J Anesth (2014) 28:94–101
DOI 10.1007/s00540-013-1675-8

INVITED REVIEW ARTICLE

CT-guided nerve block: a review of the features of CT fluoroscopic guidance for nerve blocks

Shiro Koizuka · Kunie Nakajima · Rie Mieda

Received: 12 June 2013 / Accepted: 9 July 2013 / Published online: 20 July 2013

Abstract Nerve blocks are an attractive interventional therapy in pain medicine. Several image guidance methods are available to secure the safety, accuracy, and selectivity of the nerve block. Computed tomography (CT) guidance provides a clear view of the vital viscera and vessels that should be avoided by the needle, and accurate placement of the needle tip before neuro-destructive procedures. A recent advance in CT technology is multi-slice CT fluoroscopy, which allows for rapid and easy correction of needle tip placement during insertion. To reduce the radiation dose for both patients and staff, the lowest radiation setting, intermittent quick-check fluoroscopy, and shortening of the planning scan should be used. Preliminary CT scanning with excellent spatial resolution may facilitate the application of CT fluoroscopic guidance to various types of nerve blocks. Here we review celiac plexus and splanchnic nerve blocks, trigeminal nerve block, neurolytic sympathectomy, and spinal intervention performed under CT guidance. Additional large-scale studies are needed to optimize the use of image guidance, especially CT fluoroscopy guidance, for nerve blocks.

Keywords Nerve block · Interventional pain therapy · CT guidance · CT fluoroscopy

Introduction

Nerve blocks are an optional method for the relief of severe pain. Nerve blocks are an attractive tool in pain medicine because, although analgesics may reduce pain, nerve blocks can completely stop pain [1]. Several methods are used for therapeutic nerve blocks. In general, two types of nerve blocks, local anesthetic injection or a neuro-destructive method, are used for pain management. Because of the short duration of action of local anesthetic agents, local anesthetic blocks are used to protect against acute incident pain and for diagnostic tests. Neuro-destructive blocks using neurolytic agents or radiofrequency thermocoagulation are used for intractable chronic pain.

For optimal therapeutic application of nerve blocks, physicians must be aware of the potential side effects and complications. The potential complications of nerve blocks can be categorized as (1) inadvertent damage to structures other than nerves, (2) nerve damage, (3) systemic effects of the injected drugs, and (4) physiological effects of the procedure.

The needles used for nerve blocks can pierce and damage structures along the course of the insertion or near the target point. Examples of this include pneumothorax following a nerve block around the thoracic region; and penetration of the aorta, inferior vena cava, or retroperitoneal organ (such as kidney or ureter) following a thoracic, celiac, or lumbar sympathetic plexus block [1–5]. Blood vessels might also be pierced, causing bleeding or hematoma.

Neuro-destructive methods, especially those using injection of a neurolytic agent, may cause long-term damage to structures around the target. To avoid inadvertent damage to structures other than nerves and to achieve optimal therapeutic effects, accurate needle insertion during nerve blocks is important. For some blocks, palpable landmarks can be used to ensure the accuracy of the blocks. When nerves and landmarks are not palpable and precision is required, image guidance should be used to ensure safety, accuracy, and selectivity [1].

S. Koizuka (✉) · K. Nakajima · R. Mieda
Department of Anesthesiology, Gunma University Hospital, 3-39-15 Showa-machi, Maebashi 371-8511, Japan
e-mail: skoizuka@yahoo.co.jp

Types of image guidance for nerve blocks

X-ray fluoroscopy

X-ray fluoroscopy is the most commonly used form of image guidance in interventional pain therapy. The advantages of fluoroscopy include a wide field of view around the target region and continuous real-time views when needed. In the event of intravascular injection, the physician can easily check the flow of contrast medium away from the target point. In addition, the apparatus is not excessively expensive. The limitation of fluoroscopy, however, is that it shows only bones. Therefore, it is suitable only for target nerves with a dependable relationship to a bony landmark.

