Radiography 30 (2024) S10–S16

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

Virtual reality simulation for mastery learning of wrist radiograph technique

J. Jensen [a, b, *, 1], B.R. Mussmann [a, b, c], M.R.V. Pedersen [d, e, f, g], K. Brage [a, h, i], A. England [g], H. Precht [e, f, g, i], S.D. Mørup [j], M.W. kusk [f, k, l], C.N. Bollerup [m], S. Lysdahlgaard [f, k, l], A.V. Dietrich [b], K.E. Hansen [b], P.I. Pietersen [a, b]

[a] Research and Innovation Unit of Radiology, University of Southern Denmark, Denmark
[b] Department of Radiology, Odense University Hospital, Denmark
[c] Department of Life Sciences and Health, Radiography, Oslo Metropolitan University, Oslo, Norway
[d] Department of Radiology, Lillebaelt Hospital, Vejle, University Hospitals of Southern Denmark, Denmark
[e] Department of Radiology, Lillebaelt Hospital, Kolding, University Hospitals of Southern Denmark, Denmark
[f] Department of Regional Health Research, University of Southern Denmark, Denmark
[g] Discipline of Medical Imaging & Radiation Therapy, University College Cork, Ireland
[h] Radiography Education, University College Lillebelt, Odense Denmark
[i] Health Sciences Research Centre, UCL University College, Denmark
[j] Department of Radiology, Lillebelt Hospital, Middelfart, University Hospitals of Southern Denmark, Denmark
[k] Department of Radiology and Nuclear Medicine, University Hospital of Southern Denmark, Esbjerg, Denmark
[l] Imaging Research Initiative Southwest (IRIS), University Hospital of Southern Denmark, Esbjerg, Denmark
[m] Vitasim, Odense, Denmark

ARTICLE INFO

Article history:
Received 8 May 2024
Received in revised form
26 August 2024
Accepted 4 September 2024

Keywords:
Virtual reality
Wrist radiography
Patient positioning
Radiography training

ABSTRACT

Introduction: Virtual reality (VR) simulation is a technology that empowers students and radiographers to practice radiography in a virtual environment that resembles real-life clinical scenarios. The purpose of this randomised study was to examine the relationship between clinical specialty and the ability to assess and obtain a lateral wrist radiograph using a VR simulator.

Methods: Radiographers and radiography students were recruited from the EFRS Research Hub at the 2024 European Congress of Radiology. After completing a background questionnaire, participants entered a VR simulator where they assessed lateral wrist radiographs and, if necessary, attempted a retake. Fisher's exact test was used to evaluate the relationship between specialties and participants' ability to assess positioning and perform retakes. Rank-biserial correlation estimated the relationship between participants' ability to reposition the VR patient and their VR experience and self-perceived confidence in wrist radiograph positioning.

Results: The cohort included 173 participants from 14 specialties across 21 countries. There was a borderline significant trend between clinical specialty and correct positioning assessment ($p = 0.052$) and between self-perceived confidence in acquiring wrist radiographs and repositioning for a retake ($p = 0.052$). Neither clinical specialty ($p = 0.480$) nor previous VR experience ($p = 0.409$) correlated with ability to reposition for a retake.

Conclusion: While results indicated a potential correlation between participants' ability to position a VR patient and both clinical specialty and confidence in wrist radiography, these trends were not statistically significant. Nevertheless, the findings suggest that VR holds promise for radiography training, though further research is necessary to explore the factors that influence performance and learning.

Implications for practice: The incorporation of VR technology into standard radiography training programs could potentially improve patient outcomes by ensuring that radiography students are more skilled at acquiring quality radiographs prior to their first clinical practice. It should be noted though, that knowledge on positioning criteria and anatomy is an advantage when practicing correct positioning in a VR simulator.
© 2024 The Authors. Published by Elsevier Ltd on behalf of The College of Radiographers. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

* Corresponding author.
E-mail address: Janni.jensen@rsyd.dk (J. Jensen).
[1] www.linkedin.com/in/janni-jensen-x-ray

https://doi.org/10.1016/j.radi.2024.09.002
1078-8174/© 2024 The Authors. Published by Elsevier Ltd on behalf of The College of Radiographers. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Introduction

