background such as a growing number of medico-legal claims [7, 8]. In the current circumstances, the novice trainee has less chance to gain experience before an actual surgery [9]. Therefore, virtual reality simulation surgery (VRSS) has been applied in the surgical training field, especially in general surgical programs [10]. VRSS has a positive effect on trainees and patients in those areas [11, 12].

✉ Yasuhiro Homma  
yhomma@juntendo.ac.jp

<sup>1</sup> Department of Orthopaedic Surgery, Juntendo University, 2-1-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

<sup>2</sup> Department of Orthopaedic Surgery, Juntendo University Shizuoka Hospital, 1129 Nagaoka, Izunokuni, 410-2295, Shizuoka, Japan

In the musculoskeletal field, VRSS is also considered an emerging educational tool [13–15]. In increasingly ageing societies worldwide, fractures due to bone fragility are serious problems. Hip fractures are one of the most frequent fractures and are accompanied by high mortality and morbidity. However, the surgery for hip fractures is usually conducted by junior surgeons with or without senior supervision and is often considered part of the early phase of the novice's surgical experience. The current situation contains some problems to solve, such as an ethics and quality of preoperative educational methods. In hip fracture surgery, the learning curve must be minimal because patients are often elderly and have various comorbidities. Indeed, several studies demonstrated that inexperienced trainees contribute to a higher rate of readmissions and reoperations [16, 17]. Besides, a fluoroscopy, which is often handled by trainees, is needed in those trauma surgeries. Unnecessary excessive radiation exposure to the staff in the operation room adds the potential risk of radiation-induced diseases [18].

Swemac Trauma Vision<sup>®</sup> is a virtual reality simulator developed for orthopaedic and trauma surgical training. Few studies have been performed so far to determine its usefulness [14]. Ideally, VRSS would quantitatively evaluate trainee's surgical experience. However, it is unclear whether the experiences of actual surgery are reflected in virtual reality simulation surgery (VRSS) using a simulator. Therefore, we hypothesized that the result of VRSS using the Swemac Trauma Vision could reflect the difference in actual surgical experience between an expert and a novice. The aim of this study is to investigate whether the parameters in VRSS such as procedure time and implant positioning differ between a trauma expert and a trauma novice.

## Materials and methods

The VRSS that we used was the Swemac Trauma Vision (Fig. 1). It comprises a computer with two screens and Trauma Vision 5.12 software, which contains various orthopaedic procedures. A robot arm (Phantom Omni) is connected to a computer and mimics the operation tools and generates haptic feedback. The robot arm can be handled by the right hand or the left hand with a stylus according to the user's preference. The stylus is manipulated in space and used to represent a guide wire and fixed-angle guide, cannulated reamer, drill, depth gauge, and screwdriver on the computer screen. The haptic feedback allows users to feel resistance when in contact with tissue and bone and even permits tactile differentiation between cortical and cancellous bones. Fluoroscopy is administered by pressing a foot-controlled paddle, and the total time and number of use of the fluoroscopy are recorded.



Fig. 1 Working station of the Swemac Trauma Vision

Doctors in our hospital who had never used the VRSS were included in this study. Two groups were created: Group A (expert), comprising ten orthopaedic trauma surgeons who were able to independently perform standard trauma operations, and Group B (novice), comprising ten residents within 2 years after graduation from medical school, who had only observed trauma surgery and had no experience of performing the surgery.

The VRSS was conducted as follows [14]. The same supervisor assisted the VRSS through all steps. At first, as a 'warm-up', all participants were allowed to get used to the simulator by placing 2 simulated distal locking screws in a femoral nail (20 min) (Step 1). Then, 2 procedures of internal fixation for hip fractures using the VRSS were performed (Steps 2 and 3). The Step 2 is the insertion of two Hansson hook-pins (Test 1). The Step 3 is the insertion of Hansson twin hook plate. All test procedures started with placing the K-wire guide; the incision and handling of soft tissue

were not simulated. Screw lengths were fixed and announced before the procedure.