Ultrasound guidance

Ultrasound guidance is being increasingly used and explored in pain medicine [6]. Ultrasound reveals muscles, ligaments, vessels, joints, and bone, and provides a continuous real-time view. Moreover, if high-resolution transducers are used, thin nerves can be directly visualized. Importantly, ultrasound also does not involve radiation exposure. The limitations of ultrasound are poor resolution of deep tissue, tissue under bone, or air. There is a slight limitation of the direction of needle insertion in relationship to transducer location. In addition, the condition of the tissue may influence the quality of view.

CT guidance

The first use of computed tomography (CT) to guide needle insertion for biopsy was reported in 1975 [7]. In 1977, Haaga and colleagues [8, 9] reported a CT guidance technique for a celiac plexus nerve block and lumbar sympathetic block. Following introduction of the CT-guided celiac plexus block, several investigators modified and refined the techniques, helping to establish its low complication rate [9–13].

In contrast to conventional X-ray fluoroscopy, CT provides a clear view of vital viscera and vessels that should be avoided by the needle. In addition to avoiding inadvertent puncture of vital structures, the CT guidance method allows accurate placement of the needle tip before the injection of a neurolytic agent with a clear view of the muscles and soft tissue, especially in lumbar sympathectomy [14].

The major potential disadvantages of conventional (non-fluoroscopic) CT guidance, however, are the longer procedure time and excessive radiation exposure for the patient. In classical CT guidance, non-fluoroscopic CT scanning must be performed frequently to confirm the needle position, which interrupts and prolongs the procedure and involves considerable radiation exposure [1, 15]. In addition, the flow of contrast medium in the vessels is more difficult to visualize in classical CT guidance and CT equipment is more expensive to install than X-ray fluoroscopy or ultrasound equipment. Therefore, CT guidance is justified only in selected cases.

In the early 1990s, CT fluoroscopy was developed and reported by Katada et al. [16, 17]. A slip-ring spiral (helical) CT scanner was modified by the addition of a high-speed array processor to increase the speed of image reconstruction. The system allowed for real-time reconstruction and display of CT images. CT fluoroscopy allowed for real-time visualization of the needle, expediting the procedure and markedly reducing its overall length, partly because operators did not need to leave the scanning room [15–18]. Katada and colleagues [17] described the first case of celiac plexus block under real-time CT fluoroscopy in 1996.

Recent advances in CT technology allow for at least three slices (cranio-caudal series slices) in one fluoroscopic view by multi-slice CT (MS-CT) fluoroscopy (or multi-detector low CT fluoroscopy) [19, 20], allowing for easy correction of longitudinal deflection of the needle tip during insertion (Fig. 1). In addition, some types of recent MS-CT devices provide three-dimensional views within a few minutes after scanning so that correct needle tip placement in relation to the surrounding anatomic structures and diffusion of contrast medium or neurolytic agent can be immediately confirmed (Fig. 2) [19, 20]. Use of an image-guided technique with CT fluoroscopy may increase the efficacy and safety of several types of nerve blocks.

The present study does not provide concrete objective data regarding the safety, accuracy, or selectivity of CT-guided nerve block. Although a double-blind prospective study is required to objectively compare the efficacy of the CT fluoroscopic method with the classic radiograph fluoroscopic method for nerve blocks, this is difficult to achieve because the differences in the devices are obvious to both patients and operators during the procedure.

Advantages and features of recent advances in CT fluoroscopic guidance for nerve block

Preliminary CT scanning for planning the needle insertion route

In CT fluoroscopy-guided interventions, pre-procedure helical CT planning images are obtained for planning a safe insertion route [4, 5, 8–20]. Because CT provides high contrast and spatial resolution, bone structures (such as the skull base [19, 20] and spine [21]) and vital anatomic structures (such as vessels, pleura, retroperitoneal organs,