A wrist radiograph is a commonly performed radiographic examination, often following trauma. Proper patient positioning is important, particularly regarding forearm rotation (supination/protonation), where deviation from the neutral position significantly influences the diagnostic interpretation of the Radiograph.[1–4] An important aspect of the decision to offer surgery to a patient with a fractured wrist is the measurements derived from the Radiograph.[5] If the wrist is improperly positioned during the acquisition of the lateral radiograph, it can result in inaccurate measurements and potentially incorrect treatment or treatment failure. Therefore, correct positioning of the wrist during the examination is of crucial significance.[6,7] Students of radiography are typically taught patient positioning in a classroom, followed by clinical skills labs, and subsequently in clinical practice under supervision; the latter involving patients.[8]

Virtual reality (VR) simulation is a technology that empowers students and radiographers to engage in radiography practice within a virtual environment, mimicking real-life clinical scenarios including assessment of performance. It has previously been demonstrated that active learning with realistic VR simulations prepares radiography students for clinical practice. This includes training radiographic acquisition in VR, where students of radiography acknowledged the importance of preparation for clinical practice.[9,10] The advantage of “hands-on” training in VR is that this solution offers a platform for practice-oriented learning, without involving patients and radiation in the training process. The educational value of VR has been explored in other health-related fields with VR-based learning in ultrasound.[11–13] Sapkaroski et al. (2019) showed, that students training in VR prior to clinical practice significantly improved their ability to correctly position hand Radiographs in a clinical setting.[14] A pilot study demonstrated potential for training acquisition of wrist radiographs using VR,[15] however, to the best of the author's knowledge, larger studies examining the correlation between radiographic appearance and patient positioning, as well as repositioning the patient for a retake, remain largely unexplored. Neither has the correlation between clinical specialty and ability to correctly reposition for a wrist radiograph been explored, to contrast those who routinely work in projection radiography and those who do not.

Accordingly, the objectives of this study were to investigate the following in a three-dimensional VR universe: 1) the relationship between clinical specialty and the ability to assess the positioning of a lateral wrist radiograph. 2) the relationship between clinical specialty and the ability to reposition a VR patient based on the appearance of a given wrist radiograph. 3) the relationship between the individual's ability to reposition a VR patient and respectively their experience with VR, and their self-perceived experience with acquisition of wrist radiographs.

Methods

This is a cross-sectional randomized study where radiographers and radiography students of all stages of their training were recruited from an international congress. The methods applied were two-fold, with data collected through a brief questionnaire, and afterwards within a VR simulator. Data collection took place at a dedicated site, the EFRS Research Hub, at the European Congress of Radiology (ECR) in Vienna, Austria, over a three-day period from February 28th to March 1st 2024. Participation was voluntary, and informed consent was mandatory. The Research Ethics Committee at the University of Southern Denmark approved the study (ID number 22/29,639).

Questionnaire

Demographic information was collected using an online questionnaire that included study information followed by consent to participate. Participants were asked questions on: age, gender, country of residence, radiographer/student of radiography, area of primary/secondary specialisation, including years of experience. Additionally, using a scale from 1 to 10 (1 was not experienced/confident at all and 10 was extremely confident/experienced), participants were asked to state their experience with VR and their confidence when positioning for a lateral wrist, respectively. The survey was developed using Research Electronic Data Capture (REDCap) database.[16]

Virtual reality simulator

After completion of the online questionnaire, participants were informed orally about the tasks in the VR simulator by trained instructors. Specifically, they were instructed to evaluate the lateral wrist radiograph based solely on positioning relating to forearm rotation. They were instructed how to rotate the radiograph with fingers pointing up or down according to their preference, how to accept or reject the radiograph, reposition the VR patient in case they rejected the initial radiograph, and how to retake the radiograph. Repositioning the VR patient was limited to forearm rotation, specifically supination and protonation, while all other anatomical forearm movements were restricted for the purpose of this study. There were two ways to rotate the forearm; the participants could either grab the forearm and supinate or pronate or they could grab a stick that had restricted movement to either supinate or pronate (Fig. 1).

After the briefing, participants were given a VR headset and two controllers, and they entered the virtual X-ray room. Within this simulated X-ray room, there was a lateral wrist radiograph, an X-ray machine, and a virtual patient prepositioned to mirror the presented radiograph (Fig. 2). Participants were randomly presented with one of three potential scenarios (Fig. 3A–C).

A. a true lateral wrist radiograph, with overlap of the dorsal aspects of the distal radius and ulna, ***and*** the volar aspect of the pisiform positioned in the central third of the interval between the volar cortices of the scaphoid and the capitate,[17,18]

OR.

B. a lateral wrist radiograph with the forearm supinated in relation to the true lateral, the distal radius positioned dorsally to the ulna and the pisiform positioned volarly,

Figure 1. Set up in the VR simulator depicting forearm rotation by grabbing and moving the stick in front of the forearm.