Parameters evaluated were total procedure time (s), fluoroscopy time (s), number of times X-ray was used (defined by the number of times the foot pedal was used), number of retries in guide placement, and final implant position (measured automatically by the simulator).

## Statistical analysis

Baseline characteristics were expressed as mean  $\pm$  standard deviation. The Student's *t*-test and Welch test were used for continuous variables. *F* test was used for analysis of variance between novices and experts. A *p* value  $< 0.05$  was considered statistically significant, and all tests were two-sided. Data were statistically analysed using IBM SPSS Statistics for Macintosh (version 22.0; IBM, Armonk, NY, USA).

## Results

Table 1 shows the result of procedure time and fluoroscopy-related parameters. No significant differences in total procedure time between groups were observed in Tests 1 and 2. In Test 1, Group B (novices) showed significantly longer fluoroscopy time and tendency of fewer number times of X-ray used than Group A (experts) ( $182.3 \pm 67.5$  vs  $125.5 \pm 60.3$ ,  $p < 0.01$ ). In Test 2, Group B (novices) showed significantly fewer uses of X-ray ( $34.27 \pm 14.6$  vs  $51.6 \pm 21.8$ ,  $p = 0.046$ ) and a longer fluoroscopy time ( $141.8 \pm 55.1$  vs  $113.5 \pm 79.9$ ,  $p = 0.211$ ) than Group A (experts). These results indicate that members of Group B stood on the foot pedal for longer durations. Details of implant position are shown in Tables 2 and 3. In Test 1, there was a significant difference in an average in four parameters between Groups A and B: distance

to posterior cortex ( $1.60 \pm 1.41$  vs  $-0.6 \pm 1.47$ ,  $p = 0.009$ ), distal pin distance above lesser trochanter ( $-0.30 \pm 5.67$  vs  $8.07 \pm 6.59$ ,  $p = 0.015$ ), distal pin hook angular error ( $-8.72 \pm 5.87$  vs  $-3.54 \pm 4.40$ ,  $p < 0.01$ ), and distal pin tip distance to centre ( $1.98 \pm 2.67$  vs  $-0.61 \pm 4.37 \pm 2.12$ ,  $p < 0.01$ ). Only two parameters in a variance showed significant differences between groups (guide wire distance to joint surface:  $3.93 \pm 1.66$  vs  $1.90 \pm 6.61$ ,  $p < 0.01$ , and proximal pin hook angular error:  $-1.44 \pm 5.87$  vs  $-0.03 \pm 1.43$ ,  $p < 0.01$ ). In Test 2, no parameter's average was significantly different between groups, but seven parameters in variance were significantly different between groups (guide wire distance to joint surface ( $p = 0.0191$ ), twin hook length outside barrel ( $p = 0.011$ ), twin hook tip distance to centre (lateral) ( $p = 0.042$ ), twin hook distance to centre of lateral cortex (lateral) ( $p = 0.016$ ), plate end alignment error (lateral) ( $p = 0.027$ ), guide wire angle with lateral cortex (front) ( $p = 0.024$ ), and 3.2-mm drill outside cortex ( $p = 0.000$ ).

## Discussion

VRSS has been considered as an alternative educational tool in various medical fields [9, 11–15]. More efficient training methods are desired in the musculoskeletal field as the number of operations for fractures due to bone fragility increases. The Swemac Trauma Vision has recently been introduced as the VRSS for hip fractures [14]. However, it is unclear whether differences in actual surgical experience are shown in VRSS using the Swemac Trauma Vision. In this study, it was revealed that differences in surgical experience in actual trauma surgery were well reproduced in VRSS using the Swemac Trauma Vision. These differences appeared in how participants conducted the fluoroscopy and where they positioned the implant.