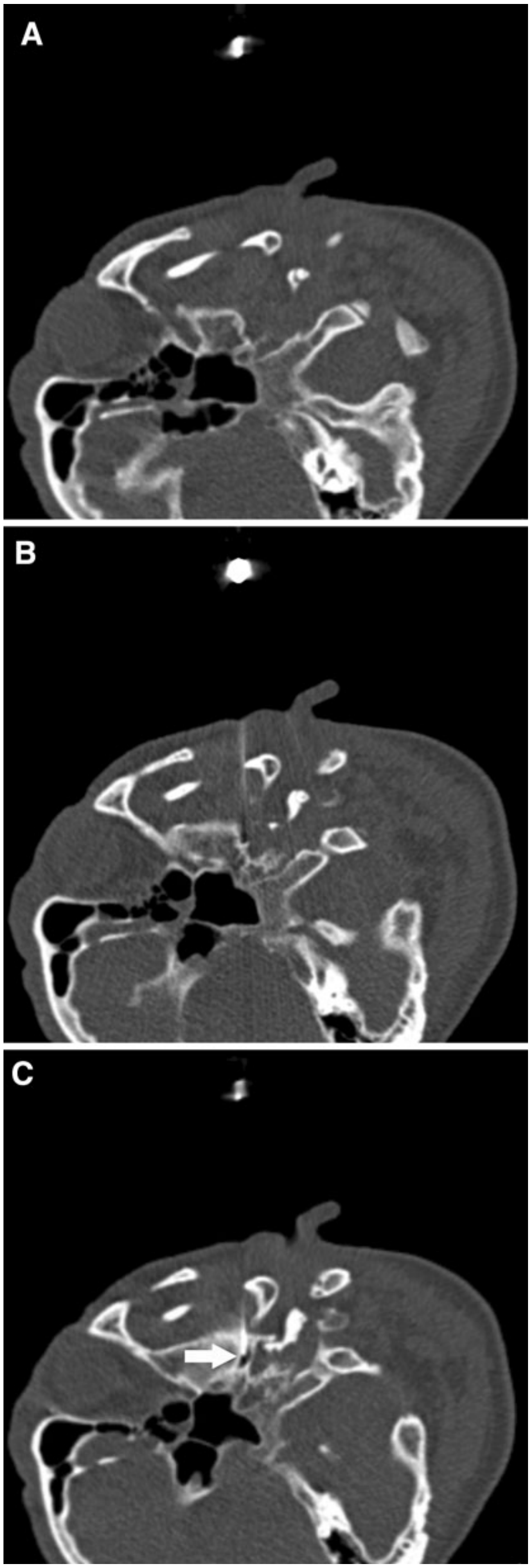

Fig. 1 Multi-slice computed tomography (CT) fluoroscopic view in which three slices (**a–c**, cranio-caudal series slices) are visualized simultaneously during mandibular nerve block. **c** The needle tip (*white arrow*) is located in the target site just at the foramen ovale

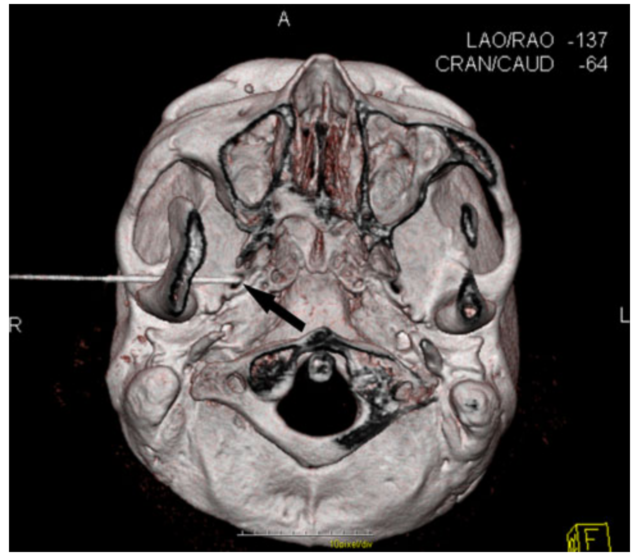

Fig. 2 Three-dimensional computed tomography (CT) view constructed after the needle tip was advanced to the foramen ovale during CT fluoroscopy-guided mandibular nerve block. *Arrow* indicates the needle tip just at the foramen ovale

and peri-spinal muscles) can be visualized directly. In addition, CT also depicts the extent of tumor spread or invasion and anatomic anomalies [4, 5, 9, 13, 21–23]. Therefore, a safe insertion route can be easily determined, despite individual anatomic variations.

