IN VIVO *39*: 713-723 (2025)
doi: 10.21873/invivo.13875

Cervical Selective Nerve Root Block: Three-dimensional Puncture Planning With Dyna-CT Is Superior to Conventional CT-guidance in an *Ex Vivo* Model

SEBASTIAN SCHNEIDER[1*], HANS ULRICH KERL[1*], MIRIAM FREUNDT[2], KATRIN E. HERRMANN[1], CHRISTOPH GRODEN[1], MÁTÉ E. MAROS[1,3] and SHERIF A. MOHAMED[1]

[1]Department of Neuroradiology, University Medical Center Mannheim, University of Heidelberg, Mannheim, Germany;
[2]The Christ Hospital Health Network, Department of Cardiac Critical Care, Cincinnati, OH, U.S.A.;
[3]Department of Biomedical Informatics at the Mannheim Institute for intelligent Systems in Medicine (MIISM), Medical Faculty Mannheim, Heidelberg University, Mannheim, Germany

Abstract

Background/Aim: Cervical selective nerve root block (CSNRB) is a widely used percutaneous procedure to diagnose and treat cervical radicular pain. The feasibility of a three-dimensional puncture planning and two-dimensional laser-guidance system has previously been shown in an *ex vivo* model. The purpose of this study was to further compare this technique to the conventional computed tomography (CT-)-guided approach.

Materials and Methods: Thirty CSNRBs were performed, each with Dyna-CT and the Syngo iGuide® laser-guidance system (Artis Zee® Ceiling, Siemens Medical Solutions, Erlangen, Germany), and with conventional CT-guidance (Somatom Volume Zoom, Siemens Healthcare, Erlangen, Germany) in an *ex vivo* lamb model. The number of puncture attempts, procedural planning time, puncture time, and trajectory length were evaluated and compared.

Results: All 60 punctures were rated as successful. Significantly less puncture attempts were needed with Dyna-CT compared to conventional CT-guidance (p<0.0001). Procedural planning time and puncture time were significantly shorter with Dyna-CT ($p_{plan.t}$<0.0001 and $p_{punc.t}$=0.0004) (median 77 s and 56 s, respectively) than with conventional CT-guidance (median 109 s and 159.5 s, respectively), There were no significant differences in trajectory length (Dyna-CT median 3.18 cm; conventional CT median 3.33 cm, p=0.651).

*These Authors contributed equally to this work.

Sherif A. Mohamed, Department of Neuroradiology, University Medical Center Mannheim, Medical Faculty Mannheim, University of Heidelberg, Theodor-Kutzer-Ufer 1-3, 68167 Mannheim, Germany. Tel: +49 6213832443, Fax: +49 6213832165, e-mail: sherif.mohamed@umm.de

Received December 19, 2024 | Revised January 8, 2025 | Accepted January 9, 2025

Conclusion: Dyna-CT with Syngo iGuide® laser-guidance is superior to conventional CT-guidance for CSNRB in an *ex vivo* model. It significantly shortens the overall procedure time by reducing planning time, puncture time, and puncture attempts.

Keywords: Cervical selective nerve root block, Dyna-CT, CT-guidance, laser-guidance, interventional radiology, cervical radiculopathy, procedural time, *ex vivo* model, spinal intervention, fluoroscopy.

Introduction

Cervical radicular pain is a disabling condition that occurs in approximately 0.8 to 1.8 per 1,000 persons per year (1-3). Patients often present with neck pain, numbness and/or paresthesia in arms and fingers with or without motor weakness. Symptoms often correspond to the dermatomes involved. The most common etiology of cervical radiculopathy is root compression due to narrowing of the foraminal space secondary to spondylarthrosis (1), followed by cervical disc herniation (2). Cervical spine surgery is the last option if conservative treatment has failed (4). However, in the majority of patients spontaneous recovery over time is seen (3, 5). As a minimally invasive, percutaneous procedure, cervical selective nerve root block (CSNRB) is well-established to treat cervical radiculopathy by selective injection of local anesthetics and steroids in the neural foramen and into the periradicular space. This can block the production of phospholipase A, a transmitter in perineural inflammation, which is responsible for the perception of pain. Furthermore, it can reduce the activity of C-fibers, decreasing transmission of pain impulses to the central nervous system. Moreover, it can achieve inhibition of an increased endoneural vascular permeability, that is associated with increased pain (6-8). In 60-90% of cases of herniated discs the disc material will be reabsorbed and symptoms will resolve spontaneously with time (6). Especially in cervical radiculopathy caused by disc herniation, CSNRB can relief pain as a bridge until the extruded disc has shrunk. Despite these therapeutic options, CSNRB can be used diagnostically in cases of diffuse spinal stenosis or multiple disc herniations to locate the affected nerve root more precisely.

Initially CSNRB was performed simply by using palpable anatomical landmarks. Today the use of imaging guidance with ultrasound, fluoroscopy, computed tomography (CT), or CT fluoroscopy is standard. Major devastating post-procedural (neurological) complications, including brain stem, cerebellar and spinal cord infarction, can occur (6, 9-12). These complications are mostly caused by accidental injection into the radicular artery. Imaging guidance reduces those complications by providing accurate visualization of surrounding soft tissue, blood vessels, and localization of the needle tip.

With technical improvement new imaging techniques are becoming available for three-dimensional puncture planning and two-dimensional laser-guided needle control. Our research group previously published the feasibility of CSNRB with Dyna-CT and Syngo iGuide® in an *ex vivo* lamb model. In our previous article, we showed that Dyna-CT and Syngo iGuide® provide detailed three-dimensional puncture planning and accurate and intuitive two-dimensional laser-guided puncture control (13).

The purpose of this study was to further compare Dyna-CT and Syngo iGuide® to conventional CT-guidance for CSNRB in an *ex vivo* lamb model.

Materials and Methods

*Ex vivo lamb model. T*his cadaveric study was performed according to our institutional guidelines for cadaver work. In this study, human cervical spine anatomy was resembled with the same lamb neck model with paravertebral tissue including autochthonous back muscles (1.5 kg). The lamb model was received from a local slaughterhouse (Yalya, Mannheim, Germany), with verbal consent to use it for this study. In our study, the lamb spine was placed in prone position on the intervention table with cellophane wrap for hygiene reasons.

