Surgeries of lower extremities are one of the most often performed procedures in surgical and orthopedic wards. Many of them are executed as so-called one-day surgery. Even so, the vast majority of these procedures are performed under general (GA) or neuraxial anaesthesia (NA), which is associated with the potential for certain complications, prolonged immobilization of the patient, as well as longer time and increased cost of hospitalization.

Peripheral nerve anaesthesia (PNA) could be a safer and more efficient alternative to GA and NA in these patients. Traditional methods of performing PNA, based on the identification of anatomical landmarks, require much experience, are unreliable, time consuming, and carry a risk of complications. In recent years, techniques of PNA performed under ultrasound guidance have been introduced in clinical practice.

The aim of this article is to review the current knowledge on PNA of the lower extremities performed under ultrasound guidance as an alternative to GA and NA.

PNA as an alternative for GA and NA

Anaesthesiologists are often faced with a situation where several types of anaesthesia can be chosen interchangeably for an operation of a lower limb. NA is currently the method of choice in operations on the lower extremities, provided there are no contraindications. The most commonly performed NA in Poland is spinal anaesthesia, epidural anaesthesia is performed much less often. PNA is extremely rarely performed anaesthesia. While making the choice of the type of anaesthesia, one should first and foremost keep in mind the risk of complications, which when occur, may require difficult and prolonged treatment. Adverse side effects in spinal anaesthesia are associated with the block of preganglionic sympathetic fibres. The following effects of this block are particularly hazardous in cardiologically affected patients:

- decreased venous return resulting in a fall of arterial pressure and cardiac output;
- drop in coronary flow with exacerbation of heart ischemia symptoms;
- deceleration of heart action due to blocking of the accelerator nerves (Th1-Th4). Bradycardia occurs in 10-15% of patients undergoing spinal anaesthesia (1).

The motor block of the thoracic spinal nerves during spinal anaesthesia also decreases vital capacity (VC) of the lungs (by about 20%), expiratory reserve volume (ERV) and cough efficiency. The patients experience then a feeling of dyspnoea due to the impaired mobility of abdominal muscles. A high block (C3-C5) car-
ries a risk of respiratory insufficiency caused by the impairment of diaphragm mobility.

Block of preganglionic sympathetic fibres with prevalence of vagal activity results in increased peristalsis and tension of the smooth muscle layer, and may cause nausea and vomiting.

Because of these side effects, anaesthesiologists often decide not to do NA in patients with cardiac diseases, performing GA instead. A particularly undesirable situation during spinal anaesthesia consists of abrupt hemodynamic changes, such as bradycardia and hypotension, which are especially manifested when changing the position of the anesthetized patient. Therefore, if it is necessary to reposition the patient during treatment, it should be done with extreme caution.

In clinical conditions a technical success of spinal and epidural blocks is confirmed by a loss of resistance and confirmation of the free outflow of cerebrospinal fluid, respectively. However, in obese or elderly patients, those who underwent previous surgical interventions in the place of injection, suffering from highly advanced scoliosis or degenerative changes of the spinal column, or patients with lumbosacral spine injuries, performing these blocks may be fraught with many technical difficulties. The aforementioned problems become insignificant in the case of PNA.

It should be also noted that a motor anaesthesia during NA may increase the risk of position injuries, lead to back pains after the treatment, and deterioration of neurological symptoms related to degenerative lesions and discopathy (2). There have also been reports of subarachnoid hemotoma after performing spinal anaesthesia in a patient without any coagulation disorders (3, 4, 5). The possibility of post-puncture headaches also has to be considered, as well as the risk of total spinal anaesthesia, which represents an acute life-threatening state and usually leads to admission to the intensive care unit (ICU) (6). Problems with passing urine that require the use of urethral catheter occur quite frequently after central blocks (7). The reported incidence of this complication in patients undergoing spinal anaesthesia varies from 14 to 37% (1).

In contradistinction to PNA, NA also carry the risk of severe neurological complications, such as nerve root injury by a needle, disturbances in spinal cord blood flow, spinal and cerebral aseptic meningitis, hematomas and abscess in epidural space (8). However the reported overall severe complication rate associated with NA is under 4 per 10000 patients (2).