OR.

C. a lateral wrist radiograph with the forearm pronated in relation to the true lateral, the distal ulna positioned dorsally to the radius and the pisiform positioned dorsally.

Participants were randomly allocated to one of the scenarios using block randomization with a block size of nine. This meant that for every group of nine participants, each scenario was randomly presented three times, ensuring a balanced distribution of scenarios while maintaining a randomized approach. In the VR simulator, the first task was to answer the following question: ***Is the forearm correctly positioned in the* radiograph** (Yes/No) If the response was “yes”, the participant's task was complete ending the simulation. If the answer was “No” the participant would be asked to reposition the patient to improve positioning and retake the radiograph. Hereafter, the participant was shown the new radiograph and asked: “***Is the forearm correctly positioned in this new radiograph?***” (Yes/No). At this point, the participant's involvement was complete and they exited the VR room (Fig. 4).

Figure 2. The X-ray room with the patient and the initial wrist radiograph.

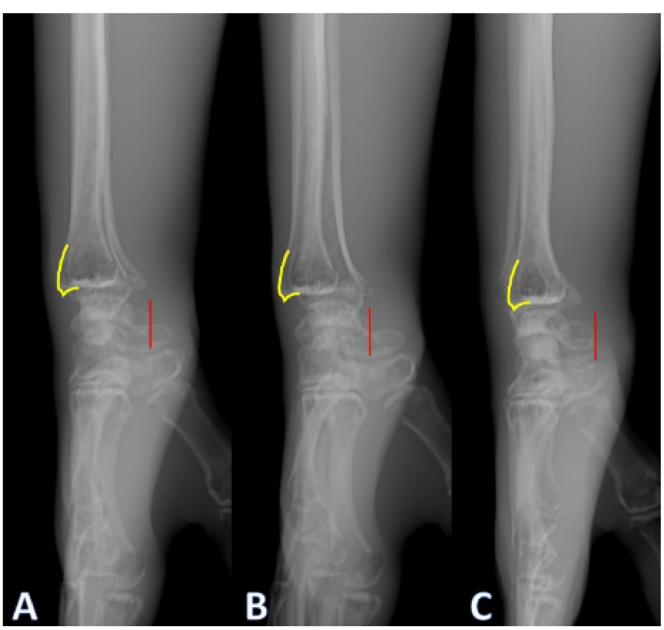

Figure 3. The yellow lines delineate the dorsal aspect of the distal ulna and the red lines indicate the most volar aspect of the pisiform. Image 3A is a true lateral image, where the dorsal aspects of the distal radius and ulna overlap, ***and*** the volar aspect of the pisiform is positioned in the central third of the interval between the volar cortices of the scaphoid and the capitate. Image 3B is pronated as seen by the more dorsal position of the ulna and the pisiform. Oppositely, in image 3C, the forearm is supinated as seen by the more volar position of both the ulna and the pisiform.

Data analysis

Demographic data were presented using descriptive statistics. The Fishers exact test was used to examine the relationship between categorical demographic data (specialty including students) and two outcomes: the ability to assess the positioning of a lateral wrist radiograph and the ability to reposition the forearm. The ability to reposition the forearm was dichotomized as a binary variable: whether the individual rotated the forearm in the correct direction (yes/no). The Rank-biserial correlation test was used to assess the relationship between the ability to reposition the VR patient and respectively experience with VR, and self-perceived confidence in positioning for a wrist radiograph. P-values <0.05 were considered statistically significant. Stata Version 18 (StataCorp. 2023, College Station, TX, USA) was used for all statistical analyses.

Results

Participant demographics

A total of 179 radiographers or radiography students participated in the study. Two participants were excluded for not completing the VR simulation and four were excluded due to duplicate participant IDs, leaving 173 participants in the final sample. The mean age (SD) of the included participants was 33.8 (11.7) years. Of these, 106 (61.3%) were female, 63 (36.4%) were male, and four (2.3%) did not specify their gender or chose ‘other.’ The participants represented 21 different countries, with most coming from Denmark (31%), Italy (13%), and the Netherlands (9%) (Fig. 5). In total, participants from 14 different clinical subspecialties took part in the study. The largest groups were radiography students (38%), CT radiographers (13%), and planar radiography specialists (12%) (Fig. 6).