**Table 1** Result of procedure time and fluoroscopy-related parameters

	Expert	Novice	<i>p</i> -value for <i>t</i> -test of means	<i>p</i> -value for <i>F</i> -test of variances
<i>Hansson hook-pins</i>				
Procedure time (s)	440 $\pm$ 138.9	484.8 $\pm$ 124	0.379	0.363
Fluoroscopy time (s)	125.5 $\pm$ 60.3	182.3 $\pm$ 67.5	0.044*	0.378
Number of times X-ray was used	63.0 $\pm$ 20.3	49.5 $\pm$ 16.6	0.149	0.264
Number of times of retries in guide placement	2.00 $\pm$ 1.6	1.6 $\pm$ 2.4	0.395	0.116
<i>Hansson twin hook plate</i>				
Procedure time (s)	330 $\pm$ 131.5	339 $\pm$ 96.7	0.741	0.174
Fluoroscopy time (s)	113.5 $\pm$ 79.9	141.8 $\pm$ 55.1	0.211	0.129
Number of times X-ray was used	51.6 $\pm$ 21.8	34.27 $\pm$ 14.6	0.046*	0.109
Number of times of retries in guide placement	1.9 $\pm$ 2.3	1.00 $\pm$ 1.4	0.395	0.068

\*Significant difference

**Table 2** Details of parameters of implant position in Hansson hook-pin

Parameters of implant position in Hansson hook-pin (mm)	Expert	Novice	<i>p</i> -value for <i>t</i> -test of means	<i>p</i> -value for <i>F</i> -test of variances
Distance to medial cortex	2.92 ± 1.60	4.35 ± 3.18	0.276	0.283
Distance to posterior cortex	1.60 ± 1.41	−0.61 ± 1.47	0.009*	0.460
Guide wire distance to joint surface	3.93 ± 1.66	1.90 ± 6.61	0.749	0.000*
Distal drill distance to joint surface	5.56 ± 2.57	5.60 ± 1.75	0.549	0.119
Distal pin distance to joint surface	5.88 ± 2.76	5.88 ± 1.81	0.471	0.100
Proximal drill distance to joint surface	5.76 ± 2.83	4.32 ± 3.63	0.459	0.236
Proximal pin distance to joint surface	6.89 ± 2.77	5.02 ± 2.80	0.131	0.498
Distal pin distance above lesser trochanter	−0.30 ± 5.67	8.07 ± 6.59	0.015*	0.337
Distal pin hook angular error**	−8.72 ± 5.87	−3.54 ± 4.40	0.004*	0.187
Proximal pin hook angular error**	−1.44 ± 5.87	−0.03 ± 1.43	0.912	0.000*
Distal pin tip distance below caput centre (front)	10.17 ± 4.09	9.93 ± 3.97	0.596	0.455
Distal pin tip distance to centre (lateral)	1.98 ± 2.67	4.37 ± 2.12	0.015*	0.238
Distal pin distance to centre of lateral cortex	1.46 ± 1.32	2.12 ± 2.25	0.857	0.064

\*Significant difference, \*\*unit (°)

