The usefulness of vertebral needle targeting simulation training system using ray-summation imaging: experimental study

Fumiya Uchiyama1,4,6, Tomoyuki Noguchi2,3,4,5,6, Shunsuke Kamei1, Koji Yamashita2,6, Yoshitaka Shida3,6, Takashi Okafuji3,6, Ryotaro Kamei2,6, Tsuyoshi Tajima3,6

Received: 30 January 2022 / Accepted: 28 April 2022 / Published online: 10 June 2022 © The Author(s) 2022

Abstract

Purpose Using the multi-detector computed tomography and related three-dimensional imaging technology, we developed a vertebral needle targeting simulation training system named spinal needling intervention practice using ray-summation imaging (SNIPURS). Herein, we assessed the utility of SNIPURS by evaluating changes in the learning curves of SNIPURS trainees.

Methods Twenty-one examinees were enrolled: seven experienced operators (expert group), seven trainees with coaching (coaching group), and seven trainees without coaching (non-coaching group). They performed six tests of vertebral needle targeting simulation on the workstation-generated spinal ray-summation images of six patients with vertebral fractures. In each test, they determined the bilateral trans-pedicular puncture points and angles on two thoracic and two lumbar vertebrae on ray-summation imaging (i.e., 8 simulations per test). The coaching group received coaching by a trainer after Tests 1 and 4, while the others did not. Scores were given based on the trans-pedicular pathway (1 point) or not (0 point). Eight virtual needles were evaluated in each of Tests 1–6.

Results Among the three groups, the expert group had the highest average scores on Tests 1–4 (expert: 3.86, 6.57, 7.43, and 7.57; coaching: 1.86, 6.14, 6.0, and 6.29; and non-coaching: 1.14, 4.14, 4.71, and 4.86). The coaching group’s scores caught up with the expert groups’ average scores on Tests 5 and 6, whereas those of the non-coaching group did not (expert and coaching: 7.86 and 8.00, non-coaching: 5.86 and 7.14). All examinees in the expert and coaching groups achieved a perfect score on the final Test 6, whereas three of the seven non-coaching trainees did not.

Conclusion SNIPURS might be suitable for vertebral needle targeting training. The coaching provided during SNIPURS training helped the trainees to acquire the spinal puncture techniques in PVP.

Keywords Vertebroplasty · Vertebral needle targeting · Learning curve · Virtual fluoroscopy · Ray-summation image
Vertebral needle insertion is an important step in the percutaneous vertebroplasty (PVP) procedure. The common puncture route for PVP procedures is trans-pedicular from the dorsal region with the patient in the prone position [1]. The procedure with this route is inherently safe, because there are no other adjacent anatomical structures that can be damaged by the needle as long as its position is carefully selected. A dorsal puncture also allows compression hemostasis of a patient in the supine position after a PVP procedure to minimize postoperative bleeding. Punctures deviating from the trans-vertebral route can cause neurological damage or hemorrhagic complications [2–6], and an improper puncture can lead to an improper distribution of cement, that is, cement leakage to the outside of the vertebrae, which might result in serious complications [6–9].

Vertebral needle insertion is not always easily accomplished, as it is difficult to recognize and puncture the narrow pedicle of the vertebral arch in fluoroscopy [10–12]. Radiology trainees must learn the basic procedures and be given opportunities for intensive practice, although the available training period is limited and there are concerns about patient safety [13]. A new method of puncture training for beginners based on a new concept has thus been desired.

Recent developments in multi-detector computed tomography (MDCT) and its associated three-dimensional CT imaging (3D-CT) technology have contributed considerably to interventional radiology [14–16]. The authors in previous papers pointed out that the use of 3D-CT would give a first-hand understanding of the entire structure being evaluated, and that the location details could be identified by examining the original axial image. Ray-summation imaging, which is also known as a “virtual fluoroscopy imaging”, shows a projected image that is similar to digital radiography [17]. A ray-summation image is created from the signal values of the ray with the average value in the projection and is used in practice for the pre-procedural planning of percutaneous trans-hepatic biliary drainage and bronchoscopy for pulmonary peripheral lesions [15, 16]. These facts led us to the hypothesis that the ray-summation imaging could be applied to the puncture simulation training in PVP. We thus developed a vertebral needle targeting training system named spinal needling intervention practice using ray-summation imaging generated from MDCT data (SNIPURS).

