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ARTIGO DE REVISÃO

3D and 4D Ultrasound-Guided Peripheral Nerve Blocks: A Rapid Evidence Review

Bloqueio de Nervos Periféricos Guiados por Ecografia 3D e 4D: Uma Revisão Rápida das Evidências

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Brachial Plexus; Imaging, Three-Dimensional; Nerve Block; Ultrasonography
Palavras-chave
Bloqueio Nervoso; Imagem Tridimensional; Plexo Braquial; Ultrassonografia

ABSTRACT

Introduction: The employment of the 3D and real-time 3D (widely known as 4D) ultrasound (US) as imaging technique for performing peripheral nerve blocks (PNB) has some advantages compared to the classical 2D ultrasound imaging. The aim of this review is to synthesize the current existing literature data concerning the feasibility of employing 3D and 4D ultrasound in performing PNBs, as opposed to the classical 2D US.

Methods: This paper is a rapid evidence review of the existing English language literature on this topic in 3 database libraries: PubMed, Embase and Web of Science up to December 2021, undertaken to establish the opportunity of employing these imaging techniques in performing peripheral nerve blocks compared to the standard 2D ultrasonography. Inclusion criteria for the studies encompassed in the review were the following: patients and healthy volunteers who consented to undergo a PNB; intervention studied was any type 3D or 4D ultrasound-guided PNB; conditions of interest were those who required the employment of a PNB in their treatment; the comparison was made with the standard 2D ultrasound-guided PNB technique; outcomes of interest were diverse: the success rate of the blockage, the circumferential spread of the local anaesthetic around the nerve desired to be blocked, rate of failure, rate of complications. Exclusion criteria were the employment of the 3D and 4D ultrasound for other procedures than PNBs or interventions for which PNBs were performed but without the aid of 3D or 4D US imaging.

Results: Eleven studies encompassing a total of 94 subjects (patients and healthy volunteers) were included in a qualitative synthesis, the majority of them being case reports and case series (eight out of eleven). The studies described different types of PNBs and in each study, the advantages and drawbacks of 3D or 4D US employment identified by authors were noted. Overall, the number of identified advantages is higher than the number of identified drawbacks (twenty vs eleven). Moreover, major complications were not reported in any of the eleven studies.

Conclusion: A positive balance between the advantages and the drawbacks of 3D and 4D US imaging methods in PNBs compared to the classical 2D US was identified, therefore employment of these imaging techniques in the field of regional anaesthesia might represent a promising option. However, due to the weak strength of evidence of the studies included, further research is warranted.

RESUMO

Introdução: O uso da ecografia (ECO) 3D e 3D em tempo real (conhecida como 4D) como técnica de imagem para a realização de bloqueios de nervos periféricos (BNP) apresenta algumas vantagens em relação à ecografia 2D. O objetivo desta revisão é sintetizar os dados atuais existentes na literatura sobre a vantagem em utilizar ecografia 3D e 4D na realização de BNP em oposição à ECO 2D clássica.

Metodologia: Trata-se de uma revisão rápida da evidência existente na literatura científica em inglês sobre o tema pesquisada em três bases de dados: PubMed, Embase e Web of Science até dezembro de 2021, realizada para estabelecer a oportunidade do uso das técnicas de imagem em questão na realização de BNP comparadas com a estandardizada ECO 2D. Os critérios de inclusão dos estudos para revisão foram: pacientes e voluntários saudáveis que consentiram a realização de BNP; a intervenção estudada foi qualquer BNP guiado por ecografia 3D ou 4D; as condições de interesse foram aquelas que exigiam o emprego de BNP no seu tratamento; foi realizada comparação com a técnica BNP guiada por ecografia 2D *standard*; foram diversos os resultados de interesse: taxa de sucesso do bloqueio, dispersão circunferencial do anestésico local ao redor do nervo alvo, taxa de insucesso e taxa de complicações.

Os critérios de exclusão foram: o emprego da ecografia 3D e 4D para

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outros procedimentos que não o BNP; intervenções para as quais o BNP foram realizados, mas sem o auxílio de imagens de ECO 3D ou 4D.

Resultados: Onze estudos envolvendo um total de 94 indivíduos (pacientes e voluntários saudáveis) foram incluídos numa síntese qualitativa, sendo a maioria deles relatos de casos e séries de casos (oito de onze). Os estudos descreveram diferentes tipos de BNP e em cada estudo as vantagens e desvantagens da utilização da ECO 3D ou 4D identificadas pelos autores foram devidamente registadas. Na generalidade, o número de vantagens identificadas é superior ao número de desvantagens (vinte v. onze). Não foram também relatadas complicações major em nenhum dos onze estudos.