Imaging systems. All procedures were performed with the Dyna-CT (Siemens Medical Solutions, Erlangen, Germany), a ceiling mounted flat-panel detector-based 3D imaging system along with the Syngo iGuide® software. In addition, punctures were performed with a conventional computed tomography scanner (Somatom Volume Zoom, Siemens Medical Solutions).

Dyna-CT and Syngo iGuide®. The Dyna-CT consists of an Artis Zee® Ceiling (Siemens Medical Solutions) and a free-floating full-carbon intervention table that allows for supine and prone position of the patient or model. The 40×30 cm flat panel detector and C-arm are completely free moveable in all directions around the intervention table.

We used the dedicated program Syngo iGuide® (Siemens Medical Solutions) for puncture planning and puncture performance. The imaging field was 48 cm to optimize the visualization of the spine. The rotation time (for Dyna-CT) was 8 s acquiring 60 frames per second. Source power was 90 kVp. The images were transmitted to a local workstation (Leonardo, Siemens Medical Solutions) equipped with the software MMWP VE 40A 3D for 3D rendering and post-image processing. From the acquired data set, slice image reconstructions and a 3D model with a matrix of 512×512×512 was generated in 48 s, which was displayed in 2D (Multiplanar Reformat, MPR) with a voxel matrix of 512×512 and a slice thickness of 3 mm. Syngo iGuide® offers detailed 3D-pre-puncture planning and 2D-laser guidance of the needle during the puncture. It clearly displays the length and the angulation of the needle path and automatically positions the C-arm for planning of the needle trajectory. The integrated laser crosshair is projected onto the skin and indicates the entry point and the angle of the needle. It allows accurate and safe needle guidance with the possibility to overlay on to live fluoroscopy.

In a first step, a full series of CT-like slice images with multiplanar reconstructions was obtained. Skin entry site and puncture target point were marked in the reconstructed slice images of the spine (axial, coronal and sagittal view) by the investigator at the computer workstation, avoiding interference of the needle path with soft tissue structures such as vessels, vital organs, or glands. The distance between the puncture target point and the desired point for skin entry resembled the depth of needle insertion. Syngo iGuide® subsequently provided three different views of the planned puncture, including a so-called bull eyes view, an oblique and a lateral view with different angles, in which the generated access path had to be approved by the investigator. After approval, the puncture was performed at the intervention table. The best way to start the puncture is to bring the bulls eye view with the laser pointer system marking the previously planned puncture site with a 2D laser cross on the model. By keeping this laser cross permanently in line while inserting the needle (BD Quincke Spinal Needle, 20GA, 3.00 IN, 0.9×75 mm, Beton Dickinson GmbH, Heidelberg, Germany), the needle tip automatically follows the previously planned puncture channel. By knowing the distance between skin entry site and puncture target point, the investigator could estimate the depth of the needle insertion. Supposed to be at the target point, the investigator acquired fluoroscopic images in three different angles (bulls eye view, oblique and lateral view). After confirming the correct position of the needle tip in all three above-mentioned planes, the investigator injected 1 ml of CT contrast dye (Imeron 300, Bracco Imaging, Konstanz, Germany), and obtained an additional series of fluoroscopic control images (Figure 1).

Conventional CT-guidance. We used a Somatom Volume Zoom (Siemens Medical Solutions) multislice scanner. The model featured 500 ms rotation time, a 60 kW generator and was able to obtain 160 slices in 20 s breath holds.

A radio-opaque marker was placed on the skin at the indicated level. The target area was identified on a lateral scout image, and CT-images with 2.5 mm slices were obtained through the desired cervical nerve root foramen.

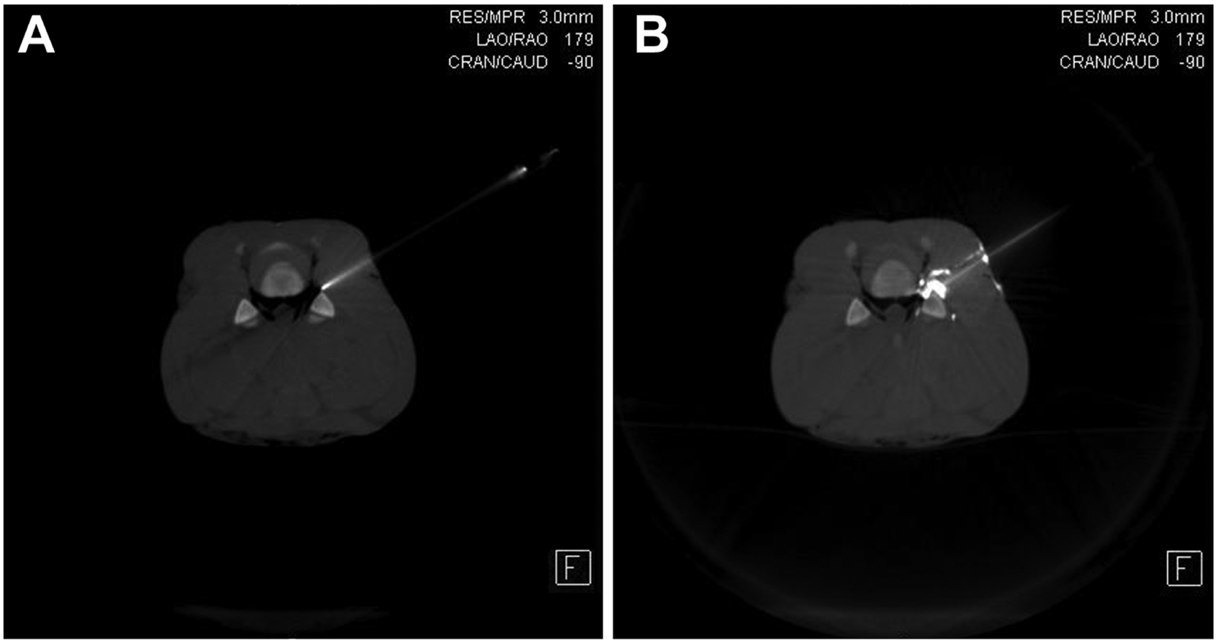

Figure 1. *Post-puncture control Dyna-CT images. A) Needle tip position in the axial view of the multiplanar reconstructions. The needle tip is located in the posterior part of the neural foramen. B) Control image of contrast dye distribution. The contrast dye spreads in the ipsilateral nerve root foramen and into the periradicular space.*