Initial radiographic assessment

The initial radiograph was randomly presented in one of three positions: optimally positioned (true lateral), pronated, or supinated, with a distribution of 55, 57, and 61, respectively. When evaluating the initial radiograph for correct positioning, 125 participants (72%) answered correctly, while 48 participants (28%) provided an incorrect answer. Most correct assessments of rotation were seen in the mal-positioned radiographs with 93% and 92% correct answers for respectively pronated and supinated radiographs. In contrast, there were 29% correct evaluations of the true lateral wrist radiograph. Relation between clinical specialty and ability to assess positioning correct neared but did not reach significance ($p = 0.052$) (Table 1).

Repositioning

When repositioning the wrist for a retake, 76 participants (51%) rotated the wrist in the correct direction, while 72 participants (49%) did not. There was no significant difference in ability to correctly reposition for a retake and the clinical specialties ($p = 0.480$) (Table 2).

Experience with VR and wrist radiography

Mean experience with VR was 2.2 (SD 2.5) in our sample. Data indicated no significant correlation between previous experience

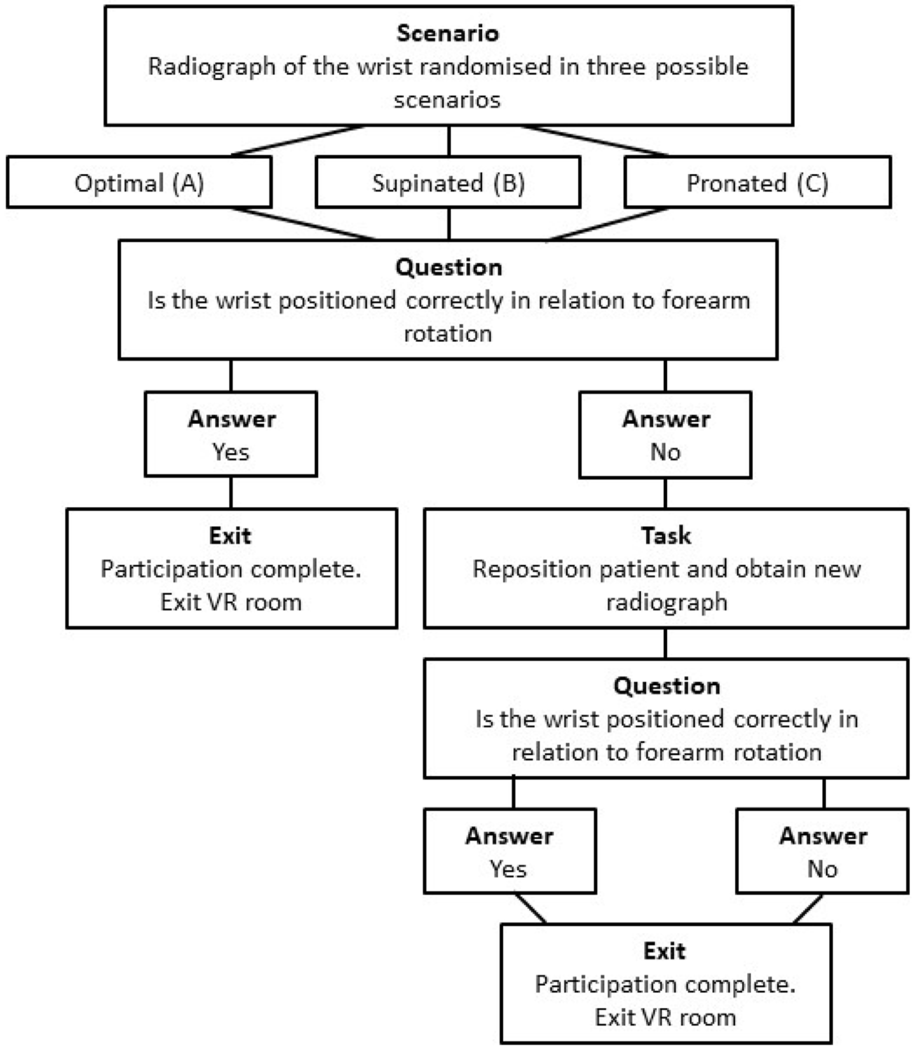

Figure 4. Flowchart of participants tasks in the virtual reality simulator.