Radiology trainees can undergo simulation training for the vertebral needle targeting on the SNIPURS system, using the workstation-generated spinal ray-summation images. Sufficient preoperative simulation training can improve the trainees’ skills without compromising patients’ safety and reduce the risk to patients undergoing PVP. We conducted the present study to assess the usefulness of the SNIPURS system as a preparatory training for PVP by evaluating changes in trainees’ learning curve.

Methods

Study design

This study was approved by the Ethics Review Committee of our hospital (approval no. NCGM-G-003447-00). Written informed consent was obtained from all of the examinees. Specifically, examinees decided to participate in this study on their own will after receiving an explanation of the content of this study and an explanation that they would not suffer unreasonable disadvantages by refusing to participate this study. The need for written informed consent from the patients whose anonymous MDCT data were used for the SNIPURS testing was waived.

A spinal ray-summation image of the patients

We first selected the patients whose MDCT data were used for the testing as follows. PVP was performed in 199 consecutive patients including 213 procedures in our hospital during the period from April 2014 to December 2017. Of those patients, we selected the thoraco-lumbar spine CT data of six patients based on the following criteria: (1) The target vertebra for the vertebral needle targeting simulation training test is limited to the 11th thoracic to 3rd lumbar vertebrae, where vertebral fractures were frequently encountered and treated with PVP [18]; (2) Genant classification [19] grade 2 (moderate) or 3 (severe) fractures were present in both the lumbar and thoracic vertebrae of a candidate patient; (3) Genant classification grade 1 (mild) fractures or grade 0 (unfractured) vertebra were present in both the lumbar and thoracic vertebrae. We included criterion (3) because most trainees were inexperienced in PVP and would benefit from training with a simple vertebra as well as deformed vertebrae for their training in vertebral needle targeting.

The characteristics of the selected patients and target vertebra were summarized in Table 1. The patients’ preoperative 1-mm thickness MDCT images were transferred

1. Introduction

Vertebral needle insertion is an important step in the percutaneous vertebroplasty (PVP) procedure. The common puncture route for PVP procedures is trans-pedicular from the dorsal region with the patient in the prone position [1]. The procedure with this route is inherently safe, because there are no other adjacent anatomical structures that can be damaged by the needle as long as its position is carefully selected. A dorsal puncture also allows compression hemostasis of a patient in the supine position after a PVP procedure to minimize postoperative bleeding. Punctures deviating from the trans-vertebral route can cause neurological damage or hemorrhagic complications [2–6], and an improper puncture can lead to an improper distribution of cement, that is, cement leakage to the outside of the vertebrae, which might result in serious complications [6–9].

Vertebral needle insertion is not always easily accomplished, as it is difficult to recognize and puncture the narrow pedicle of the vertebral arch in fluoroscopy [10–12]. Radiology trainees must learn the basic procedures and be given opportunities for intensive practice, although the available training period is limited and there are concerns about patient safety [13]. A new method of puncture training for beginners based on a new concept has thus been desired.

Recent developments in multi-detector computed tomography (MDCT) and its associated three-dimensional CT imaging (3D-CT) technology have contributed considerably to interventional radiology [14–16]. The authors in previous papers pointed out that the use of 3D-CT would give a first-hand understanding of the entire structure being evaluated, and that the location details could be identified by examining the original axial image. Ray-summation imaging, which is also known as a “virtual fluoroscopy imaging”, shows a projected image that is similar to digital radiography [17]. A ray-summation image is created from the signal values of the ray with the average value in the projection and is used in practice for the pre-procedural planning of percutaneous trans-hepatic biliary drainage and bronchoscopy for pulmonary peripheral lesions [15, 16]. These facts led us to the hypothesis that the ray-summation imaging could be applied to the puncture simulation training in PVP. We thus developed a vertebral needle targeting training system named spinal needling intervention practice using ray-summation imaging generated from MDCT data (SNIPURS).