At the computer workstation (Leonardo, Siemens Medical Solutions) the investigator marked entry site and puncture target point in the axial slice images of the spine, avoiding interference of the needle path with soft tissue structures such as vessels, vital organs, or glands. The distance between the puncture target point and the planned point of skin entry allows for estimation of the depth of needle insertion. The skin entry site was then marked, and the puncture was performed with the aid of the integrated laser system. Differently from the Syngo iGuide®, it just marks the slice or spine level at which the puncture is planned. However, the lateral puncture angle has to be estimated by the interventionalist. Therefore, the system only provides static 1D visualization and no real-time imaging. When assumed to be at the target point, control CT-images were obtained to validate correct needle tip position in the nerve root foramen. Then, 1 ml of CT contrast dye (Imeron 300, Bracco Imaging) was injected, followed by an additional series of CT (control) images (Figure 2).

Procedural analysis. Two authors performed 30 independent punctures of random cervical nerve roots ranging from C2/C3 to C5/C6 bilaterally, fifteen punctures each with Dyna-CT and fifteen with conventional CT-guidance.

Each puncture was planned separately. Planning and puncture time were recorded manually with a stopwatch. Tract length, fluoroscopy time, and dose area product (DAP), or dose length product (DLP), were acquired from the exam protocol. DAP/DLP was measured for the entire procedure including planning scan, and separately for fluoroscopic controls only. Planning time was defined as time needed from placing the first mark at the workstation until adjustment of the intervention table. Puncture time was defined as time from first needle skin contact until confirmation of successful placement of the needle tip at the nerve root either in fluoroscopic images using Dyna-CT in the three above-mentioned planes or using CT control images. Correct needle position was defined as location of the needle tip in the nerve root foramen and was analyzed visually by both investigators independently.

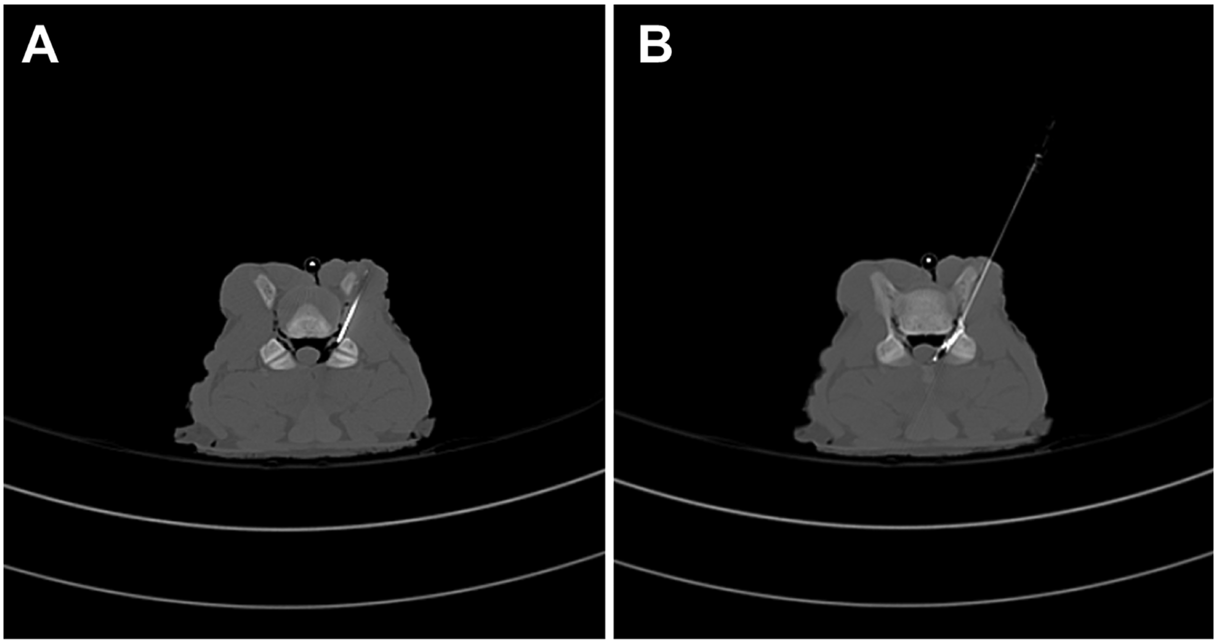

Figure 2. *Post-puncture control CT images. A) Axial CT image to verify needle tip position. The needle tip is located in the posterior part of the neural foramen. B) Control image after contrast dye injection.*

Statistical analysis. The statistical analyses were descriptive and performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). We used mixed linear models (MIXED procedure using unstructured covariance), which provide the flexibility of modelling the means, the variances, and covariances of correlated data arising from repeated measurements (14). We defined puncture time as the primary and number of (missed) attempts as the secondary outcome parameters. Units of measurement were the punctured cervical segments (8; both left and right). We considered each intervention of a given segment and side as an independent measurement, which was nested under the investigator [levels: experienced (HUK); unexperienced (MF)]. Investigators were crossed with device type (levels: Dyna-CT with Syngo iGuide® or conventional CT). Planning time and tract length were included as covariates into the model. We adjusted for possible interaction between investigators and device types (15).

Number of (missed) attempts intuitively showed a highly right skewed distribution, resembling the Poisson distribution. Thus, initially we applied generalized estimating equations (GEE) to fit the above model (GENMOD procedure). However, it showed convergence problems. Therefore, we limited the model to device type, user, and their interaction. To check the stability of the results, we also used robust nonparametric method (ANOVA F statistics with unstructured covariance) on the limited model (*p*-values are reported) (16). To assess the association between number of attempts and puncture time, the Spearman's rank correlation analysis was used.