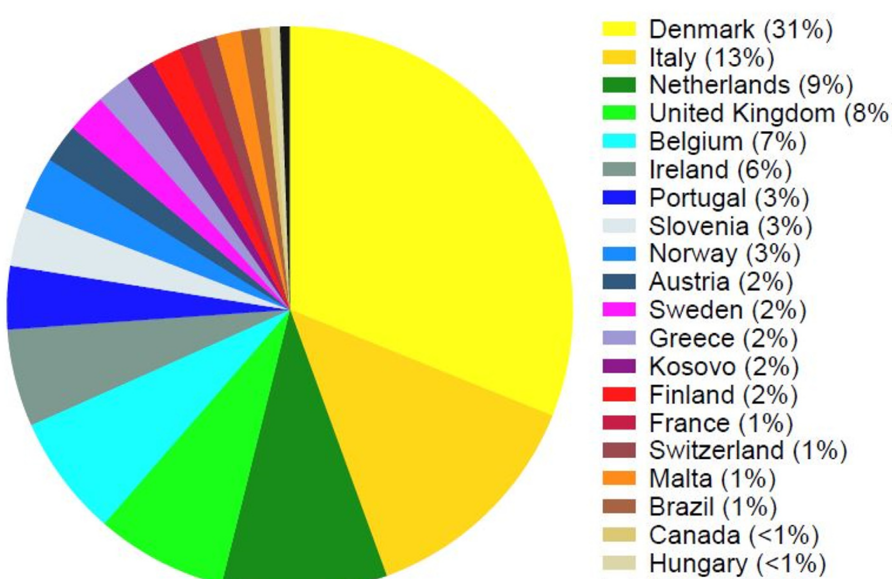

Figure 5. Participant demographics: Country.

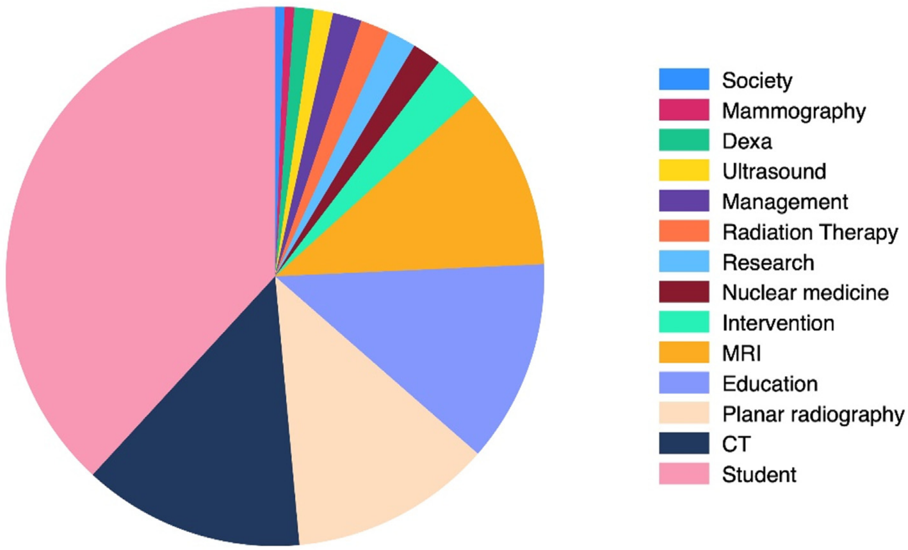

Figure 6. Participant demographics: Specialty.

Table 1
Evaluation of initial wrist radiograph (n = 173). Correct and incorrect evaluation of forearm positioning by specialties.

	Initial forearm positioning							
	Optimal		Pronated		Supinated		Total	
Specialty	Correct/incorrect (% correct) n = 55		Correct/incorrect (% correct) n = 57		Correct/incorrect (% correct) n = 61		Correct/incorrect (% correct)	
CT	2/4	(33%)	9/0	(100%)	6/2	(75%)	17/6	(74%)
DEXA	NA		2/0	(100%)	0/0		2/0	(100%)
Education	3/6	(33 %)	5/1	(83%)	6/0	(100%)	14/7	(67%)
Intervention	1/0	(100%)	1/0	(100%)	3/0	(100%)	5/0	(100%)
MRI	2/3	(40%)	4/0	(100%)	10/0	(100%)	16/3	(84%)
Manager	NA		1/0	(100%)	2/0	(100%)	3/0	(100%)
Nuclear	0/2	(0%)	1/0	(100%)	NA		1/2	(33%)
Planar Radiography	2/9	(18%)	3/1	(75%)	5/1	(83%)	10/11	(48%)
Research	1/0	(100%)	2/0	(100%)	NA		3/0	(100%)
Student	4/12	(25%)	23/1	(96%)	24/2	(92%)	51/15	(77%)
Ultrasound	1/1	(50%)	NA		NA		1/1	(50%)
Society	0/1	(0%)	NA		NA		0/1	(0%)
Mammography	0/1	(0%)	NA		NA		0/1	(0%)
Radiation therapy	NA		2/1	(67%)	NA		2/1	(67%)
Total correct in %	29%		93%		92%			

CT; Computed tomography, DEXA; dual-energy X-ray absorptiometry, MRI; Magnetic resonance imaging, NA; Not applicable.