Conclusão: Identificou-se um balaço positivo entre as vantagens e as desvantagens nos métodos de imagem de ECO 3D e 4D em BNP comparativamente à ECO 2D, portanto, o emprego dessas técnicas de imagem no campo da anestesia regional pode representar uma opção promissora. No entanto, devido à fraca força de evidência dos estudos incluídos, mais pesquisas são necessárias.

INTRODUCTION

Regional anaesthesia is a technique widely employed in various surgical interventions with widely acknowledged benefits. Peripheral nerve blocks (PNBs) are considered a subtype of the broader field of regional anaesthesia and are employed mainly when a unilateral blockage is desired (e.g. in the case of limb surgery). With this type of anaesthetic technique, the patient's recovery after the intervention is extremely fast (e.g. total hip or knee replacement surgeries performed in an outpatient setting with 23-hour observation),[1] making it possible to undergo such procedures in hospital outpatient departments (HOPDs) or ambulatory surgery centres (ASCs). According to a study by the New York School of Regional Anesthesia (NYSORA), the number of the ASCs in the United States, increased from only 67 in 1976 to 5344 in 2011, with more than 580.000 PNBs performed in 2006.[1]

While anatomical landmarks were historically of use for the identification of certain nerves, nowadays direct visualization has become standard. Two-dimensional ultrasound has been used for decades now for the visualization of the nerve desired to be blocked, but with some well-known limitations: in order that the entire block needle to be visualized, it must be aligned perfectly in the beam generated by the ultrasound probe; the structures localized either anterior or posterior to the section of the ultrasound beam cannot be visualized; the spread of the local anaesthetic (LA) outside this plane cannot be visualized.[2,3]

In the later years, novel techniques have been developed, which allow even better visualization of the nerve anatomy and the surrounding structures. Three-dimensional ultrasound (3D US) and real-time three-dimensional ultrasound (the so-called 4D US) have broadened the array of information the operator can obtain through imaging techniques. Being a relatively new imaging technique employed in the field of regional anaesthesia, evidence regarding its feasibility in this area is scarce.[4] Moreover, given the wide array of existent peripheral nerve block techniques and the high technological demands this technique implies, its research is even more laborious. The aim of this study is to provide a rapid evidence review of the current literature evidence for the feasibility of employing the 3D and 4D ultrasound imaging techniques for patients who are candidates for a surgical procedure in which a PNB is to be employed.

METHODS

Devising the PICO question

In patients who are candidates for undergoing a PNB but also in healthy volunteers willing to undergo a PNB, what is the difference between peripheral nerve block performed with the aid of 3D or 4D ultrasound direct visualization and the already established PNB techniques made with the aid of classical 2D US on the following: success rate of the block, circumferential spread of the local anaesthetic around the blocked nerve, rate of failure, rate of complications?

Definition of inclusion and exclusion criteria for studies

Since the objective of the review is to find evidence about the feasibility of the 3D and 4D ultrasound imaging technique in PNB, studies were included in this protocol by the following criteria:

- Patients who were candidates for undergoing a PNB (e.g. orthopaedicc, trauma etc.) and healthy volunteers who consented to undergo a PNB;
- The intervention to be studied is to be considered both a therapeutic and a diagnostic one: peripheral nerve block, peripheral neural blockade performed with the aid of 3D or 4D ultrasound direct visualization. Any type of PNB in which one of these images techniques was employed was considered eligible;
- Conditions which required a PNB either for direct treatment (e.g. for chronic pain management), or employed as an anaesthetic technique during a surgical intervention;
- A comparison was made with the already established PNB techniques made with the aid of classical 2D US;
- The outcomes were multiple since the objective of the review is to designate multiple advantages and possible drawbacks of this technique employed in PNB: Success rate of the blockage, circumferential spread of the local anaesthetic around the nerve desired to be blocked, rate of failure, rate of complications;

- Types of studies included: Case reports, case series, cohort studies, randomized control trials;
- Period during the studies were published (all the studies published respecting the desired intervention and outcomes up to December 2021 were included).

Exclusion criteria were the following:

- Employment of the 3D or 4D ultrasound as an imaging technique, but with another purpose than performing a PNB (e.g. in specialities like obstetrics, gastroenterology, cardiology etc.);
- Interventions consisting in PNB, but in which there was no mention of usage of 3D or 4D ultrasound neither for performing the nerve block nor for post-procedural data acquisition;
- Other types of studies.