Results were visualized using the ggplot2 package in R [version 3.2.2; R Core Team (2015); R: A language and environment for statistical computing; R Foundation for Statistical Computing, Vienna, Austria; http://www.R-project.org].

The distributions of the variables were provided as median with interquartile range (IQR). $p<0.05$ were considered statistically significant. Due to the explorative-experimental nature of our study, *p*-values were not adjusted for multiple testing (15).

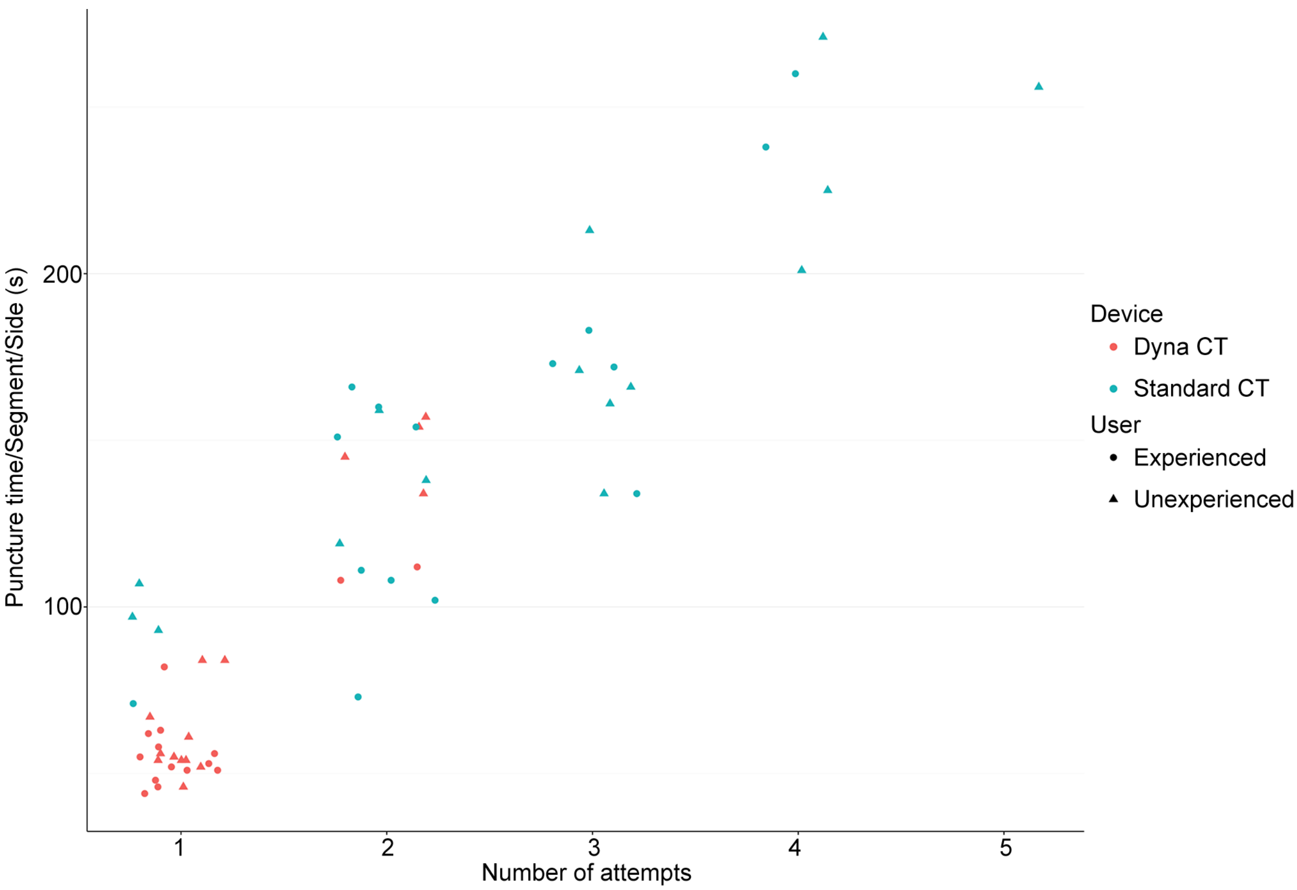

Figure 3. *Scatterplot of number of attempts versus puncture time on pooled. data. Puncture time and number of attempts have a statistically significant correlation ($rho_{Spearman}$=0.91, F=232.31, df=58, p<0.0001). The scatterplot shows that both users had a substantially shorter puncture time ($p_{ANOVA\ F}$<0.0001) and lower number of attempts using Dyna-CT (red dots) compared to standard CT (green dots). Circles and triangles represent the measurements of an experienced and an unexperienced user ($p_{ANOVA\ F}$=0.8365), respectively. There was no relevant interaction between device type and user ($p_{ANOVA\ F}$=0.5924). Random noise was added along the x-axis to reduce the number of overlaying points.*

Results

All 60 CSNRBs with Dyna-CT and Syngo iGuide® and with conventional CT were rated as successful by two independent investigators.

Distributions of the modelled parameters. Pooling all puncture times over user and device type, it showed a right skewed distribution (mean=116.1 s; median=107.5 s, LQ=56.0 s, UQ=159.2 s, IQR=103.2 s). Puncture time of Dyna-CT was substantially shorter ($median_{pooled\ user}$=56 s, range=44-157 s, LQ-UQ: 52.25-83.5 s, IQR=31.25 s) compared to conventional CT ($median_{pooled\ user}$=159.5 s, range=71-271 s, LQ-UQ: 113-180.5 s, IQR=67.5 s) for both users (Figure 3 and Figure 4B).

Procedural planning time pooled over users with Dyna-CT was in median 77 s (range=52-178 s, LQ-UQ: 67-110.25 s, IQR=43.25 s) and 109s with standard CT (range=88-149 s, LQ-UQ: 101-118.2 s, IQR=17.2 s).The number of attempts presented a highly right skewed distribution (resembling the Poisson distribution; Figure 4A) with one (n=28, 46.7%) and two (n=17, 28.3%) attempts being sufficient in 75% of the cases.

The length of puncture trajectory showed a biphasic distribution within a narrow range of 2.9-3.6 cm ($median_{pooled}$=3.3 cm; LQ-UQ: 3.1-3.4 cm, IQR=0.31 cm).