Radiology trainees can undergo simulation training for the vertebral needle targeting on the SNIPURS system, using the workstation-generated spinal ray-summation images. Sufficient preoperative simulation training can improve the trainees’ skills without compromising patients’ safety and reduce the risk to patients undergoing PVP. We conducted the present study to assess the usefulness of the SNIPURS system as a preparatory training for PVP by evaluating changes in trainees’ learning curve.

Methods

Study design

This study was approved by the Ethics Review Committee of our hospital (approval no. NCGM-G-003447-00). Written informed consent was obtained from all of the examinees. Specifically, examinees decided to participate in this study on their own will after receiving an explanation of the content of this study and an explanation that they would not suffer unreasonable disadvantages by refusing to participate this study. The need for written informed consent from the patients whose anonymous MDCT data were used for the SNIPURS testing was waived.

A spinal ray-summation image of the patients

We first selected the patients whose MDCT data were used for the testing as follows. PVP was performed in 199 consecutive patients including 213 procedures in our hospital during the period from April 2014 to December 2017. Of those patients, we selected the thoraco-lumbar spine CT data of six patients based on the following criteria: (1) The target vertebra for the vertebral needle targeting simulation training test is limited to the 11th thoracic to 3rd lumbar vertebrae, where vertebral fractures were frequently encountered and treated with PVP [18]; (2) Genant classification [19] grade 2 (moderate) or 3 (severe) fractures were present in both the lumbar and thoracic vertebrae of a candidate patient; (3) Genant classification grade 1 (mild) fractures or grade 0 (unfractured) vertebra were present in both the lumbar and thoracic vertebrae. We included criterion (3) because most trainees were inexperienced in PVP and would benefit from training with a simple vertebra as well as deformed vertebrae for their training in vertebral needle targeting.

The characteristics of the selected patients and target vertebra were summarized in Table 1. The patients’ preoperative 1-mm thickness MDCT images were transferred
to a workstation (Synapse Vincent® software, Fujifilm Co., Tokyo, Japan) to generate the spinal ray-summation images.

**Examinees**

Since we could not find existing studies or tests that are similar to our present investigation, we could not properly estimate the statistical effect size to calculate the minimum sample size of examinees [20]. We thus sought to recruit at least three subjects in each group so that we could perform the Kruskal–Wallis test [21–23]. We enrolled seven experienced examinees (the expert group) and 14 trainees who were alternately assigned to two groups (coaching and non-coaching groups, n = 7 each). The members of the expert group were all radiologists, and seven of 14 trainees were medical interns and the others were radiological residents. Table 2 provided the profiles of the examinees in each group.

**Virtual PVP procedure and score evaluation**

A single trainer (F.U.) first explained the SNIPURS procedures to the examinee, including the imaging tools to zoom, rotate, and reset the view on the workstation with the computer mouse, using the spinal ray-summation image of Test 1. The examinee was not allowed to try to complete the pre-test examination, e.g., to point out the puncture site or obtain the result before starting the test described below.

The examinee then started the SNIPURS training as follows: (1) The examinee viewed the spinal ray-summation image from any directions using the mouse on the workstation (Fig. 1a–c), (2) selected a single-puncture view to perform puncturing on-end (which is called the bull’s-eye modification method [24]), (3) determined the position of the puncture point on that view (Fig. 1d), and (4) performed steps (1) to (3) to determine the puncture points and angles of the bilateral sides for two thoracic and two lumbar vertebrae with the trans-pedicular approach on the ray-summation images. After the selection of the puncture location, post-processing was conducted: a total of eight virtual needles (1 mm in diameter, 50 mm in length) were visualized with an excavation tool, and then the pathway of the puncturing needle was evaluated on the workstation (Fig. 1e). The examinee was not allowed to obtain the score result while performing SNIPURS.

Scores were given based on whether the puncturing needle’s pathway was inside or overlapped on the bone cortex of the vertebral pedicle (trans-pedicular route, 1 point), or outside the vertebral pedicle (non-trans-pedicular route, 0 points), which was evaluated by the trainer. Each examinee completed a total of six tests (Tests 1–6) with the highest possible score of 8 points on each test, and the learning curves for the average score of each of the three examinee groups was obtained.