Thus, there is a great number of patients, particularly those with cardiac diseases, with neurological symptoms (multiple sclerosis), anatomical defects of the spine, infections in the place of injection, and previous complications after anaesthesia, in whom GA is usually performed, while PNA under ultrasound guidance could be the method of choice in these cases. PNA has numerous advantages compared to GA and NA. First of all, the risk of complications is diminished in patients with important comorbidities, the threat associated with intubation and pulmonary aspiration of gastric contents is eliminated, the state of consciousness in patients afraid to lose it is preserved, the whole procedure can be performed on ambulatory basis, and the post-operative anesthesiological supervision is also usually not necessary (1, 9). PNA has the following benefits: satisfaction of the patient, alleviation of pain, earlier post-operative motor activity, decreased opioid use in post-operative period, and less frequent post-operative complications as well (10, 11, 12). The reported frequency of complications of PNA is low and oscillates between 0 and 5% (13). Fowler et al. published a systematic review and meta-analysis of all randomized trials comparing epidural analgesia with PNA for major knee surgery. Authors observed less side-effects in patients whom received femoral PNA and less likely to cause a severe neuraxial complication then patients whom received epidural anaesthesia (14).

A PNA can obviously be performed in patients without comorbidities, in which case, apart from avoiding the complications associated with NA, the patients will benefit from the advantages of PNA, such as quick mobilization of the patient, high degree of safety, patient’s cooperation and finally, short hospitalization time (15, 16, 17).

However PNA are much less frequent in clinical use for lower limb operations for three reasons. Firstly, it is not possible to achieve the block of a lower limb with a single injection and multiple injections may be perceived as uncomfortable and also due to the amount of local anaesthetic used as dangerous to the
patients. Secondly, performing a NA may seem easier in such a situation and, thirdly, there is a belief among anaesthesiologists that PNA of the lower limb are difficult to perform and not very reliable. In case of standard techniques of PNA a reported mean success rate does not exceed 80% (18). Therefore, a conversion to GA may be required that is associated with a significant discomfort to the patient and an increased risk of complications. What is more, the necessity to use another anaesthetic technique increases the cost considerably.

That is why in daily practice it is often so that, for instance, a hallux valgus is operated on under spinal anaesthesia, and a reposition of lower limb fracture is done under GA. It seems logical that anaesthesia limited only to the area of the operation should be more profitable to the patient. The primary aim should be to choose a targeted anaesthesia that least affects the patient, which is perfectly realized by PNA.

We are usually afraid of nerve damage in the case of using PNA, in fact, post-operative neurological complications occur more frequently after GA and NA. This damage was primarily a result of pressure and stretching of the nerves and ganglia during the positioning of the patient for operation. Injuries to peripheral nerves after administering GA are most often located in the ulnar nerve and brachial plexus, whereas injuries to lumbosacral plexus are usually complications of NA.

Ultrasound-guided PNA and its advantages over the method using anatomic landmarks and paresthesia or nerve stimulator

In the case of PNA, six basic categories of complications can be distinguished, namely: injury with a needle, intraneural administration of anaesthetic, nerve ischemia, neurotoxicity of local anaesthetics, placement of a needle in an undesirable location, accidental administration of a wrong drug and infection (19, 20). The beginning of a new era in PNA, the so-called “direct visualization era”, had place in 1994, when Kapral et al. published the first paper on the subject of using direct ultrasound visualization to perform a PNA (21). The technique of PNA under ultrasound guidance has been gaining significant popularity for the recent years. Thanks to the ultrasound equipment now available, it is possible to identify nerve structures. The decrease in cost and miniaturization of high-resolution ultrasound equipment made available ultrasound devices, which allow visualization of peripheral nerves and the tissues surrounding them. An enormous advantage ultrasound has over other diagnostic methods is that the diagnostic equipment can be brought to the patient, and it is not necessary to do the opposite. Thus, using ultrasound in an operating room has become simple and available. It should always be considered that the way the local anaesthetic is distributed is the determining factor responsible for the efficiency of anaesthesia. In the case of the standard techniques of PNA of the lower limb currently in use, in which needle location is determined indirectly, the distribution of the anaesthetic cannot be predicted with a certainty. The ability to directly observe the propagation of the local anaesthetic is one of the most important advantages of the ultrasound. In the case of inadequate distribution of the drug, e.g., if only a partial drug distribution around nervous structures is observed, it is always possible to adjust the placement of the needle to obtain proper distribution of the anaesthetic. The result is optimal if the anaesthetic surrounds the nerve on all sides and the so-called „doughnut effect” is visible in the ultrasound (fig. 1).