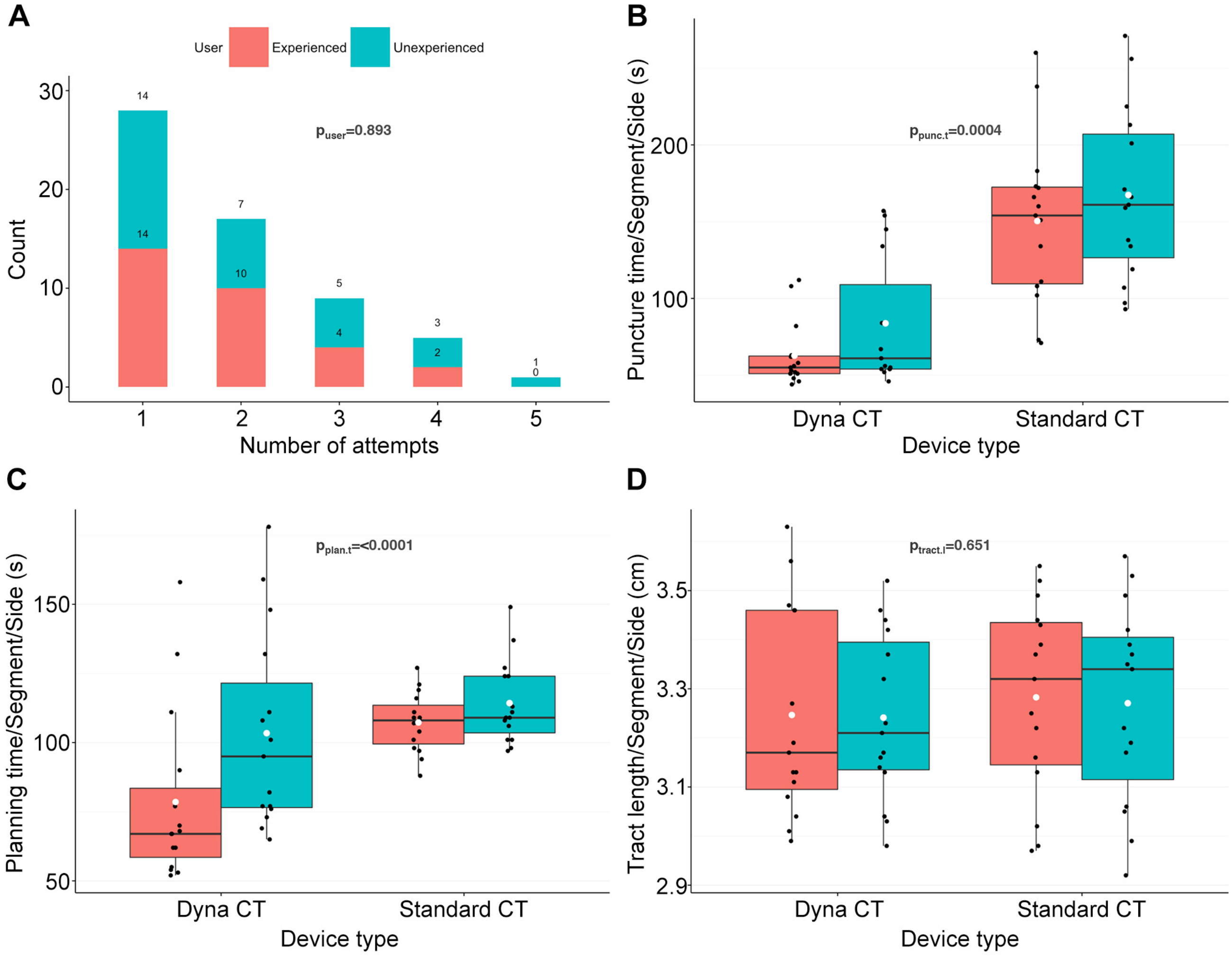

Figure 4. *Combined histogram and boxplots of number of attempts, puncture- and planning time, and trajectory length versus device type and investigator. A) Histogram of number of attempts colored according to users (orange: experienced, green: unexperienced). There was no relevant difference between the number of attempts and level of user experience in the model (*p_{user}*=0.893). Boxplots of puncture time (B), planning time (C), and tract length (D) for each level and side of cervical segment comparing device types and users. The horizontal lines and the white points represent the median and mean values, respectively. Single measurements (n=2×2×15=60) are plotted as black dots. Dyna-CT showed a significantly shorter puncture time (B; *$p_{punc.t}$*=0.0004) and planning time (C; *$p_{plan.t}$*<0.0001). Puncture time with standard CT had a higher variance, whereas it was higher for planning time with Dyna-CT. Tract lengths are not different between devices (*$p_{tract.l}$*=0.651). Random noise was added along the x-axis (i.e., measurement values stayed intact) to reduce the number of overlaying points.*

Similarly, the covariate planning time showed a two-peaked distribution with $\text{median}_{\text{pooled}}$ of 102.5 s (range= 52-178 s, LQ-UQ: 77-113.8 s, IQR=36.8 s).

Number of attempts versus device type and user experience. There was an obviously high association between the number of attempts and the puncture time (Figure 3; Spearman's rho=0.91, F=232.31, df=58, p<0.0001 – results on pooled data independent from user or device type).

Both investigators had a substantially lower number of attempts ($p_{\text{ANOVA F}}$<0.0001) when using Dyna-CT compared to conventional CT, without significant difference between users ($p_{\text{ANOVA F}}$=0.8365) or interaction between device type and investigator ($p_{\text{ANOVA F}}$=0.5924). The latter finding supports that the effect magnitude based on user's training status is consistent.

In detail: both investigators independent from the CT-device performed successful CSNRB in 46.67% of cases on first attempt (14/30). The experienced user (HUK) was successful in 80% of punctures [(14+10)/30] on second attempt. The unexperienced user (MF) in 70% [(14+7)/30]. If we further differentiate based on device type (Dyna-CT or conventional CT), both experienced and unexperienced users had significantly higher "hit rates" on first attempt using Dyna-CT: (HUK) 86.7% (13/15 *vs.* conventional CT: 1/15) and (MF) 73.3% (11/15 *vs.* conventional CT: 3/15). As expected, using conventional CT, the trained user needed a smaller number of maximum attempts for success (4 *vs.* untrained: 5) and a higher success rate at each attempt level (Figure 4A).