**Coaching for technical development**

The coaching group received the coaching after Tests 1 and 4 by the trainer using the spinal ray-summation images of Tests 1 and 4. The ideal position of the needle was determined so that the needle could pass through the center of

### Table 1 The characteristics of the selected patients and target vertebra

| Test no. | Test1 | Test2 | Test3 | Test4 | Test5 | Test6 |
|----------|-------|-------|-------|-------|-------|-------|
| Level of target vertebra (Grading by Genant classification [17]) | T11(3) | T11(0) | T11(0) | T11(3) | T11(0) | T11(0) |
|          | T12(0) | T12(2) | T12(3) | T12(0) | T12(3) | T12(3) |
|          | L2(1)  | L2(3)  | L2(0)  | L1(3)  | L2(2)  | L2(0)  |
|          | L3(3)  | L3(0)  | L3(3)  | L2(0)  | L3(0)  | L3(2)  |

T thoracic vertebra, L lumbar vertebra

### Table 2 The profiles of the examinees for the three groups

| Item                        | Expert group | Coaching group | Non-coaching group |
|-----------------------------|--------------|----------------|--------------------|
| Number of examinee          | 7            | 7              | 7                  |
| Radiologist                 | 7            |                |                    |
| Radiological resident       |              | 3              | 4                  |
| Medical intern              |              | 4              | 3                  |
| Age: average years (range)  | 42 (32–54)   | 27 (25–32)     | 28 (25–36)         |
| Sex: M/F                    | 5/2          | 4/3            | 6/1                |
| Years of experience as a medical doctor: median (range) | 18 (8–30) | 3 (1–8) | 4 (1–12) |
| Months of PVP experience: median (range) | 55 (24–204) | 0 (0–10) | 0 (0–10) |
the vertebral arch and the tip of the needle could reach the anterior third of the vertebral body. The coaching is as follows: (1) The trainer put two dot marks in the center of the pedicle arch and in the ideal tip of the puncture needle on the ray-summation image (Fig. 2a). (2) The trainees confirmed the dot marks on the axial 2D-CT, coronal 2D-CT, and ray-summation images. (3) The trainee rotated the ray-summation image until the two marks overlapped (Fig. 2b–d). The trainee was then able to understand which working angle was the best for the puncture.

**Evaluation items and statistical analyses**

We evaluated if the examinees accomplished the following three qualifying scores: (1) To determine that SNIPURS depended on the operator’s PVP experience and was suitable for vertebral needle targeting training, the expert group would achieve the highest scores among the three groups, which was assessed using the intergroup comparisons. (2) To determine that the coaching was effective, the individual coaching group should get the post-coaching scores better than the pre-coaching scores and should catch up with the expert group for the scores by the final Tests 6, which was evaluated using the intragroup comparisons. In addition, we performed an intergroup comparison between the coaching group and the non-coaching group because it could be predicted that score would increase step by step without any coaching. (3) We required all three groups of examinees to reach a perfect score by Test 6.

The intergroup comparisons among the three groups for each test and the intragroup comparisons among the six tests of each group were performed using the Kruskal–Wallis test and Scheffe’s post hoc test combined with the Bonferroni correction (nine comparisons). The significance level was set to 0.05. The statistical analyses were properly performed using Excel 2013 (Microsoft, Seattle, WA) with the add-in software Statcel-3 [23].
Results

Figure 3 depicts the learning curve of average scores and the results of the intragroup comparisons among the 3 groups. All groups showed an increase in the average scores. Average (median/range) scores for Test 1 to 6 were 3.86 (3/1–7), 6.57 (7/7–8), 7.43 (7/7–8), 7.57 (8/7–8), and 8.00 (8/8–8) in the expert group, 1.86 (2/0–3), 6.14 (7/4–8), 6 (7/3–8), 6.29 (6/4–8), 7.86 (8/7–8), and 8.00 (8/8–8) in the coaching group, 1.14 (1/0–3), 4.14 (3/2–8), 4.71 (4/2–8), 4.86 (5/1–7), 5.86 (7/2–8), and 7.14 (8/5–8) in the non-coaching group, respectively. On the other hand, the intergroup comparisons for each of the six tests revealed no significant difference.

(1) The expert group had the highest scores among the three groups

The expert group had the highest SNIPURS score of the three groups. The intragroup comparisons identified significant differences within the expert group for Test 1 versus (vs.) Test 3 ($p = 0.002$), Test 1 vs. Test 4 ($p = 0.001$), Test 1 vs. Test 5 ($p < 0.001$), and Test 1 vs. Test 6 ($p < 0.001$).