**Table 3** Details of parameters of implant position in Hansson hook plate

Parameters of implant position in Hansson hook plate (mm)	Expert	Novice	<i>p</i> -value for <i>t</i> -test of means	<i>p</i> -value for <i>F</i> -test of variances
Guide wire distance to joint surface	4.68 ± 1.8	3.93 ± 3.69	0.646	0.019*
Step reamer distance to joint surface	8.53 ± 2.6	9.19 ± 3.39	0.373	0.210
Twin hook distance to joint surface	3.14 ± 1.78	9.20 ± 3.39	0.356	0.208
Twin hook length outside barrel	1.09 ± 1.19	−0.46 ± 2.58	0.741	0.011*
Twin hook tip distance to centre (lateral)	3.14 ± 1.79	3.97 ± 3.15	0.944	0.042*
Twin hook distance to centre of lateral cortex (lateral)	1.94 ± 1.78	1.27 ± 0.86	0.596	0.016*
Twin hook tip distance below centre (front)	1.04 ± 4.49	−4.56 ± 4.98	0.159	0.373
Plate end alignment error (lateral)**	2.19 ± 2.16	1.74 ± 1.13	1.0	0.027*
Guide wire angle with lateral cortex (front)**	130.4 ± 1.39	129.26 ± 2.6	0.509	0.024*
3.2-mm drill outside cortex	9.27 ± 2.71	14.13 ± 9.75	0.226	0.000*
Cortical screw length outside cortex	1.72 ± 0.79	1.65 ± 1/17	0.447	0.113
Posterior hook distance to joint surface	5.64 ± 3.04	3.73 ± 3.1	0.293	0.477
Anterior hook distance to joint surface	3.39 ± 2.74	5.54 ± 3.70	0.087	0.179

\*Significant difference, \*\*unit (°)

We believe that VRSS using the Swemac Trauma Vision is useful for education because VRSS using the Swemac Trauma Vision quantitatively demonstrated differences in actual surgical experience. The advantage of the Swemac Trauma Vision is that the computer can automatically calculate implant position. As our data showed, the trainee knows their performance in each parameter. The novice therefore knows their skill level compared with experts and follows their own progress. On this point, VRSS is superior to other education methods such as a cadaveric training and lecture-style lessons. Our results were similar

to those of previous studies [13, 14]. Pedersen et al. [14] showed an adequate inter-class/intra-class correlation coefficient in total combined percentage of maximum scores when participants used the Swemac Trauma Vision for hip fractures. Akhtar et al. [13] demonstrated the usefulness of the Swemac Trauma Vision because surgeons undertaking the procedure most frequently performed best on the simulator. Although no study has yet been performed to confirm that VRSS contributes to direct patient benefits such as fewer complications and shorter operative time, our results using the Swemac Trauma Vision encourage

further steps to research patient benefits using VRSS with the Swemac Trauma Vision.

We think that VRSS becomes more and more playing important role in orthopaedic education. In addition to Swemac Trauma Vision, many simulators have been introduced and validated [19, 20]. Khanduja et al. [19] validated VR of hip arthroscopy. They concluded that increased experience in hip arthroscopy was reflected by significantly better performance on the VR of hip arthroscopy [19]. Furthermore, in addition to those validation studies, some reports demonstrated that VRSS showed a positive effect on the surgical skills [21, 22]. Rebolledo et al. [21] revealed that junior orthopaedic surgery residents who trained with a surgical simulator demonstrated improved arthroscopic performance in both knee and shoulder arthroscopies compared to those who trained with didactic lectures with arthroscopy models.

In this study, several considerations were raised regarding the quality of preoperative education for hip fractures. First, it may be necessary to educate participants on not only how to operate but also how to handle the fluoroscopy. Our data showed that the novices used longer radiation times when using the foot pedal in simulation surgery. Radiation exposure is a major concern for operative room staff. Many papers have shown the relationship between orthopaedic surgery and occupational radiation exposure [18, 23–25]. Chou et al. [23] reported a 2.9-fold increase in the prevalence of breast cancer for a population of 505 female orthopaedic surgeons compared with US women of similar backgrounds. Female radiographic technologists who experience long-term, low-dose radiation exposure have a similar threefold increased risk of breast cancer [24, 25]. Although the exact relationship between the prevalence of cancer and radiation exposure during surgery has not yet been clarified, it is clear that radiation exposure must be reduced. Second, it may be necessary to understand a trend of error in hip fracture operations. Our data demonstrated different trends of error in terms of the reliability or the validity between the Hansson pin and twin hook systems. In the Hansson pin method, four implant position factors were significantly different between group averages but not in their variances, which means that the novices' results were enough reliability but low validity. For example, the distance to the posterior cortex of the Hansson pin was  $1.60 \pm 1.41$  mm for experts and  $-0.61 \pm 1.47$  mm for novices. This difference was significant for the averages but not the variance. In this situation, novices might aim for a non-ideal place because their preoperative orientation (education) was insufficient. Conversely, in the twin hook method, no implant position factors were significantly different between groups in the averages, but nine factors were significantly different in the variances, which means that the novices' results were enough validity but low reliability. For example, the twin hook tip distance to centre (lateral) was  $3.14 \pm 1.79$  mm for experts and  $3.97 \pm 3.15$  mm for novices. This difference was significant for the variance but