Puncture time versus device type and user experience. We recorded a statistically significant ($p_{punc.t}$=0.0004) shorter puncture time with Dyna-CT *versus* conventional CT (Figure 4B). In detail: using Dyna-CT, the experienced user achieved a successful CSNRB in a median=55 s (range=44-112 s, LQ-UQ: 51-62.5 s, IQR=11.5 s), and the untrained user in 61 s (range=46-157 s, LQ-UQ: 54-109 s, IQR=55 s). Whereas with conventional CT guidance, the trained user needed a median of 154 s (range=71-260 s, LQ-UQ: 109.5-172.5 s, IQR=63s), and the untrained user 161s (range=93-271 s, LQ-UQ: 126.5-207 s, IQR=80.5 s).

Also, planning time was significantly shorter ($p_{plan.t}$< 0.0001) for both investigators using Dyna-CT (experienced: median=67 s, range=52-158 s, LQ-UQ: 58.5-83.5 s, IQR=25 s; unexperienced: median=95 s, range= 65-178 s, LQ-UQ: 76.5-121.5 s, IQR=45 s), compared to conventional CT (experienced: median=108 s, range=88-127 s, LQ-UQ: 99.5-113.5 s, IQR=14 s; unexperienced: median=109 s, range=97-124 s, LQ-UQ: 103.5-114.3 s, IQR=8.8 s).

Puncture time had a higher variance when using conventional CT, but planning time had larger variance using Syngo iGuide® (Figure 4B and C).

The covariate trajectory length showed no relevant difference in our model ($p_{tract.l}$=0.651) using Syngo iGuide® (pooled over users: median=3.18 cm, range=2.98-3.63 cm, LQ-UQ: 3.11-3.44 cm, IQR=0.33 cm) compared to conventional CT (pooled over users: median=3.33 cm, range=2.92-3.57 cm, LQ-UQ: 3.14-3.43 cm, IQR=0.29 cm). In this case both groups had similar variances (for details see Figure 4D).

Discussion

CSNRB is a well-established, minimally invasive method to treat cervical radicular pain. Most patients experience pain relief after CSNRB (1, 5, 6, 17-19). However, in case reports, fatal complications due to accidental injury of the vertebral artery or accidental injection into the radicular artery have been reported (6, 9-12). Therefore, a method that enables optimal visualization of the important surrounding soft tissue structures to make CSNRBs as safe as possible is needed.

CSNRB may be performed with ultrasound-, fluoroscopic-, CT-, or CT fluoroscopic-guidance. The advantage of ultrasound-guided CSNRBs is real-time imaging without exposure to radiation (20). However, ultrasound-guidance allows only limited pre-puncture planning and has inherent technical limitations, for example the visualization of anatomical structures underneath the bony surface (13). Fluoroscopy was the first imaging modality commonly used for CSNRBs to help guiding needle placement. It is common due to its wide availability, low cost, and perceived speed (6). Moreover, fluoroscopy allows real-time visualization during needle advancement, and of contrast dye distribution around the nerve root. But fluoroscopy also has some disadvantages like its inability of direct visualization of the nerve root and the surrounding soft-tissue structures, and relatively higher radiation exposure for the investigator (6, 11). The most important downside of fluoroscopic guidance for CSNRB is the missing clear visualization of soft-tissue structures, especially vessels. In 2007, Wallace *et al.* (11) presented two cases that showed potentially devastating outcomes of a CSNRB performed using fluoroscopic guidance: an inadvertent penetration of the vertebral artery during puncture procedure led to dissection, thrombosis, brainstem hemorrhagic infarction, and finally death. Unfortunately, vascular penetration during CSNRBs may occur more frequently than assumed. Furman *et al.* (21) reported intravascular needle placement in 19.4% of 504 fluoroscopically guided CSNRBs confirmed by contrast injection. Usually, intravascular needle placement is determined by aspiration of blood. However, Furman *et al.* (21) showed that visualization of blood is not a sensitive sign of intravascular tip placement (45.9%). Accordingly, contrast dye injection is usually performed to identify an intravascularly located needle tip. But confirmation of an intravascular placement of the needle tip cannot avoid dissection with possibly fatal outcome. Additionally, vertebral artery anatomy may be displaced into the neural foramen in patients with advanced cervical degenerative disease (22); but these patients are the main candidates for CSNRBs. Therefore, an imaging system that allows optimal visualization of the cervical anatomy is essential. This could be achieved by using computed tomography. With its ability to precisely visualize cervical anatomy and delineate soft-tissue structures, especially the carotid and vertebral arteries, and even the nerve root, CT-guidance may not only ensure the safety of the puncture, it may also allow precise injection of local anesthetics and steroids (6, 11, 17, 19, 23-26). Opponents of CT-guidance often argue that it does not allow for real-time visualization of the needle tip during puncture. In contrast, CT-fluoroscopy combines the advantages of both methods, CT and fluoroscopy, hereby giving the chance to improve the safety of CSNRB by combining excellent anatomic visualization of CT with the advantage of real-time imaging of fluoroscopic guidance (25, 27). For that reason, our study group previously investigated the feasibility of Dyna-CT with Syngo iGuide® for CSNRBs. With its 3D rotational C-arm with a flat panel detector and its free-floating interventional table, Dyna-CT not only enables interventional cross-sectional CT-like images, overtopping standard C-arm based 3D volume imaging, it also permits a 3D puncture planning with 2D laser guidance allowing a very accurate and intuitive puncture with the possibility of fluoroscopic control during puncture (13).

In this study, we compared guidance with Dyna-CT to CT-guidance with respect to procedural planning time, puncture time, puncture attempts, trajectory length, and contrast dye distribution. We found a significantly reduced need for puncture attempts and significantly shorter procedural planning and puncture time with Dyna-CT compared to conventional CT-guidance, whereas there were almost no differences in trajectory length and contrast dye distribution.