Reduced insertion time results from real-time MS-CT fluoroscopy

One limitation of conventional (non-fluoroscopic) CT guidance for interventions is the lack of real-time imaging capability because of the processing time required for generating the CT image. Conventional CT guidance requires prolonged scanning times. The real-time CT fluoroscopy system with a dedicated high-speed array processor and a special reconstruction algorithm provides real-time reconstruction to guide needle insertion [17]. Recent advances in CT fluoroscopy have provided newer generations of MS-CT scanners that allow for the acquisition and display of three or more slices in one rotation of the scanner [19, 20, 24]. By stepping on the foot pedal next to the patient, the operator performing the intervention can immediately obtain three contiguous slices to both verify and correct the needle position. This equipment may reduce procedure time and provide more accuracy.

Low-dose techniques in CT fluoroscopy

CT-guided interventions may be significant sources of radiation exposure for both patients and physicians.

Although CT provides better spatial resolution in some kinds of interventions than conventional fluoroscopy, the radiation dose per time is substantially higher for CT fluoroscopy than for conventional fluoroscopy [25, 26]. Preliminary CT scans for planning are a major factor contributing to the overall radiation dose [17, 25, 26]. Therefore, several low-dose modifications are suggested, as summarized below [15, 18, 25, 26].

1. Shortening the *z*-axis and using the lowest radiation settings that allow for visualization of the target.
2. Use of adequate personal protective equipment to reduce the radiation dose to both operator and patient.
3. Optimize operator's position relative to both the gantry and patient during CT fluoroscopy.
4. Intermittent quick-check fluoroscopy is recommended in most cases and real-time CT fluoroscopy should be performed rarely.
5. Use of the lowest possible CT fluoroscopy parameters necessary to visualize the target.

No previous studies have reported systematic objective data comparing the radiation dose for both patients and staff and the procedure time between MS-CT fluoroscopy-guided nerve block and X-ray fluoroscopy-guided nerve block or conventional CT-guided nerve block. Operators in interventional radiology should always be aware of methods to reduce the radiation dose in both patients and staff [18].

Versatility for several types of nerve block

Preliminary CT planning facilitates the application of CT fluoroscopic guidance to various types of nerve blocks [4, 5, 9, 17, 19, 20, 23]. In addition, because the CT gantry can be set at an oblique angle in some new CT devices, the operator can insert the needle at an oblique angle, thereby adjusting the angle for an ideal insertion route [19].

CT-guided celiac plexus and splanchnic nerve blocks

Celiac plexus and splanchnic nerve blocks are invaluable therapeutic options for managing refractory abdominal pain and have been widely used since their introduction by Kappis et al. in 1914 [9–11]. The techniques used for these blocks in the early stage were based on palpable bony landmarks or X-ray fluoroscopic guidance. An ultrasound-guided technique was introduced in the 1970s [9, 22, 27].

The utility of X-ray fluoroscopy or ultrasound guidance for celiac plexus blocks was limited, however, because it did not accurately depict the needle tip in relation to the retroperitoneal structure. This limitation paved the way for the CT-guided celiac plexus block described by Haaga and colleagues [8, 9] in 1977. Since the introduction of the CT-guided celiac plexus block, CT has superseded other imaging modalities as the preferred technique, with its proven safety record [9, 22]. With CT guidance, needle placement into the region of the celiac plexus or retrocrural space and the location of the needle in relation to vital anatomic structures, such as the pancreas, aorta, celiac artery, and superior mesenteric artery (SMA), may be directly visualized [9, 22, 28]. In addition to retroperitoneal structures, CT also depicts the extent of tumor spread and other causes of abdominal pain, such as duodenal obstruction, bone destruction, and muscle invasion [9, 22]. One of the most important aspects of CT is its ability to depict the extent of the spread of a neurolytic agent within the antecrural or retrocrural space (Fig. 3), allowing for the rapid detection of inadvertent injection into adjacent