Searching for studies

The first step was to devise a series of keywords that would be included in an advanced search. The following keywords were considered as relevant for the review's topic: 3D ultrasound, three-dimensional ultrasound, real-time ultrasound, 4D ultrasound, live ultrasound, regional anesthesia, peripheral nerve block, block, radial nerve, brachial plexus, sciatic nerve. The used keywords contain both the imaging techniques desired to be studied, as well as the intervention and some peripheral nerves targeted in regional anaesthesia. An advanced search was performed on the 3rd of August 2022 on PubMed, Embase and Web of Science online database libraries for results up to December 2021 using the following advanced search strategy ((3D) AND (ultrasound) OR (Three AND dimensional AND ultrasound) OR (Real-time AND ultrasound) OR (live AND ultrasound)) AND (4D AND ultrasound)) AND ((Regional AND anesthesia) OR (peripheral AND nerve AND block) OR (block) OR (radial AND nerve) OR (Brachial AND plexus) OR (Sciatic AND nerve)).

Case reports, randomized controlled trials, systematic reviews and meta-analyses were considered eligible for this rapid evidence review.

Moreover, after the advanced searches performed on these three databases, an extensive manual search was performed on PubMed based on the references of the articles found at the automatic search.

Selecting studies

After the searching strategy was established and the search was performed, each result underwent a process of screening. The title of each article yielded by the advanced search was analyzed for inclusion and exclusion criteria. The eligible results from each search were kept and the other search results were discarded. The resulted duplicates were afterwards removed.

Each article considered eligible after the first screening process was consulted and a manual search was performed by screening the references again by title and abstract. All the sets of potentially useful references were collected and put together. Duplicates were removed.

The articles selected up to this phase by reading the titles and the abstracts underwent a full-text reading. For each article, the presence of inclusion or exclusion criteria was followed in the integral text. Although some of the articles seemed to fulfil the inclusion criteria judging by the title or the abstract of the article, after a thorough reading process some clear exclusion criteria stated in the sub-chapter *Definition of inclusion and exclusion* criteria were identified: inadequate study type, lack of required imaging method, different intervention than PNB etc.

Collecting data from studies

Each previously declared eligible article was read and a series of data were searched for and collected. In accordance with the objectives of this rapid evidence review stated previously in the sub-chapter *Objectives*, the following data was considered of real importance:

1. Type of study;
2. The specific PNB described (e.g. radial nerve block, median nerve block, popliteal nerve block) and the imaging technique employed;
3. Additional usage of electrical nerve stimulation (ENS) for initial needle confirmation (yes/ no/ N/A);
4. All the advantages and drawbacks of these techniques are specifically stated in the article;
5. Time of onset of a complete block (value in minutes);
6. Catheter employment for postop analgesia (yes/ no/ N/A);
7. The appearance of any postoperative complications;
8. The number of patients enrolled in each study.

All the identified data was synthetized in Table 1.

Also, the most important factors which might affect the applicability of the evidence must be determined. To do this in a systematic manner, the same PICO algorithm is used. This is a useful way to screen for conditions that may limit the applicability and present them systematically. This operation was done for the current review and the results were presented in Table 2.

Analyzing data

The data collected was analyzed with the aid of Microsoft Excel Office 365 program. The same program was used to plot the charts and calculate means. The tables and the flowchart diagram were created using Microsoft Word Office 365.