Our results resemble the findings of Wagner (27) and Wagner & Murtagh (6) who compared CT-fluoroscopy with conventional CT-guidance. They found markedly reduced puncture time for CT-fluoroscopy, particularly due to a rapid acquisition of low-dose images using partial reconstruction algorithms while allowing the investigator to remain at the intervention table, and the possibility to advance the needle with real-time imaging. Certainly, Dyna-CT is not the same as CT-fluoroscopy, but it offers similar advantages. With its ability to acquire large volume CT-like images, overtopping standard C-arm based 3D volume imaging, Dyna-CT enables a good visualization of the spinal anatomy, including the vessels, and a real-time control of the needle tip due to its feasibility of continuous or intermittent fluoroscopy, allowing a fast and safe puncture. The usefulness and high quality of multiplanar reconstructed CT-like images of a 3D rotational angiographic unit was also acknowledged by Pedicelli *et al.* (28) who found those to be helpful for precise preoperative planning, for a quick control during puncture, and for post-operative controls. Furthermore, this study to our knowledge is the first to show superiority of Dyna-CT to conventional CT-guidance for CSNRB.

A general disadvantage of both modalities is radiation. While we think that the advantages in visualization of these modalities exceed the disadvantage of radiation exposure, this study did not compare the technique to radiation-free imaging guidance.

Study limitations. All punctures were performed in the same *ex vivo* model. That means, there was no preprocedural prepping of the patient, including positioning, scrubbing and draping, and there was no interference caused by breathing or movement of the patient. This explains our very short procedural times. Furthermore, we were unable to compare radiation doses of both modalities. Radiation doses are reported as DAP for Dyna-CT, but as DLP for conventional CT. In the literature, however, previously published studies claim that the radiation doses of the Dyna-CT are higher compared to standard fluoroscopy, but do not exceed the radiation exposure of a CT-guided puncture with a multidetector CT (29, 30). Similar results were also found in other studies, which found intermittent fluoroscopic CT-guidance to significantly lower radiation doses compared with continuous fluoroscopic CT-guidance and conventional CT-guidance (27). Exact radiation doses have to be evaluated in further studies to evaluate Dyna-CT with Syngo iGuide® as a future potential alternative to conventional CT-guidance for CSNRB in clinical practice.

Conclusion

In conclusion, this study is the first to show superiority of CSNRB performed with Dyna-CT and Syngo iGuide® over conventional CT-guidance in terms of significantly less puncture attempts, shorter pre-puncture planning and puncture time with almost no difference in trajectory length and contrast dye distribution. These advantages could be useful in clinical practice to work more efficiently and increase patient safety.

Conflicts of Interest

The Authors declare no conflicts of interest in relation to this study.

Authors' Contributions

SS: data acquisition, data evaluation, manuscript writing, manuscript editing. HUK: initiator of study, puncture performance, data acquisition, data evaluation, statistical analysis, manuscript preparing, manuscript editing. MF: puncture performance, data acquisition, data evaluation, manuscript writing. KH: data evaluation, manuscript writing. CG: initiator of study, manuscript preparing, critical review of the manuscript. MM: data evaluation, statistical analyses, manuscript writing. SAM: data acquisition, data evaluation, manuscript preparing, manuscript editing.

Funding

M.E.M. acknowledges funding from the German Federal Ministry of Education and Research (BMBF) within the framework of the Medical Informatics Initiative (MII), Medical Informatics in Research and Care in University Medicine (MIRACUM) Consortium (MIRACUM: 01ZZ1801E, 01ZZ2301A) and its junior research group (Medical informatics for holistic disease models in personalized and preventive medicine (MIDorAI): 01ZZ2020). The funders had no role in study design, data collection, analysis and interpretation, decision to publish, or preparation of the manuscript.

References

1 Desai A, Saha S, Sharma N, Huckerby L, Houghton R: The short- and medium-term effectiveness of CT-guided selective cervical nerve root injection for pain and disability. Skeletal Radiol 43(7): 973-978, 2014. DOI: 10.1007/s00256-014-1843-4
2 Radhakrishnan K, Litchy WJ, O'Fallon WM, Kurland LT: Epidemiology of cervical radiculopathy. A population-based study from Rochester, Minnesota, 1976 through 1990. Brain 117(2): 325-335, 1994. DOI: 10.1093/brain/117.2.325
3 Woods BI, Hilibrand AS: Cervical radiculopathy: Epidemiology, etiology, diagnosis, and treatment. J Spinal Disord Tech 28(5): E251-E259, 2015. DOI: 10.1097/BSD.0000000000000284
4 Latka D, Miekisiak G, Jarmuzek P, Lachowski M, Kaczmarczyk J: Treatment of degenerative cervical spondylosis with radiculopathy. Clinical practice guidelines endorsed by The Polish Society of Spinal Surgery. Neurol Neurochir Pol 50(2): 109-113, 2016. DOI: 10.1016/j.pjnns.2015.12.002
5 Vallée J, Feydy A, Carlier RY, Mutschler C, Mompoint D, Vallée CA: Chronic cervical radiculopathy: lateral-approach periradicular corticosteroid injection. Radiology 218(3): 886-892, 2001. DOI: 10.1148/radiology.218.3.r01mr17886
6 Wagner AL, Murtagh F: Selective nerve root blocks. Tech Vasc Interv Radiol 5(4): 194-200, 2002. DOI: 10.1053/tvir.2002.36429
7 Johansson A, Hao J, Sjölund B: Local corticosteroid application blocks transmission in normal nociceptive C-fibres. Acta Anaesthesiol Scand 34(5): 335-338, 1990. DOI: 10.1111/j.1399-6576.1990.tb03097.x

8 Byröd G, Otani K, Brisby H, Rydevik B, Olmarker K: Methylprednisolone reduces the early vascular permeability increase in spinal nerve roots induced by epidural nucleus pulposus application. J Orthop Res 18(6): 983-987, 2000. DOI: 10.1002/jor.1100180619