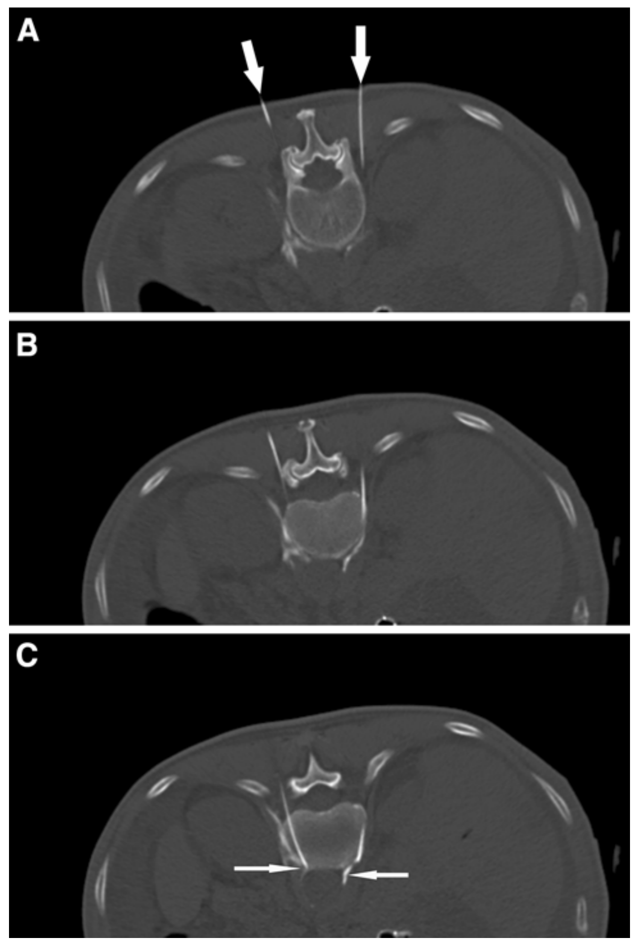

Fig. 3 Multi-slice computed tomography (CT) fluoroscopic view (**a**–**c**, cranio-caudal series slices) during splanchnic nerve block. Axial multi-slice CT image obtained with the patient in prone position (the most common position) shows the bilateral posterior trans-intervertebral disc approach to splanchnic nerve block. **a** *Arrows* indicate the percutaneous bilateral entry points. **c** *Left arrow* indicates the needle tip located at the retrocrural site. *Right arrow* indicates contrast medium spread in the retrocrural space

structures or leakage into the peritoneal cavity [9, 22, 28, 29].

Because of the advantage of preliminary planning, CT-guided celiac plexus or splanchnic nerve block has several options for needle placement, such as a bilateral posterior paravertebral antecrural approach, anterior approach, bilateral posterior paravertebral retrocrural approach, posterior transintervertebral disk approach, posterior trans-aortic approach, and direct tumor infiltration method [9–13, 22]. Preoperative images must be reviewed in detail to determine the patient's position, CT approach, needle entry site, needle path, and site of neurolytic agent injection [9].

Endoscopic ultrasonography (US)-guided celiac plexus neurolysis was introduced in 1996 and is widely accepted as a safe and alternative approach [9, 30]. The neurogenic complications associated with a posterior approach can be avoided with endoscopic ultrasonography, which has a low rate of complications [9, 30]. Endoscopic US-guided approaches may be favored when endoscopic ultrasonography is otherwise indicated for diagnostic or staging purposes [30]. This technique is more specific, however, and precise identification of the celiac plexus may be challenging at times, particularly when the neurolytic solution, which is hyperechoic, obscures the antecrural space anatomy, resulting in a "snowstorm effect" [9, 30].

CT fluoroscopy has made CT-guided celiac plexus or splanchnic nerve block more accurate and easier to perform [9, 17, 22]. The advantages and disadvantages of the imaging modalities used to guide celiac plexus or splanchnic block are reviewed by Kambadakone et al. [9].