Table 1. Characteristics of included studies

Study number	Type of Study	Type of PNB and Imaging technique employed	ENS employed	Described advantages	Described drawbacks	Time of onset complete block	Postoperative complications	Catheter placement	No. of pts
1	CR	Radial nerve block – 3D US	Yes	LA visualized surrounding the nerve	- Large probe (5x6 cm)- cumbersome usage - Lower frame display rate than in 2D US- hampers the real-time display of the needle movement	5 min	none	No	1
2	TD	Any PNB – 4D US	No	- LA visualized surrounding the nerve - Measure the volume of LA	Specialized machine and transducer required	N/A	N/A	Yes	N/A
3	CR	Infraclavicular brachial plexus block – 4D US	Yes	-Probe can be held stationary -Large band of US data can be manipulated -Real-time visualization in multiple planes	Current transducers not specially developed for regional anesthesia	N/A	none	Yes	1
4	RCT	Lateral popliteal nerve block subfascial vs extrafascial – 3D US postblock scan	No	Measure the volume of LA accurately	N/A	30 min (63% extrafascial, 90% subfascial)	none	No	60
5	CS	Thoracic paravertebral block – 3D US for spatial mapping	N/A	More detailed anatomical data	Retrospective technique	N/A	N/A	No	4
6	RCT	Median nerve block – intended circum-ferential spread of LA vs non cirumferential spread of LA – 3D US	No	Detailed information about the spread of the LA	Slow screen refresh rate of the 3D US technology doesn't assess the spread of LA in real-time	15 min -circumferential spread 20 min- non-circ spread	none	No	21
7	CR	Axillary brachial plexus block – 4D US	Yes	Able to visualize the influence of arterial pulsation on the LA spread	Upper frequency limit of 7 MHz- low resolution in superficial scanning	30 min	none	No	1
8	CR	Continuous popliteal blockade – 3D US	Yes	-LA visualized surrounding the nerve -Catheter placement confirmation -Rapid reversion between 2D and 3D images while performing the procedure – versatility	Need of 3D transducers better suited for neural structures imaging	N/A	none	Yes	1
9	CS	Continuous popliteal blockade – 3D US	No	Catheter position visualization	Complexity of the technique	N/A	none	Yes	3
		Subgluteal sciatic nerve block – 3D US		LA perineural spread	Increased amount of information makes it impractical			No	
		Axillary plexus block – 3D US						No	
10	CR	Continuous popliteal blockade – 3D US	Yes	- 3D US revealed aberrant anatomy possibly explaining the primary and secondary block failure -Catheter position visualization	N/A	N/A	Intractable pain after repair of trimalleolar fracture under regional anestheisa performed with 2D US imaging	Yes	1
11	CR	Continuous interscalene brachial plexus blockade – 4D US	Yes	-Probe can be held stationary -Large band of US data can be manipulated -Real-time visualization in multiple planes	Upper frequency limit of 7 MHz- low resolution in superficial scanning	N/A	none	Yes	1

Legend:
N/A = not available, not mentioned, **CR**= case report, **TD**= technique description, **RCT**= randomized control trial, **CS**= case series

RESULTS

Study selection

The search in PubMed yielded 35 results. Out of the 35 results, only four fulfilled the inclusion criteria stated above after reading the title and the abstracts (Fig. 1) The other results were only partially fullfilling the inclusion criteria. Twenty-five of the search results were employing 3D and 4D ultrasound imaging techniques but in other medical domains: Cardiology (nineteen results), Pneumology (three results), Gastroenterology (one result), Oncology (one result). One result was a review article that briefly descriebed different technical inovations in regional anaesthesia but it did not fulfil the inclusion criterias. Five results were articles about other imaging techiques (computed tomography-CT/ magnetic resonance imaging-MRI). The Embase search yielded twelve results. The same four articles that were previously found on PubMed search were found eligible, the other seven results were articles describing the 3D/ 4D ultrasound imaging technique in other specialty fields: five in cardiology, one in

Table 2. Results

	Conditions that may limit applicability	Example	Feature that should be abstracted in evidence tables
Population	Large differences between sample sizes in different studies	1 patient in the case reports and 60 patients in RCTs	Number of patients enrolled in a study
	Differences between demographics of selected patients	Differences in studies results due to differences in patients' demographics	Features like age, sex, race, ethnicity
	Differences in the health status of patients included in different studies	Orthopedic patients vs. healthy volunteers	Patient's comorbidities, patient's acute complaints
Intervention	3D and 4D US implies availability of high-performance technological requirements, not available routinely in healthcare settings	US probes, specially adapted for regional anesthesia purpose	Type of US machine employed and the probe(s) used
	Differences between types of PNBs chosen or combinations of PNB techniques	Interscalene brachial plexus block vs axillary brachial plexus block vs infraclavicular brachial plexus block	Type of PNB employed and motivation of the choice
Comparison	Missing of the comparison technique in the same study, and therefore the comparator is not applied on the same patients	In the case reports, only the new imaging technique was employed. Comparison with the standard in use is made on similar but distinct patients	Whether or not the patients underwent both imaging techniques for the PNBs: the 2D US and the new 3D/4D US
Outcome	Different studies follow different outcomes – some studies put little importance on some outcomes of interest for our review	Many studies do not mention the time of onset of the block	Mention for each selected study the aim of the study and the outcomes it inquired
	Different studies mention different advantages and drawbacks of the 3D and 4D US use in PNB: these are subjective observations	There are 20 advantages identified in the 11 studies analyzed, 11 of them being different	Predefined areas for finding advantages and drawbacks (e.g. image quality, technical requirements, block parameters improvement etc.)

urology and one in obstetrics. Finally, the search on Web of Science data library revealed a total of sixteen results, but after a detailed screening only three of them fulfilled the inclusion criteria. Ten of the results were articles in which 3D and/or 4D ultrasound was employed in other fields: Cardiology (five results), Hepatology (three results), Obstetrics/Gynaecology (one result), Urology (one result). One result was a not medically-related article and two results were not fulfilling the inclusion criteria since, even if they described technical innovation in the field of regional anaesthesia, no PNB was specifically considered.