(2) The coaching group had the post-coaching scores better than the pre-coaching scores and caught up with the expert group for the scores by the final Test 6.

In the coaching group, the Test 2 scores performed after the first coaching were significantly higher than the Test 1 scores ($p = 0.001$), and their Test 5 scores performed after the second coaching were better than their Test 4 scores and caught up with the expert group’s Test 5 scores. The intragroup comparisons of Test 4 vs. 5 scores within the coaching group did not reveal a significant difference. The intergroup comparisons in Test 2 or Test 5 between the coaching group and
the non-coaching group also did not show the significant difference.

(3) The non-coaching group could not reach a perfect score by the final Test 6.

All of the examinees in the expert and coaching groups got a perfect score (8 points) on Test 6, whereas only three of the seven trainees in the non-coaching group achieved a perfect score on Test 6. However, significant differences in the non-coaching group were shown by the intragroup comparisons of Tests 1 vs. Test 5 ($p = 0.045$) and Test 1 vs. Test 6 ($p = 0.002$). The average score of the non-coaching examinees never caught up with those of the expert or coaching groups.

Discussion

3D imaging techniques enable a quick perception of entire structures [14], and the details of various positions can be obtained by examining the original images or multiplanar reconstruction (MPR) images. Kinoshita et al. evaluated the usefulness of virtual fluoroscopy-based pre-procedural planning in the percutaneous trans-hepatic biliary drainage procedure, and they concluded that intraoperative referencing using virtual fluoroscopy imaging shortens the X-ray fluoroscopy time and within-procedure times [15]. An accurate and safe method for performing PVP under 3D radiography guidance generated by cone-beam CT using angiographic equipment has also been reported [11]. These 3D imaging techniques are useful for treating patients, and they can be applied to training as well. Our SNIPURS training procedure may be a useful tool for trainees to learn a procedure on a workstation without risking a patient’s safety.

In the present assessment of the utility of SNIPURS, we emphasized the following points. We speculated that since SNIPURS should be a training system for spinal puncture in PVP, PVP experts with the considerable experience who had no coaching should be able to score higher than other
trainees. We also felt that successful trainees must achieve the same score as the experts by the time they completed the SNIPURS training, because a failure to puncture the vertebral body must be avoided in PVP in practice. Therefore, the coaching was preferable for trainees to learn the vertebral needle targeting efficiently. The learning curves of the expert, non-coaching, and coaching groups in this study could be regarded as the reference standard for (i) clinicians who are experienced in performing PVP and take the SNIPURS test, (ii) beginners who need to increase their degree of proficiency, and (iii) beginners whose scores on the SNIPURS test could improve with coaching, respectively. Our results will provide important data when SNIPURS is used as an instructional approach for PVP.

In the expert group, the significant differences were seen in Tests 1 vs. 3, Tests 1 vs. 4, Tests 1 vs. 5, and Tests 1 vs. 6, suggesting that a significant scoring ability for this simulation test can be obtained after just Tests 1 and 2. Ideally, the PVP experts should have achieved high scores on Tests 1 and 2 as well. Low score on those tests in this study may suggest that preliminary experience was still required to become accustomed to SNIPURS even in the expert group. An additional reason for the experts’ initial low scores could be that SNIPURS used the single-puncture view. The puncture direction is determined using a biplane view in most facilities. SNIPURS with a single-puncture view might be difficult for experts who have usually performed vertebral needle targeting with the isocenter puncture (ISOP) method [10], cathelin needle-assisted puncture (CAP) method [25], or the angle fixation method [26]. Nevertheless, the experts obtained the highest scores of the three groups on each test and got a perfect score on Test 6 with no coaching.

The expert group tended to have higher scores than the coaching and non-coaching groups, especially on Test 1, which suggests that the ability of the coaching and non-coaching groups to grasp SNIPURS the first time tended to be lower than that of the expert group. However, the between-group differences did not reach significance, perhaps because the expert group did not acquire the ideal high scores (from the first Test) as mentioned above.