not in the averages. In this situation, the novice might aim for an ideal place with adequate preoperative orientation (education), but the surgical skill was insufficient to reach the ideal place.

Our study had several limitations: First, the order of VRSS (Hansson pin or twin hook method) may have influenced the result because of a learning curve during the test. However, the aim of this study was to detect a difference between novices and experts, which was shown. Further study is necessary to confirm the different error types in different operative procedures. Second, the number of participants was small, although the sample size was comparable to previous studies [14]. Third, the VRSS could not provide the simulation of skin incision and approach. Novice surgeons should recognize of this limitation of the VRSS. Fourth, how the VRSS could contribute to the actual patient safety has not yet been proved. Further prospective studies must be performed.

## Conclusion

Our study showed that differences in actual surgical experiences were reflected in the VRSS results. VRSS using the Swemac Trauma Vision may be useful for education because it presents the objective parameters concerning the procedure to trainees and trainers.

**Authors' contributions** YH involved in analysis and interpretation, and writing the article, AM contributed to conception, design, data collection, TB took part in analysis and interpretation, and writing the article, KN involved in analysis and interpretation, and writing the article, TW involved in analysis and interpretation, and writing the article, OO contributed to design, analysis, interpretation, and KK took part in design, analysis, interpretation. All authors read and approved the final manuscript.

**Funding** No funds were received in support of this study. No benefits in any form have been received or will be received from a commercial party related.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethics approval and consent to participate** Ethical approval was not required for this simulation-based intervention.

## References

- Wallace L, Raison N, Ghumman F, Moran A, Dasgupta P, Ahmed K (2017) Cognitive training: how can it be adapted for surgical education? *Surg* 15(4):231–239
- Atesok K, Satava RM, Marsh JL, Hurwitz SR (2017) Measuring surgical skills in simulation-based training. *JAAOS J Am Acad Orthop Surg* 25(10):665–672