Starting from the first four results, we searched the references. One article had only one reference of interest according to the inclusion criteria. The second article yielded eleven potentially useful references. One reference was excluded because it was an article about the employment of 3D/4D ultrasound in epidural catheter placement, which does not completely fulfil the intervention criteria – PNB as intervention. The third article had seven references in total, out of which five fulfilled the inclusion criteria. The other two articles described different imaging modalities (classic 2D US) employed for different medical purposes. The last of the four articles contained ten references but only five fulfilled the eligibility criteria. The other five references stated in title other medical specialties in which this technique was employed: oncology, hepatology, spinal anesthesia.

Flow of studies

An initial screening was performed by reading the titles of the articles and twenty-nine, eight, and thirteen studies were excluded from the PubMed, Embase, and Web of Science search results respectively. The reasons for exclusion were previously presented. A total of eleven studies remained but after duplicates were removed, only four potentially eligible studies resulted. The manual search retrieved a total of twenty-six studies. Out of these twenty-six, ten were duplicates and were removed. After the previously described steps, sixteen articles remained. Consecutively to a thorough reading process, five articles were discarded due to failure of meeting the inclusion criteria. A total of eleven eligible articles were included in the rapid evidence review. The algorithm of search and selection of studies is presented below in a flowchart diagram (Fig. 2).

Data extraction

For each study a series of data were recorded: the study type (e.g. case report (CR), case series (CS), randomized control trial (RCT) etc.), the type of PNB described in each study, as well as the imaging technique employed (either 3D US or 4D US) and whether or not ENS was employed to confirm the proper initial position of the needle. Moreover, the identified advantages of using this new imaging technique mentioned in each study were recorded, as well as the identified drawbacks. For a minority of the studies, the time of onset of complete block was mentioned and it was recorded in a distinct column. Any postoperative complications, whether or not a catheter was provided, and the number of patients enrolled in each study were all recorded in distinct columns. All the data from the studies was collected and registered in Table 1.