Among the examinees who received coaching, a significant increase in score was observed for Test 2 (after the first coaching). In addition, after the second coaching (post-Test 4), the coaching group’s average score on Test 5 caught up with that of the expert group. All of the examinees who received coaching achieved the perfect score of 8 points on Test 6, and thus the learning mission in SNIPURS was completed with two brief coaching sessions.

Among the examinees of the non-coaching group, a significant increase in score was observed for both Test 5 and Test 6 compared to the score on Test 1; that is, no significant learning results were obtained from Tests 1 to 4. This result may indicate that the learning curve in the non-coaching group tended to increase slowly. In addition, there were 3 trainees in the non-coaching group who did not reach the perfect 8-point score on Test 6, suggesting that they might need to take further simulation training.

Based on the results of this study, we reached the conclusion that SNIPURS with two coaching sessions can be recommended to successfully help trainees effectively acquire a precise perception of spinal puncture techniques in PVP. Losch et al. made a similar proposal: that coaching creates a high degree of satisfaction and is superior in helping participants attain their goals, whereas the absence of coaching and other support from a trainer is not sufficient for high goal attainment [27].

There are some limitations to our investigation. The sample size of examinees (n = 7, each group) and the test samples were insufficient. Our results also do not fully demonstrate that SNIPURS for learning vertebral needle targeting is actually useful for trainees to master needle puncture techniques. Further research is necessary to confirm and advance our present simulation training study.

In conclusion, we evaluated the vertebral needle targeting simulation training system SNIPURS for clinicians’ preparation to perform the PVP procedure. SNIPURS might be suitable for vertebral needle targeting training. The provision of coaching during SNIPURS trainees helped the trainees acquire the spinal puncture techniques used in PVP.

Acknowledgements This work was supported in part by Department of Clinical Research, National Hospital Organization Kyushu Medical Center.

Author contributions TN; data analysis, paper writing, corresponding author. KY; paper correction. YS; data collection. TO; data collection. RK; data collection. JM; paper correction. TT; supervision.

Funding No funding.

Declarations Conflict of interest The authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. No potential conflict of interest was reported by the authors.

Ethical statement This study was approved by the Ethics Review Board of our hospital, which waived the need for written informed consent from the patients.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated
otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