3. Anderson PA (2019) 3D printing for education and surgical planning in orthopedic surgery. 3D printing in orthopaedic surgery. Elsevier, 2019. pp 55–63
4. Hollier JM, Wilson SD (2017) No variation in patient care outcomes after implementation of resident shift work duty hour limitations and a hospitalist model system. *Am J Med Qual* 32(1):27–33
5. Quillin RC III, Cortez AR, Pritts TA, Hanseman DJ, Edwards MJ, Davis BR (2016) Operative variability among residents has increased since implementation of the 80-hour workweek. *J Am Coll Surg* 222(6):1201–1210
6. Hirschl RB (2015) The making of a surgeon: 10,000 hours? *J Pediatr Surg* 50(5):699–706
7. Rynecki ND, Coban D, Gantz O, Gupta R, Ayyaswami V, Prabhu AV, Ruskin J, Lin SS, Beebe KS (2018) Medical malpractice in orthopedic surgery: a Westlaw-based demographic analysis. *Orthopedics* 41(5):e615–e620
8. Daniels AH, Ruttiman R, Eltorai AEM, DePasse JM, Brea BA, Palumbo MA (2017) Malpractice litigation following spine surgery. *J Neurosurg Spine* 27(4):470–475
9. Stirling ER, Lewis TL, Ferran NA (2014) Surgical skills simulation in trauma and orthopaedic training. *J Orthop Surg Res* 9:126
10. Alaker M, Wynn GR, Arulampalam T (2016) Virtual reality training in laparoscopic surgery: a systematic review & meta-analysis. *Int J Surg* 29:85–94
11. White I, Buchberg B, Tsikitis VL, Herzig DO, Vetto JT, Lu KC (2014) A virtual reality endoscopic simulator augments general surgery resident cancer education as measured by performance improvement. *J Cancer Educ* 29(2):333–336
12. Gasperin BDM, Zanirati T, Cavazzola LT (2018) Can virtual reality be as good as operating room training? experience from a residency program in general surgery. *Arq Bras de Cir Dig* 31(4):e1397. <https://doi.org/10.1590/0102-672020180001e1397>
13. Akhtar K, Sugand K, Sperrin M, Cobb J, Standfield N, Gupte C (2015) Training safer orthopedic surgeons. Construct validation of a virtual-reality simulator for hip fracture surgery. *Acta Orthop* 86(5):616–621
14. Pedersen P, Palm H, Ringsted C, Konge L (2014) Virtual-reality simulation to assess performance in hip fracture surgery. *Acta Orthop* 85(4):403–407
15. Blyth P, Stott NS, Anderson IA (2007) A simulation-based training system for hip fracture fixation for use within the hospital environment. *Injury* 38(10):1197–1203
16. Palm H, Jacobsen S, Krasheninnikoff M, Foss NB, Kehlet H, Gebuhr P (2007) Influence of surgeon's experience and supervision on re-operation rate after hip fracture surgery. *Injury* 38(7):775–779
17. Leblanc J, Hutchison C, Hu Y, Donnon T (2013) A comparison of orthopaedic resident performance on surgical fixation of an ulnar fracture using virtual reality and synthetic models. *J Bone Joint Surg (Am)* 95(9):e601–e606
18. Lee K, Lee KM, Park MS, Lee B, Kwon DG, Chung CY (2012) Measurements of surgeons' exposure to ionizing radiation dose during intraoperative use of C-arm fluoroscopy. *Spine* 37(14):1240–1244
19. Khanduja V, Lawrence JE, Audenaert E (2017) Testing the construct validity of a virtual reality hip arthroscopy simulator. *Arthrosc J Arthrosc Relat Surg* 33(3):566–571
20. Roberts PG, Guyver P, Baldwin M, Akhtar K, Alvand A, Price AJ, Rees JL (2017) Validation of the updated ArthroS simulator: face and construct validity of a passive haptic virtual reality simulator with novel performance metrics. *Knee Surg Sports Traumatol Arthrosc* 25(2):616–625
21. Rebolledo BJ, Hammann-Scala J, Leali A, Ranawat AS (2015) Arthroscopy skills development with a surgical simulator: a comparative study in orthopaedic surgery residents. *Am J Sports Med* 43(6):1526–1529
22. Cannon WD, Garrett WE Jr, Hunter RE, Sweeney HJ, Eckhoff DG, Nicandri GT, Hutchinson MR, Johnson DD, Bisson LJ, Bedi A, Hill JA, Koh JL, Reinig KD (2014) Improving residency training in arthroscopic knee surgery with use of a virtual-reality simulator: a randomized blinded study. *JBJS* 96(21):1798–1806
23. Chou LB, Chandran S, Harris AH, Tung J, Butler LM (2012) Increased breast cancer prevalence among female orthopedic surgeons. *J Womens Health (Larchmt)* 21(6):683–689
24. Mohan AK, Hauptmann M, Linet MS, Ron E, Lubin JH, Freedman DM et al (2002) Breast cancer mortality among female radiologic technologists in the United States. *J Natl Cancer Inst* 94(12):943–948
25. Yoshinaga S, Mabuchi K, Sigurdson A, Doody MM, Ron E (2004) Cancer risks among radiologists and radiographic technologists: review of epidemiologic studies. *Radiology* 233(2):313–321

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.