Real-time direct observation of the needle location is also an important factor in avoiding complications such as nerve punctures, paraesthesia, toxicity of local anaesthetics, or painful muscle stimulation (fig. 2).

![Fig. 1. Obturator nerve surrounded by local anaesthetic](image-url)
Since the local anaesthetic is injected in the immediate vicinity of nervous structures, the efficacy and onset of the block occurs significantly sooner than in the case of conventional techniques. Marhofer et al. proved that with regard to femoral nerve block ultrasound guidance provides two-fold faster onset of sensory anaesthesia when compared to technic with neurostimulator (22). Chin et al reviewed 655 patients undergoing foot surgery who received either landmark-guided or ultrasound guided ankle block. The ultrasound-guided group required significantly less conversion to GA (7 vs 17%) and less additional local anaesthesia (5 vs 10%) or fentanyl injection (9 vs 18%) (23). Redborg et al. compared ultrasound-guided perivascular and a traditional landmark-based sural nerve block and observed after 10 minutes loss of sensation to ice in 94% and 56% of patients, respectively (24).

Therefore, this method decreases the duration of the procedure and the time spent waiting for the outcome (25). It was also demonstrated that anaesthesia administered using ultrasound persists significantly longer (24, 26, 27). These advantages are due to the precise injection of the local anaesthetic and do not depend on the used volume. Using ultrasound for anaesthesia seems beneficial in the frequent cases of anatomical variations. Owing to using ultrasonography, it is possible to decrease the number of needle direction changes, which results in decreased injury and pain associated with performing the procedure. If the nerve stimulation technique is used alone, the electric current is dispersed immediately after administering the initial dose of the local anaesthetic, so that later localization of the nerve and adjustment of the placement of the needle becomes virtually impossible. Ultrasonography enables better control over the placement of the needle in relation to nerves, and the anaesthesiologists well-trained in the ultrasound technique often forgo the use of stimulators.

The PNA procedure is assumed to be painless. All techniques, however, other than the ultrasonographic one, are based on the needle-nerve physical interaction (the neurostimulation technique and the rarely used now paresthesia technique) and so are accompanied by discomfort. It should be added that motor response to nerve stimulation in the case of injuries (e.g., joint dislocations, fractures) is associated with pain. Smaller volumes and lower pressure of the local anaesthetic injected while using ultrasound improve the comfort of the patient during the anaesthesia procedure.

Numerous studies have shown that it is possible to perform a block under direct visual guidance using 20-30% of previously recommended volumes of local anaesthetic (29, 30). Decreasing the volume of the drug not only limits the pain during the block but also contributes to increased safety of the procedure. Other PNA techniques use large volumes of local anaesthetics to compensate for the lack of precision. Moreover, small volumes of local anaesthetics decrease the risk of systemic toxicity. It is chiefly the patients with impaired circulatory function who benefit most from the decreased serum concentrations of local anaesthetics. It is also particularly important in children, in whom low levels of proteins binding the drug may be associated with the increased risk of its toxicity. The safety profile and relative painless character of ultrasound guided PNA allows to perform a multiple PNA at the same time that is required for efficient limb anaesthesia.

When performing PNA under ultrasound guidance, the risk of inadvertent puncture of a vessel with the tip of the needle and administering the drug intravascularly is also decreased. Even when the direct visualization of the tip of the needle is doubtful tentative injections (0.5-1 ml) may be useful in detecting intravascular injections. If it is not possible to visualize such an injection, it should be aborted immediately, and an intravascular injection should be presumed. If we take the above-mentioned advantages into consideration, using ultrasound in PNA should lead to a decreased complication rate and an increased...
rate of successful blocks. Therefore it seems that the correct use of this technique should be associated with increased safety and efficiency (18).

Economic benefits

Ultrasound guided PNA are cheap and efficient procedures providing perfect and safe anaesthesia. One of the factors responsible for decreased costs of PNA is reduction of prices of ultrasound machine within the last decade (18). Gonano and colleagues established that ultrasound guided interscalene brachial plexus block costs 33 pounds vs. 41 pounds at GA in patients undergoing arthroscopic shoulder surgery (31). Ehlers and colleagues proved that ultrasound guided continuous sciatic nerve block is cost effective (32). Sandhu and colleagues counted that ultrasound guided infraclavicular plexus brachial block including depreciation of ultrasound equipment saves $ 13.90 per case when compared to the infraclavicular block administered with nerve stimulator guidance (33). Proper education and training is crucial since the cost-effectiveness and patient satisfaction can only be achieved with an overall success rate for PNA exceeding 98%.