1. Mathis JM, Deramond H, Belkoff SM. Percutaneous vertebroplasty and kyphoplasty. New York: Springer; 2006.
2. Tropeano MP, La Pira B, Pescatori L, Piccirilli M. Vertebroplasty and delayed subdural cauda equina hematoma: review of literature and case report. World J Clin Cases. 2017;5(8):333–9.
3. Giordano AV, Arrigoni F, Bruno F, Carducci S, Varrassi M, Zagarolo L, et al. Interventional radiology management of a ruptured lumbar artery pseudoaneurysm after cryoablation and vertebroplasty of a lumbar metastasis. Cardiovasc Intervent Radiol. 2017;40(5):776–9.
4. Puri AS, Colen RR, Reddy AS, Groff MW, DiNobile D, Killoran T, et al. Lumbar artery pseudoaneurysm after percutaneous vertebroplasty: a unique vascular complication. J Neurosurg Spine. 2011;14(2):296–9.
5. Umeda A, Saeki N, Matsumoto C, Nakao M, Kawamoto M. Abdominal aortic injury during vertebroplasty. Spine (Phila Pa 1976). 2015;40(7):E439–41.
6. Baumann C, Fuchs H, Kiwitt J, Westphalen K, Hierholzer J. Complications in percutaneous vertebroplasty associated with puncture or cement leakage. Cardiovasc Intervent Radiol. 2007;30(2):161–8.
7. Hadjipavlou AG, Tzermiadianos MN, Katonis PG, Szpalski M. Percutaneous vertebroplasty and balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures and osteolytic tumours. J Bone Jt Surg Br. 2005;87(12):1595–604.
8. Hariri O, Takayanagi A, Miulli DE, Siddiqi J, Vrionis F. Minimally invasive surgical techniques for management of painful metastatic and primary spinal tumors. Cureus. 2017;9(3):e1114.
9. Shaibani A, Ali S, Bhatt H. Vertebroplasty and kyphoplasty for the palliation of pain. Semin Intervent Radiol. 2007;24(4):409–18.
10. Takizawa K, Yoshishitsu M, Nakajima Y, Sakaino S, Yagihashi K, Ogawa Y, et al. Development of a new support method for transpedicular punctures of the vertebral body: the isocenter puncture method. Cardiovasc Intervent Radiol. 2007;30(4):757–60.
11. Tenjin H, Mandai A, Umebayashi D, Yamamoto S, Osaka Y, Nakahara Y, et al. Percutaneous vertebroplasty under three-dimensional radiographic guidance. Technical note. Neurol Med Chir (Tokyo). 2009;49(4):179–83 (discussion 83).
12. Ali S, Qandeel M, Ramakrishna R, Yang CW. Virtual simulation in enhancing procedural training for fluoroscopy-guided lumbar puncture: a pilot study. Acad Radiol. 2018;25(2):235–9.
13. Yamagami T, Hasebe T, Yoshimatsu R, Matsumoto T, Hashimoto T, Komemushi A, et al. Training on insertion and retrieval of optional inferior vena cava filters for interventional radiologists with little or just some experience with the combined use of blood vessel and animal models. Springerplus. 2013;2:354.
14. Karatas OH, Toy E. Three-dimensional imaging techniques: a literature review. Eur J Dentistry. 2014;8(1):132–40.
15. Kinoshita M, Shirono R, Takeuchi K, Yonekura H, Iwamoto S, Shinya T, et al. The usefulness of virtual fluoroscopic preprocedural planning during percutaneous transhepatic biliary drainage. Cardiovasc Intervent Radiol. 2017;40(6):894–901.
16. Fukusumi M, Ichinose Y, Arimoto Y, Takeoka S, Homma C, Matsuoka H, et al. Bronchoscopy for pulmonary peripheral lesions with virtual fluoroscopic preprocedural planning combined with EBUS-GS: a pilot study. J Broncho Interv Pulmonol. 2016;23(2):92–7.
17. Suzuki S, Ichikawa K, Tamaki S. Image quality and clinical usefulness of ray-summation image reconstructed from CT data, compared with digital radiography. Nihon Hoshasen Gijutsu Gakkai Zasshi. 2017;73(5):372–81.
18. Kobayashi N, Noguchi T, Kobayashi D, Saito H, Shimojaya K, Tajima T, et al. Safety and efficacy of percutaneous vertebroplasty for osteoporotic vertebral compression fractures: a multicenter retrospective study in Japan. Interv Radiol. 2021;6(2):21–8.
19. Genant HK, Wu CY, van Kuik C, Nevitt MC. Vertebral fracture assessment using a semiquantitative technique. J Bone Miner Res. 1993;8(9):1137–48.
20. Serdar CC, Cihan M, Yücel D, Serdar MA. Sample size, power and effect size revisited: simplified and practical approaches in pre-clinical, clinical and laboratory studies. Biochem Med (Zagreb). 2021;31(1):010502.
21. Fan C, Zhang D, Zhang CH. On sample size of the kruskal-wallis test with application to a mouse peritoneal cavity study. Biometrics. 2011;67(1):213–24.
22. Morgan CJ. Use of proper statistical techniques for research studies with small samples. Am J Physiol Lung Cell Mol Physiol. 2017;313(5):L873–7.
23. Yani H. Statcel-the useful addin forms on excel. 3rd ed. Tokorozawa: OMS Publications; 2011. (in Japanese).
24. Appel NB, Gilula LA. “Bull’s-eye” modification for transpedicular biopsy and vertebroplasty. AJR Am J Roentgenol. 2001;177(6):1387–9.
25. Noguchi T, Shida Y, Okafuji T, Kamei S, Yokoyama K, Uchiyama F, et al. Safety and efficacy of percutaneous vertebroplasty in lateral decubitus position: a retrospective evaluation. Interv Radiol. 2018;3(3):115–20.
26. Gertzbein SD, Robbins SE. Accuracy of pedicular screw placement in vivo. Spine (Phila Pa 1976). 1990;15(1):11–4.
27. Losch S, Traut-Mattausch E, Muhlberger MD, Jonas E. Comparing the effectiveness of individual coaching, self-coaching, and group training: how leadership makes the difference. Front Psychol. 2016;7:629.