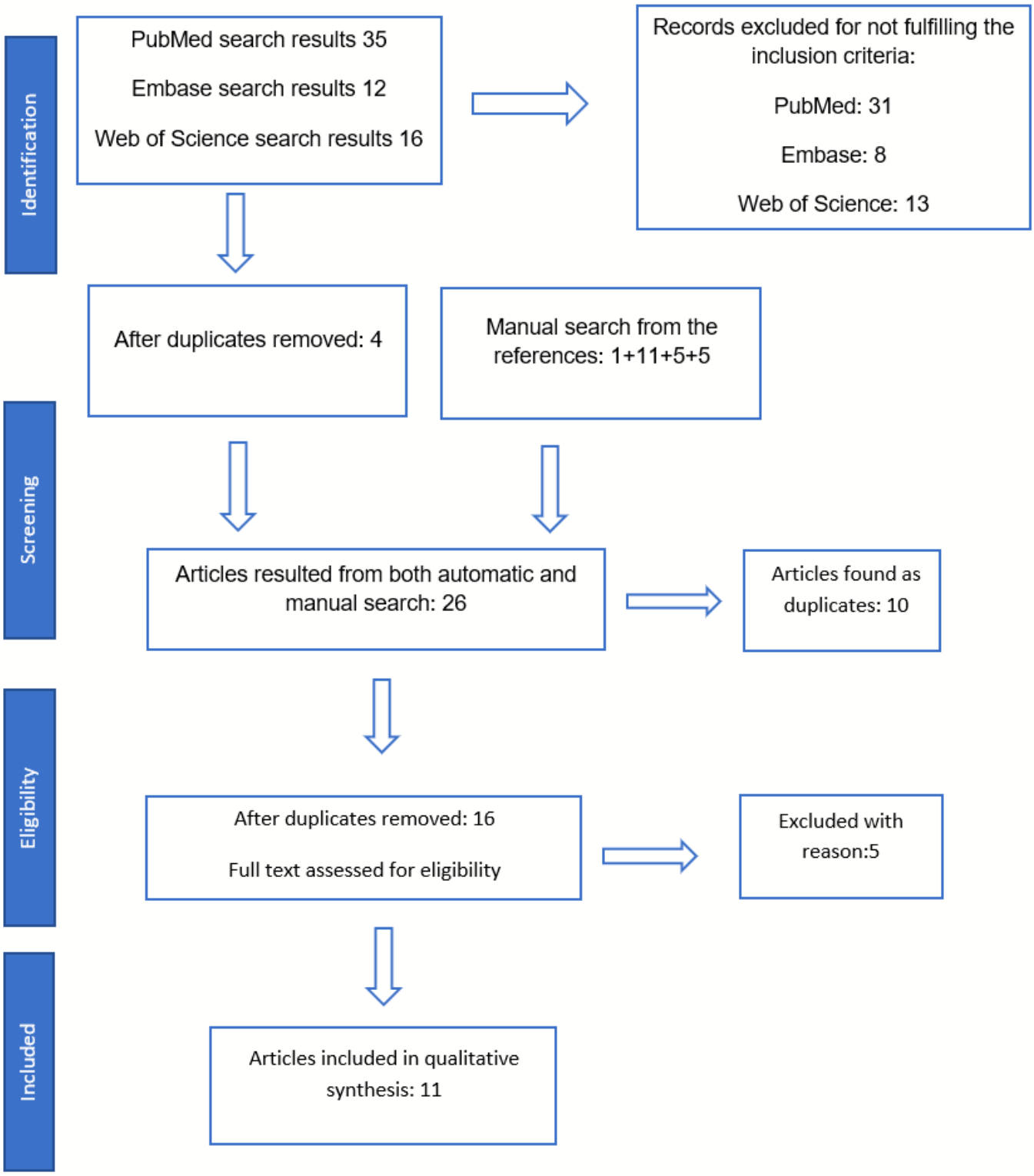

Figure 1. Systematic Review Flowchart Diagram

Studies' analysis

Out of the eleven studies selected, six were case reports, two were case series, two were randomized control trials and one study is a technique description.

In all studies, a total number of 94 patients were included (also comprising healthy volunteers) who underwent a type of PNB in which either 3D US or 4D US was employed as imaging method. One of the studies did not include any patients since it was a technique description – the procedure of performing a PNB with the aid of 4D US for direct vizualisation is described step by step.[21]

Regarding the imaging technique that was used, in 7 out of the 11 studies 3D US was employed.[9–13,15,22] In the other 4 articles, real-time US (4D US) was the chosen technique.[5,6,16,21] The following types of PNBs were identified in the eligible studies: radial nerve block,[22] infraclavicular brachial plexus block,[5] popliteal nerve block with and without catheter insertion for

postoperative analgesia,[10,12,13,15] thoracic paravertebral block,[9] median nerve block,[11] axillary brachial plexus block,[12,16] interscalene block with catheter placement[6], subgluteal sciatic nerve block.[12] In some studies, more than one type of PNB was described (e.g. in case series).[12]

As an adjunctive method, ENS was employed for initial confirmation of needle placement in the proper position in 6 studies.[5,6,13,15,16,22] In 4 of the studies, the PNB was performed without the aid of ENS,[10–12,21] and in 1 study it was not specified whether or not this was used.[9]

The time of onset of complete block is only mentioned in 4 of the studies,[10,11,16,22] being highly variable, ranging from 5 min (in case of the radial nerve block)[22] to 30 min in case of axillary brachial plexus block and lateral popliteal block.[10,16] In the other 7 studies, the time of onset of complete block is not mentioned.[5,6,9,12,13,15,21] Continuous peripheral blockade by catheter placement was provided in 6 described cases (including the cases comprised in the case series).[5,6,12,13,15,21]

The presence of postoperative complications was also recorded. In 8 out of the 11 studies, it was specifically stated that no complications occurred.[5,6,10–13,16,22] These included a number of 89 PNB interventions in which either 3D or 4D US was used, either as direct imaging technique or for confirmation of complete neural surrounding by LA. The other 3 studies did not indicate any complication directly linked with the usage of 3D or 4D US as imaging techniques either.[9,15,21] In 2 of them,[9,21] this aspect was not approached, and in the other one15 a complication is mentioned but is attributed to a previous PNB procedure in which classic 2D US was the chosen imaging technique.

The advantages and drawbacks of these imaging techniques identified in each study were listed in the corresponding column of the Table 1. These were noted as advantages or drawbacks by comparison to a standard imaging technique such as 2D US or by comparison to the usage of ENS alone.

In total, in all the 11 studies,[5,6,9–13,15,16,21,22] 20 advantages of 3D and 4D US techniques were mentioned. Some advantages were identified in multiple studies. Among those 20 benefits identified, 11 are distinct from each other.