Table 2
Did participant rotate the correct way by specialty. n = 148.

	No. correct/incorrect (% correct)	
Specialty		
CT	11/8	(58%)
DEXA	2/0	(100%)
Education	7/10	(41%)
Intervention	2/2	(50%)
MRI	6/11	(35%)
Manager	2/1	(67%)
Nuclear	2/1	(67%)
Planar Radiography	7/10	(41%)
Research	2/0	(100%)
Student	33/26	(56%)
Ultrasound	0/1	(0%)
Society	0/1	(0%)
Radiation therapy	2/0	(100%)
Mammography	0/1	(0)
Total correct/incorrect (% correct)	76/72	(51%)

with VR and the ability to rotate the wrist in the correct direction ($p = 0.409$). Although there was a trend towards a correlation between self-perceived confidence in acquisition of wrist radiographs and the ability to rotate the wrist in the correct direction, it did not reach statistical significance ($p = 0.052$), mean 5.9 (SD 2.5).

Discussion

We aimed to explore impact of specialty and previous experience with respectively VR and acquisition of wrist radiographs on ability to assess and obtain a wrist radiograph in a VR setup. Most of the participants (72%) accurately assessed positioning of the initial radiograph, suggesting that evaluating positioning in a virtual environment is feasible. However, correlating the anatomical appearance in the radiograph to patient positioning and adjusting for retakes proved more challenging, with only 51% of the participants rotating the forearm in the correct direction. Whether this finding directly translates to a clinical setting is uncertain, as this study did not explore that aspect. Previous research has indicated that dedicated musculoskeletal (MSK) radiographers tended to evaluate wrist positioning in a radiograph more accurately than non-MSK radiographers.[17] However, our data showed no significant difference in the ability to evaluate positioning between radiographers of different specialties. This discrepancy may stem from the inclusion of radiographers from 14 different specialties, with only 12% specialising in planar radiography, potentially limiting our statistical power to detect significant differences. Additionally, the use of VR technology may not be entirely familiar to radiographers as a professional tool. Participants in our study reported a mean experience level of 2.2 on a scale from 1 to 10, thus indicated a limited familiarity with VR within our cohort. Time spend in our VR simulator was an estimated 5 min, while students of radiography have previously reported needing approximately 60 min to become accustomed to a VR system.[8] Moreover, students of radiography have previously mentioned missing the ability to palpate the patient when training in VR.[8] Nonetheless, as our study focused on the correct direction of forearm rotation rather that achieving a perfectly positioned true lateral wrist radiograph, the lack of tactile interaction likely had minimal impact on the results.

While no significant correlation was found between prior VR experience and the ability to correctly rotate the wrist, there was a trend towards a positive relationship between self-perceived confidence in acquiring wrist radiographs and successful wrist rotation. This suggests that individuals who felt more confident in their wrist radiograph acquisition skills may also have performed better in the VR simulator, pointing to a potential connection between clinical experience and performance in the VR setting. Future research should investigate this further though, and perhaps consider incorporating methods to enhance the VR training, such as interactive tutorials or feedback systems that could help refine the manipulation skills needed for correct radiographic imaging of the wrist in the clinical setting. Virtual reality has been explored in other fields of medical education e.g., for learning ultrasound examinations. In this study, gamification, i.e. incorporating game-like elements, such as points, and rewards, to enhance user engagement, was also investigated but was not found superior as an educational tool in VR.[11] Another study found participants to achieve almost the same level of skills when training focused abdominal ultrasound in VR as participants undergoing an instructor-led course using a screen-based simulator.[19] As mentioned, VR possesses the ability to repeat a procedure or take repeated radiographs in a calm setting with the potential of integrated feedback, and the visualization of the bones in correct, supine, or pronated position to increase the understanding of the placement of the bones in the different positions. Additionally, it is possible to incorporate assessments – either formative or summative, to ensure sufficient knowledge and skills.[20] This could increase the use of self-directed learning and the mastery learning approach advocating that all trainees can learn a specific skill but with different learning paces and need for supervision, feedback and assistance.[21]

The ability to position the patient correctly is an important skill in the clinical setting as research has indicated that mal-positioned radiographs can influence the diagnostic outcome.[4,22,23] In clinical practice, there is typically a brief time interval to evaluate the radiograph and, if necessary, decide how to reposition the patient for a retake before the patient changes position. This emphasizes the value of using VR for training purposes, as it allows individuals to practice acquisition and positioning in a controlled environment without exposing patients to radiation or feeling rushed due to patient discomfort or time constraint. Furthermore, it has been estimated that VR reduces the carbon footprint by at least 1272 kg of CO2 annually compared to using conventional radiography.[24]