Clinical experience with ultrasound guided PNA

So far the reported clinical experience of ultrasound guided PNA in lower extremity interventions comes mainly from orthopaedic surgery. It is often used as a method of post interventional analgesia. Postoperative ultrasound guided combined femoral and sciatic nerve block or femoral and tibial nerve block proved to be effective methods of postoperative analgesia in patients after knee surgery (34). The combined femoral and tibial nerve block seems to be especially useful because it does not cause a foot drop (34). Osaka et al. described the successful postoperative pain control with PNA in a patient with spondylolysis after reconstruction of anterior cruciate ligament (35). The ultrasound was also used for the insertion of femoral perineural catheter in patients after knee arthroplasty (36). The ultrasound guided femoral nerve block is also used in emergency setting in patients that suffered a femur fracture (37).

There are also reports of multiple ultrasound guided PNA as main anaesthesia for lower limb surgery. Davarci et al. compared unilateral spinal anaesthesia and ultrasound-guided combined sciatic-femoral nerve block in ambulatory arthroscopic knee surgeries. They observed that sciatic-femoral nerve PNA reduces complications rate and extends sensory blockade (38). The addition of ultrasound guided obturator nerve block to sciatic and femoral nerve block further decreases the requirements for opioid analgesics during an anterior cruciate ligament reconstruction (39). Ultrasound-guided sciatic nerve block in the popliteal fossa, separate tibial and common peroneal nerve block or ankle blocks are used with very high efficacy reaching 100% in patients undergoing foot surgery (40, 41). The more distal block site the more rapid onset of anaesthesia averaging 10 minutes in case of ultrasound guided ankle block (40). According to Lopez et al in 3% of patients undergoing bunion surgery ultrasound guided saphenous nerve block is also necessary (40). Bech et al. published a report of four patients with severe cardiac insufficiency where peripheral nerve blocks guided by either nerve stimulation or ultrasonography were the sole anaesthetic for above-knee amputation (42).

The ultrasound guided femoral nerve block as an adjunctive anaesthesia in patients subjected to endoluminal laser ablation of the greater saphenous vein. Authors proved that ultrasound-guided femoral nerve block is safe and effective option that lowers volume of tumescent anaesthesia, decreases the number of hemodynamic complications and increases patients’ comfort during the procedure (30).

CONCLUSIONS

Thanks to ultrasonography, the technique of administering a local anaesthetic into the direct vicinity of nerve structures was made more reliable and repeatable, which helped it gain acceptance among anaesthesiologists worldwide. Using ultrasound to control PNA improves the quality of the block, increases the successful block rate, and decreases the risk of complications (43). Even though, there is still no widespread consensus on the teaching and performing of this technique. Practical
experience and available scientific research data on the use of ultrasonography in PNA is very scarce in comparison to the data on the traditional nerve identification techniques in PNA. Many anaesthesiologists still believe that using ultrasound in nerve blocks is an experimental endeavour by a few ultrasonographers. This situation rather hinders than promotes using this valuable technology, especially by beginners. Therefore, every user of this technique can contribute significantly to the efforts made to ensure that ultrasound imaging in PNA receives appropriate support in the form of scientific research. Once it is done, the greatest number of patients will benefit from the most modern technique possible. The success of PNA performed under ultrasound guidance depends on many factors, but it is the skills of the anaesthesiologist and his or her determination in performing this anaesthesia, which are the most important and necessary in PNA. Learning the anatomical cross-sections and the ultrasonographic images of nerves requires time and experience. So, as it is the case of every medical procedure, the proper training is an absolute condition of proper and successful anaesthesia with this method. Most anaesthesiologists who use ultrasonography to perform PNA hope that this technique will spread, which will contribute to the increase in the quality of the care and safety of the patient.

The technique of ultrasonography appears to be an effective method used to localize nerve structures, which increases the efficiency of blocks and safety of patients. PNA under ultrasound guidance seems to be an alternative for the patients in whom, due to chronic diseases, performing spinal, epidural, or GA carries a high risk of complications. It also may be a solution for patients with anatomic defects, deformations, and anomalous anatomy of nerves, in whom there are serious technical difficulties in performing other types of anaesthesia. The direct real-time observation of the distribution of local anaesthetic increases the efficiency of the block, the comfort of the patient, and allows to adjust the placement of the needle at any time, and thus decreases the uncertainty of the procedure.

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