CT-guided trigeminal nerve block

Trigeminal nerve block is an established treatment for idiopathic trigeminal neuralgia and cancer pain in the trigeminal nerve region [19, 20, 23, 31, 32]. Trigeminal nerve blocks, such as Gasserian ganglion block, mandibular nerve block, and maxillary nerve block, are traditionally performed by referring to external anatomic landmarks and using X-ray fluoroscopy. The precise location of the targets, such as the foramen ovale and pterygomaxillary fossa, however, is difficult to determine using uniplanar fluoroscopy [19, 20, 23, 33–35]. Moreover, the classical technique using landmarks and fluoroscopy is not always accurate and carries risks from individual anatomic variability or cancer invasion [19, 20, 23, 33–35].

Percutaneous electrocoagulation of the trigeminal nerve using conventional CT guidance was introduced by Krol and Arbit [36] in 1988. Okuda et al. [33, 34] reported the use of conventional CT guidance for maxillary nerve and mandibular nerve blocks. Following the introduction of real-time CT fluoroscopic-guided intervention, a CT

Fig. 4 The needle was advanced through the foramen ovale following the predesigned route under computed tomography (CT) fluoroscopy. *Arrow* indicates the needle tip advanced through the foramen ovale

fluoroscopy-guided trigeminal nerve radiofrequency rhizotomy through the foramen ovale was reported by Gusmao et al. [37] and by Sekimoto et al. [35]. A case of CT fluoroscopy-guided mandibular nerve rhizotomy for cancer pain was reported by Koizuka et al. [23]. After high-speed MS-CT fluoroscopy was introduced, the techniques for Gasserian ganglion (Fig. 4) and mandibular nerve rhizotomy guided by MS-CT fluoroscopy were described by Koizuka et al. [19, 20]. Some types of recently developed MS-CT devices provide three-dimensional views within minutes after scanning, and correct needle tip placement near the foramen ovale can be confirmed immediately (Fig. 2) [19, 20]. Although limited in number, these case series of CT fluoroscopy guidance for trigeminal nerve block suggest potential advantages with regard to safety, speed, and effectiveness.

CT-guided neurolytic sympathectomy

Lumbar sympathectomy is an effective treatment for severe peripheral vascular disease that is resistant to other types of treatment and no longer suitable for arterial reconstruction [1, 2, 4, 5, 14, 21]. In addition, lumbar sympathectomy may also provide effective relief for some chronic lower limb pain, especially that associated with sympathetic activity [1, 2]. Lumbar sympathectomy is conventionally performed using laparoscopy or X-ray fluoroscopy. Although percutaneous methods are less invasive than a laparotomy, percutaneous methods under classic X-ray fluoroscopy can potentially cause injury to organs and major vessels that are not visualized [4, 5, 14, 21]. Puncture of the kidney or ureter may cause renal dysfunction [3, 4], and puncture of a major vessel can lead to critical hemorrhage [5, 14]. In addition, lumbar sympathectomy can be difficult to perform in patients with a deformed lumbar spine or other anatomic variability [4, 5, 14, 21].

Percutaneous chemical lumbar sympathectomy using conventional CT guidance was described by Redman et al. [14] in 1986. They presented two cases with potential risks that were avoided by CT guidance in their case series. Although one patient had an undiagnosed giant aortic aneurysm and another had a renal cyst, neither of these structures was perforated following precise needle placement under CT guidance [14]. Heindel et al. [38] reported the effectiveness of CT-guided lumbar sympathectomy in a total of 152 cases.

The efficacy of the refined technique for CT fluoroscopy guided lumbar sympathectomy was reported by Tay et al. [39] in 2002. They provided demographic, clinical, and laboratory data collected from the records of 146 cases in which CT fluoroscopy was used to guide chemical lumbar sympathectomy and suggested that the CT fluoroscopy-guided technique was simple, safe, and effective [39].