In the current study, 28% of the participants initially misinterpreted radiographic positioning. This error could lead to unnecessary accept or retakes of radiographs in clinical practice. This finding aligns with Steward et al. (2023) who reported that approximately 85% of their rejected lateral wrist radiographs were clinically acceptable upon review.[25] In the commercial version of the VR tool utilized in our study, an evaluation of positioning was provided after each retake, along with suggestions for improving positioning. However, for the purposes of this study, this feature was not available to participants. In a clinical setting, the inclusion of this feedback mechanism could potentially reduce the rejection rate. Further investigation into the efficacy of such a feature in clinical practice is warranted should be a feature of future research.

Strengths and limitations

To our knowledge, this is one of the largest randomized studies in VR for medical educational purposes including participants from various countries. The study explored the potential of VR for radiography learning purposes. However, different definitions of patient positioning for a lateral wrist radiograph exist and can potentially have biased the participants' ability to re-position the VR-patient. The radiographic positioning of a lateral wrist radiograph regarding forearm rotation (supination/protonation), is typically evaluated either by alignment of the dorsal aspects of the distal radius and ulna or by the pisiform-scaphoid-capitate relationship, where the most volar aspect of the pisiform should overlay the central third of an interval defined by the volar cortices of the scaphoid and the capitate.[18] To accommodate both definitions, the wrist radiographs in the simulator were presented in keeping with both definitions; for example, if the forearm was pronated the distal ulna would be positioned dorsally in relation to the radius ***and*** the pisiform would be positioned dorsally. Moreover, to ensure that viewing conditions did not bias the evaluation, the wrist radiographs could be rotated with fingers pointing up or down according to preference of individual participants.

In conclusion, this study demonstrated that most participants were able to accurately assess positioning in the presented radiograph. There was a tendency, although not statistically significant, towards a relation between clinical specialty and ability to assess positioning. Clinical specialty did not significantly influence the ability to reposition patients for improved positioning. While participants' self-assessed proficiency in acquiring wrist radiographs suggested a tendency to correlate with their repositioning capabilities, this relationship was not statistically significant. Furthermore, prior experience with VR did not provide a measurable advantage in the ability to reposition within the VR environment.

Further research is needed on the value of VR in radiographic positioning, preferably with the inclusion of larger, more homogeneous cohorts. Additionally, it would be beneficial to explore the efficacy of feedback mechanisms within VR and the impact on clinical practice.

Funding

The research received no specific grant from any funding agency in the public, commercial, or non-for-profit sectors.

Conflict of interest statement

CNB is Senior Account Executive at VITASIM, Odense, Denmark. CNB was responsible for technical assistance during data collection at the ECR 2024, contributed to the study design and final approval of the manuscript. CNB had no access to study data and did not take part in data analysis. The other authors declare no conflict of interest.

Acknowledgements

The authors express their gratitude to the EFRS Research Hub for the opportunity to participate in the Research Hub at ECR 2024. We extend our thanks to the members of the Research Hub and to all radiographer colleagues and students who participated or helped spread the word, thereby aiding in the recruitment process.