The identified advantages were listed in Table 3, in descending order of the frequency with which they were mentioned. In accordance to a specific imaging technique, for the PNB employing 3D US, 11 advantages of this imaging technique were reported in the 7 studies containing this technique.[9–13,15,22] The 4 articles presenting PNB performed with the aid of 4D US, outlined 9 advantages of this specific technique, in total.[5,6,16,21]

A series of disadvantages or drawbacks were also described and recorded accordingly in Table 1. In the 11 studies analyzed[5,6,9–13,15,16,21,22] a total of 11 drawbacks were identified. The identified drawbacks were also listed in Table 3 in the descending order of their mentioning frequency, as some of them were noted in multiple studies. Specifically considering the imaging technique employed, the seven studies which contained the 3D US[9–13,15,22] outlined a series of seven drawbacks, while in the four studies in which 4D US was used as imaging technique a number of four drawbacks was found.[5,6,16,21]

DISCUSSION

Summary of main results

The evidence on which the results are based has low strength, since the majority of the identified studies are case reports (6 out of 11) and 2 out of 11 are case series, each consisting of only 3 and 4 cases respectively.

In the 11 selected studies, a total of 12 types of PNBs were described in which either 3D or 4D US were employed directly in block performance or indirectly for checking the LA distribution. Some articles comprise several different types of PNB. Out of the 12 PNBs described in the selected studies, 25% of them were popliteal blocks, suggesting that this was a preferred type of nerve block in which these new imaging techniques might be feasible.

Overall, a total of 8 different types of PNBs, in whose performance either 3D or 4D US were employed, were identified. This suggests that these new imaging techniques might prove relatively versatile in the field of regional anesthesia.

However, only in case of the popliteal nerve block these imaging methods were described in four studies and for the axillary brachial plexus block in two different studies. The other 6 types of PNBs in which these novel imaging techniques were used, were presented in singular studies – mostly case reports.

This suggests a weak, mostly insufficient evidence supporting these two imaging techniques in regional anesthesia as standard of care at this point. Further research in this field is warranted.

As with the 2D US, ENS was proven a valid option in conjunction with the 3D and 4D US, being employed in the majority of the discussed studies (6 out of 11). According to this observation, it could be stated that the 3D and 4D imaging techniques might be considered an adjunct to the ENS rather than an alternative to it.

In respect of the time of onset of the neural block, the studies revealed a similar time obtained by the classic 2D US. Even if the 3D and 4D US techniques allow for better visualization of the spreading of the LA, this does not seem to influence significantly the parameters of success. This observation was noted in a RCT conducted by Marhofer *et al.*[11]

The 11 studies comprised a relatively low number of patients – 94 in total, including healthy volunteers. Given the low number of subjects, the results of the studies cannot be extrapolated to a general population of patients.

Table 3. Identified advantages and drawbacks

Nº.	Identified advantages	No. of studies in which the advantage was reported	Identified drawbacks	No. of studies in which the drawback was reported
1	LA visualized surrounding the nerve[12,13,21,22]	4	Upper frequency limit of 7 MHz translates into a low resolution in superficial scanning[6,16]	2
2	Catheter position visualization/ confirmation[12,13,15]	3	Current transducers not properly suited for regional anesthesia[5,13]	2
3	Possibility to measure the volume of LA from a certain area[10,21]	2	Lower frame display rate than the 2D US (in the case of 3D US) – difficulties in assessing the spread of LA in real-time[11,22]	2
4	Possibility to hold the probe stationary[5,6]	2	Large probe (5x6 cm) – cumbersome usage[22]	1
5	Real-time visualization of multiple planes[5,6]	2	Complex technique[12]	1
6	Large band of US data can be manipulated[5,6]	2	Specialized machine and transducer required[21]	1
7	Possibility to rapidly switch the mode between classic 2D view and 3D view, conferring versatility to the technique[13]	1	Increase amount of information gathered makes the technique impractical[12]	1
8	Possibility to identify aberrant anatomy[15]	1	Retrospective technique (3D US)[9]	1
9	Possibility to visualize the influence of arterial pulsation on the LA spread[16]	1		
10	Detailed information about the LA spread[11]	1		
11	More detailed anatomical data acquisition[9]	1		

Only two studies included a relatively higher number of enrolled patients: the 2 RCTs.

From the analyzed data resulted that catheter placement for postoperative analgesia is a feasible procedure to be performed under 3D or 4D US guidance. In the case where classic 2D US is elected as the imaging method employed during the catheter insertion, these modern techniques can be very effective in checking the proper position of the catheter.[5,6,12,13,15,21]

Concerning the advantages of these 2 imaging methods outlined in the 11 discussed studies, the most frequent advantage mentioned was the clear visualization of the LA surrounding the nerve.[12,13,21,22] It is true that this feature can be many times obtained by experienced operators with the classic 2D US, but the array of data generated by the 3D imaging is higher and the image is clearer. Therefore, the operator can state with a higher confidence whether or not the LA totally surrounded the nerve. Similarly, the possibility to confirm a correct catheter placement in the perineural place was one of the top outlined advantages of these techniques.