9 Wolter T, Mohadjer M, Berlis A, Knoeller S: Cervical CT-guided, selective nerve root blocks: improved safety by dorsal approach. AJNR Am J Neuroradiol 30(2): 336-337, 2009. DOI: 10.3174/ajnr.A1222

10 Rozin L, Rozin R, Koehler SA, Shakir A, Ladham S, Barmada M, Dominick J, Wecht CH: Death during transforaminal epidural steroid nerve root block (C7) due to perforation of the left vertebral artery. Am J Forensic Med Pathol 24(4): 351-355, 2003. DOI: 10.1097/01.paf.0000097790.45455.45

11 Wallace MA, Fukui MB, Williams RL, Ku A, Baghai P: Complications of cervical selective nerve root blocks performed with fluoroscopic guidance. AJR Am J Roentgenol 188(5): 1218-1221, 2007. DOI: 10.2214/AJR.04.1541

12 Brouwers PJ, Kottink EJ, Simon MA, Prevo RL: A cervical anterior spinal artery syndrome after diagnostic blockade of the right C6-nerve root. Pain 91(3): 397-399, 2001. DOI: 10.1016/S0304-3959(00)00437-1

13 Freundt MI, Ritter M, Al-Zghloul M, Groden C, Kerl HU: Laser-guided cervical selective nerve root block with the Dyna-CT: initial experience of three-dimensional puncture planning with an *ex-vivo* model. PLoS One 8(7): e69311, 2013. DOI: 10.1371/journal.pone.0069311

14 Maros ME, Schnaidt S, Balla P, Kelemen Z, Sapi Z, Szendroi M, Laszlo T, Forsyth R, Picci P, Krenacs T: *In situ* cell cycle analysis in giant cell tumor of bone reveals patients with elevated risk of reduced progression-free survival. Bone 127: 188-198, 2019. DOI: 10.1016/j.bone.2019.06.022

15 Maros ME, Brekenfeld C, Broocks G, Leischner H, McDonough R, Deb-Chatterji M, Alegiani A, Thomalla G, Fiehler J, Flottmann F, GSR Investigators*: Number of retrieval attempts rather than procedure time is associated with risk of symptomatic intracranial hemorrhage. Stroke 52(5): 1580-1588, 2021. DOI: 10.1161/STROKEAHA.120.031242

16 Wenz H, Maros ME, Meyer M, Gawlitza J, Förster A, Haubenreisser H, Kurth S, Schoenberg SO, Groden C, Henzler T: Intra-individual diagnostic image quality and organ-specific-radiation dose comparison between spiral cCT with iterative image reconstruction and z-axis automated tube current modulation and sequential cCT. Eur J Radiol Open 3: 182-190, 2016. DOI: 10.1016/j.ejro.2016.05.006

17 Cyteval C, Thomas E, Decoux E, Sarrabere MP, Cottin A, Blotman F, Taourel P: Cervical radiculopathy: Open study on percutaneous periradicular foraminal steroid infiltration performed under ct control in 30 patients. AJNR Am J Neuroradiol 25(3): 441-445, 2004.

18 Devulder J, Deene P, De Laat M, Van Bastelaere M, Brusselmans G, Rolly G: Nerve root sleeve injections in patients with failed back surgery syndrome: a comparison of three solutions. Clin J Pain 15(2): 132-135, 1999. DOI: 10.1097/00002508-199906000-00010

19 Zennaro H, Dousset V, Viaud B, Allard M, Dehais J, Senegas J, Caille JM: Periganglionic foraminal steroid injections performed under ct control. AJNR Am J Neuroradiol 19(2): 349-352, 1998.

20 Jee H, Lee JH, Kim J, Park KD, Lee WY, Park Y: Ultrasound-guided selective nerve root block *versus* fluoroscopy-guided transforaminal block for the treatment of radicular pain in the lower cervical spine: A randomized, blinded, controlled study. Skeletal Radiol 42(1): 69-78, 2013. DOI: 10.1007/s00256-012-1434-1

21 Furman MB, Giovanniello MT, O'Brien EM: Incidence of intravascular penetration in transforaminal cervical epidural steroid injections. Spine 28(1): 21-25, 1976. DOI: 10.1097/00007632-200301010-00007

22 Fitzgerald RT, Bartynski WS, Collins HR: Vertebral artery position in the setting of cervical degenerative disease: implications for selective cervical transforaminal epidural injections. Interv Neuroradiol 19(4): 425-431, 2013. DOI: 10.1177/159101991301900404

23 Quinn SF, Murtagh FR, Chatfield R, Kori SH: CT-guided nerve root block and ablation. AJR Am J Roentgenol 151(6): 1213-1216, 1988. DOI: 10.2214/ajr.151.6.1213

24 Murthagh F: The neuroradiologist as pain therapist. AJNR Am J Neuroradiol 19: 353–354, 1998.

25 Wagner AL: CT fluoroscopic-guided cervical nerve root blocks. AJNR Am J Neuroradiol 26(1): 43-44, 2005.

26 Murtagh R: The art and science of nerve root and facet blocks. Neuroimaging Clin N Am 10(3): 465-477, 2000.

27 Wagner AL: Selective lumbar nerve root blocks with ct fluoroscopic guidance: Technique, results, procedure time, and radiation dose. AJNR Am J Neuroradiol 25(9): 1592-1594, 2004.

28 Pedicelli A, Verdolotti T, Pompucci A, Desiderio F, D'Argento F, Colosimo C, Bonomo L: Interventional spinal procedures guided and controlled by a 3D rotational angiographic unit. Skeletal Radiol 40(12): 1595-1601, 2011. DOI: 10.1007/s00256-011-1282-4

29 Ritter M, Rassweiler MC, Michel MS: The Uro Dyna-CT enables three-dimensional planned laser-guided complex punctures. Eur Urol 68(5): 880-884, 2015. DOI: 10.1016/j.eururo.2015.07.005

30 Rassweiler MC, Banckwitz R, Koehler C, Mueller-Allissat B, Michel MS, Häcker A, Ritter M: New developed urological protocols for the Uro Dyna-CT reduce radiation exposure of endourological patients below the levels of the low dose standard CT scans. World J Urol 32(5): 1213-1218, 2014. DOI: 10.1007/s00345-013-1195-z