References

1. Pennock AT, Phillips CS, Matzon JL, Daley E. The effects of forearm rotation on three wrist measurements: radial inclination, radial height and palmar tilt. *Hand Surg* 2005;**10**(1):17–22.
2. Zanetti M, Gilula LA, Jacob HA, Hodler J. Palmar tilt of the distal radius: influence of off-lateral projection initial observations. *Radiology* 2001;**220**(3):594–600.
3. Jensen J, Tromborg HB, Rasmussen BS, Gerke O, Torfing T, Precht H, et al. The effect of forearm rotation on radiographic measurements of the wrist: An experimental study using radiostereometric analyses on cadavers. *Eur Radiol Exp* 2021;**5**:15.
4. Jensen J, Tromborg HB, Rasmussen BS, Gerke O, Torfing T, Precht H, et al. Dorsal tilt of the distal radius fracture changes with forearm rotation when measured on radiographs. *J Hand Surg Glob Online* 2021;**3**:182–9.
5. Lichtman DM, Bindra RR, Boyer MI, Putnam MD, Ring D, Slutsky DJ, et al. American Academy of Orthopaedic Surgeons clinical practice guideline on: the treatment of distal radius fractures. *J Bone Joint Surg Am* 2011;**93**:775–8.
6. Yeh GL, Beredjiklian PK, Katz MA, Steinberg DR, Bozentka DJ. Effects of forearm rotation on the clinical evaluation of ulnar variance. *J Hand Surg* 2001;**26**(6):1042–6.
7. Jensen J, Graumann O, Gerke O, Torfing T, Precht H, Rasmussen BS, et al. Accuracy of radiographic measurements of fracture-induced deformity in the distal radius. *Acta Radiol Open* 2023;**12**(9). 20584601231205986.
8. O'Connor M, Stowe J, Potocnik J, Giannotti N, Murphy S, Rainford L. 3D virtual reality simulation in radiography education: the students' experience. *Radiography* 2021;**27**(1):208–14.
9. O'Connor M, Rainford L. The impact of 3D virtual reality radiography practice on student performance in clinical practice. *Radiography* 2023;**29**(1):159–64.
10. Rainford L, Tcacenco A, Potocnik J, Brophy C, Lunney A, Kearney D, et al. Student perceptions of the use of three-dimensional (3-D) virtual reality (VR) simulation in the delivery of radiation protection training for radiography and medical students. *Radiography* 2023;**29**(4):777–85.
11. Larsen JD, Jensen RO, Pietersen PI, Jacobsen N, Falster C, Nielsen AB, et al. Education in focused lung ultrasound using gamified immersive virtual reality: A randomized controlled study. *Ultrasound Med Biol* 2023;**49**:841–52.
12. Jacobsen N, Larsen JD, Falster C, Nolsøe CP, Konge L, Graumann O, et al. Using immersive virtual reality simulation to ensure competence in contrast-enhanced ultrasound. *Ultrasound Med Biol* 2022;**48**:912–23.
13. Nielsen MS, Clausen JH, Hoffmann-Petersen J, Konge L, Nielsen AB. Can virtual-reality simulation ensure transthoracic echocardiography skills before trainees examine patients? *Int J Med Educ* 2022;**13**:267–73.
14. Sapkaroski D, Baird M, Mundy M, Dimmock MR. Quantification of student radiographic patient positioning using an immersive virtual reality simulation. *Simulat Healthc J Soc Med Simulat* 2019;**14**(4):258–63.
15. Jensen J, Graumann O, Jensen RO, Gade SKK, Thielsen MG, Most W, et al. Using virtual reality simulation for training practical skills in musculoskeletal wrist X-ray - A pilot study. *J Clin Imaging Sci* 2023;**13**:20.
16. Harris PA, Taylor R, Minor BL, Elliott V, Fernandez M, O'Neal L, et al. The REDCap consortium: building an international community of software platform partners. *J Biomed Inf* 2019;**95**:103208.
17. Mussmann BR, Milner R, Barlow N, Jensen J. The lateral wrist radiograph - To retake or not to retake. *Radiography* 2022;**29**(1):119–23.
18. Yang Z, Mann FA, Gilula LA, Haerr C, Larsen CF. Scaphopisocapitate alignment: criterion to establish a neutral lateral view of the wrist. *Radiology* 1997;**205**(3):865–9.
19. Junge K, Larsen JD, Stougaard SW, Jensen RO, Falster C, Posth S, et al. Education in focused assessment with sonography for trauma using immersive virtual reality: a prospective, interventional cohort study and non-inferiority analysis with a historical control. *Ultrasound Med Biol* 2024;**50**(2):277–84.
20. Yudkowsky R, Downing SM. *Assessment in health professions education*. 2nd ed. New York: Routledge; 2019.
21. McGaghie WC. Mastery learning: it is time for medical education to join the 21st century. *Acad Med* 2015;**90**(11):1438–41.
22. Midtgaard M, Pedersen MRV, Christensen NL, McKnight KL, Jensen J. Patient positioning during the radiographic procedure affects the radiological signs of acetabular retroversion - A systematic review. *J Clin Imaging Sci* 2023;**13**:34.
23. Ha AS, Porrino JA, Chew FS. Radiographic pitfalls in lower extremity trauma. *Am J Roentgenol* 2014;**203**(3):492–500.
24. Brage K, Hansen KB, Rasmussen JV, Brage O, Precht H. Revolutionizing Radiography with VR Education. J Med Imaging Radiat Sci 2024;*In press*.
25. Steward A, Semsem S, Currie K, Bentley L, Mineo R, Holliday M, et al. The cost of perfection: an investigation into the unnecessary rejection of clinically acceptable lateral wrist imaging. *J Med Radiat Sci* 2023;**70**:380–7.