An important addition which these two techniques are bringing is the possibility to accurately measure volumes of interest. The volume of LA which surrounds a nerve or is dissipated in a fascial plane etc. can be determined with the aid of 3D US.[10,21]

Overall, a total number of eleven different advantages were mentioned in the selected studies which brings an important number of reasons in favor of considering these techniques as a valid option for PNB good practice. Considering such an important number of possible advantages, the 3D/4D US could be viewed as a promising alternative to the classic 2D US.

Besides the clear benefits these two techniques might bring in the field of regional anesthesia, some downsides were also pointed out by the studies. Current technical limitation and lack of transducers specially designed for the purpose of PNBs were the main problems identified. Overall, a number of 11 drawbacks were stated in all the 11 studies, which suggest a beneficial ratio between the advantages and the drawbacks, namely 20:11.

Agreements or disagreements with other studies or systematic reviews

There are limited studies published on this topic. The most important review published on this matter so far dates back to 2015.[4] That review comprises some of the studies included also in this review. In the end, the authors conclude by stating the necessity of further research on this matter due to the novelty of technology. The current review supports this opinion.

Another review from 2019 presents the technological novelties employed in the field of regional anesthesia. Here, 3D and 4D US are discussed briefly, with the following conclusion: "Larger studies and much more research is needed to further validate the use of 3D US for regional techniques."[20]

The current review agrees with that conclusion due to the reasons stated above.

Applicability of evidence

In order to assess the applicability of found evidence, a series of steps must be followed, steps which have been described in the work *Methods Guide for Comparative Effectiveness Reviews in the chapter Assessing the Applicability of Studies When Comparing Medical Interventions*.[23]

The next step is to make and report judgments about the limitation of applicability of individual studies included in the review. The major limitation was already stated previously: the fact that 6 of the 11 studies included in the review are case reports.[5,6,13,15,16,22]

This means they have a sample size of one, making the generalization of the applicability of the results to other patients impossible.

Two other studies have enrolled instead of patients, healthy volunteers.[9,11] This particular feature of their design might be an impediment in generalizing the applicability of their results.

Limitations

Although efforts have been made to conduct the current review in the spirit of good scientific practice, following the required steps as strictly as possible, it is clear that it also has some important limitations.

The most important factor that might represent an important limitation to applicability of evidence is the heterogeneity of studies' sample sizes. Moreover, the majority of presented studies being case reports (sample size = 1) and only 2 being RCTs, the results of these studies cannot be generalized to other patients. However, considering the novelty of this imaging method and the high technical requirements it imposes, the scarcity of ample studies is understandable.

Another important limitative factor which should be outlined is represented by the heterogen outcomes different studies follow.

Due to this reason, the data obtained for the purpose of our review is limited and therefore the results are affected.

In the searching for studies process of this review only three medical databases were consulted: PubMed, Embase and Web of Science. A more extensive advanced automatic search on more databases may have generated more studies to be included. Similarly, as stated in the inclusion criteria, only the studies published up to December 2021 were included.

Finally, a thorough quality of evidence analysis including a risk of bias table to encompass every of the eleven considered studies is missing.

This is to be considered also as a major limitation of the current rapid evidence review.

Considering the previously mentioned limitations, the quality of the evidence of the current review is a relatively low one. All the studies included in this work mention the importance of further research in this field. These two imaging techniques - 3D and 4D US – being relatively new, particularly in the field of regional anesthesia and the technical requirement being prohibitive for many healthcare settings, the scarcity of ample studies is understandable.

CONCLUSION

This systematic review of the literature evidence on employing 3D and 4D US in PNBs, identified a positive balance between the advantages and the drawbacks of these techniques, compared with the current standard of care (ENS or 2D US). Moreover, the lack of reported complications gives hopes for the inclusion of these new imaging techniques in future standard practice. On the other side, the currently difficult to attain technical requirements make the option of commonly employing 3D/4D US in PNBs impossible for the time being. However, the relatively low number of studies included, majority being case reports, the low sample sizes of these studies and the subjective character of some data (e.g. advantages and drawbacks identified), limits the applicability of the evidence. To conclude, it should be stated that 3D and real-time 3D US (4D US) represent a promising option in the field of regional anesthesia, by their employment as imaging techniques in PNBs. However, their development being at its inception, further research and technical development in this field is warranted.

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