Koizuka et al. [4, 5] provided anatomic data from CT images obtained during fluoroscopic CT guided percutaneous lumbar sympathectomy. The data indicated that there is potential risk of kidney puncture at the L2 vertebral level when the needle is placed according to textbook descriptions [4]. In addition, needle insertion for right-side sympathectomy at the L3 level may present a higher risk of major vessel puncture than sympathectomy at other sites [5]. These findings suggest that CT guidance may be recommended for lumbar sympathectomy to reduce the risk of vascular and vital organ puncture [4, 5].

CT-guided intervention for spinal region

Local spinal pain and radiculopathy are very common conditions that lead to serious social loss. Most cases are successfully treated conservatively with rest or physical therapy. Medication or, in some cases, surgery may also be performed. Percutaneous injection or interventional pain therapy have been used for spinal management for many years, but radiographic guidance was used infrequently until just a few decades ago [40, 41]. Newer, minimally invasive imaging-guided percutaneous techniques were recently added to the list of available treatment options for spinal pain [40–42]. Although the evidence supporting the need for routine radiographic guidance continues to evolve, the intuitive appeal of this more precise approach has caught firm hold, and the majority of practitioners now perform spinal intervention using fluoroscopic guidance [40].

Gangi et al. [42] described CT-guided interventional analgesic techniques for the lumbosacral spine, such as periradicular infiltration, percutaneous laser disk decompression, facet joint block, and percutaneous vertebroplasty with abundant CT images. Silbergleit et al. [41] also described imaging-guided injection techniques with X-ray fluoroscopy and CT guidance for spinal pain management with abundant images. They demonstrated techniques for injections of local anesthetics or long-acting steroids into facet joints, sacroiliac joints, selective nerve roots, spondylolytic areas, and epidural space in cervical, thoracic, lumbosacral, and sacroiliac regions [41].

Wagner reported refined CT fluoroscopic guidance techniques for spinal interventions, such as selective lumbar nerve root blocks [43], epidural injections [44], and cervical nerve root blocks [45]. Wagner [43–45] suggested that the use of the intermittent CT fluoroscopy technique with low milliamperes (mA) could result in minimal radiation dose levels and procedure times comparable to X-ray fluoroscopic guidance.

The radiation dose of conventional fluoroscopy-guided lumbar epidural steroid injections and CT fluoroscopy-guided lumbar steroid injection based on both clinical data and anthropomorphic phantoms was compared by Hoang et al. [26]. They reported that the effective dose for CT fluoroscopy-guided epidural injection was almost half that of conventional fluoroscopy because of the shorter fluoroscopy time [26]. The overall radiation dose for CT fluoroscopy guidance, however, could be up to four times higher when a full diagnostic lumbar CT scan is performed as part of the procedure [26]. Hoang et al. [26] suggested that radiation dose reduction for CT fluoroscopy guidance was best achieved by minimizing the dose of the preliminary planning CT scan.

Eckel and Bartynski [46] postulated that X-ray fluoroscopy could be a routine approach to image-guided procedures of epidural injection and lumbar nerve root block, and that CT fluoroscopy could be used as the primary approach in those procedures or as an alternative technique in unique cases.

In some cases, such as in patients with intractable pain associated with metastatic cancer, radiographic guidance, especially CT fluoroscopic guidance, may prove invaluable for planning and implementation of pain relief by nerve block [47, 48].

Conclusion

Nerve blocks are an attractive therapeutic intervention in pain medicine, but physicians must be aware of the potential side effects and complications of the procedures. Therefore, the most appropriate image guidance technique available should be used to ensure safety, accuracy, and selectivity. CT guidance provides a clear view of vital viscera, vessels that should be avoided by the needle, and accurate placement of the needle tip before injection of a neurolytic agent. Recent advances in CT technology led to MS-CT fluoroscopy, which allows for rapid and easy correction of longitudinal deflection of the needle tip during insertion. Use of new CT fluoroscopy guidance techniques and devices may increase the efficacy and safety of several types of nerve blocks. However, there are no systematic objective data regarding the safety, accuracy, or selectivity of CT-guided nerve block as compared with other guided nerve blocks. Further large-scale studies are needed to optimize the use of image guidance, including CT fluoroscopy, for nerve blocks.

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