The role of Power Doppler in ultrasound-guided percutaneous procedures: the Jet sign

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Abstract

In recent decades, ultrasound-guided percutaneous infiltrative procedures have gained prominence in treating musculoskeletal disorders, providing enhanced accuracy over traditional blind techniques. This study examines the utility of the Power Doppler ultrasound technique, specifically the Jet sign, in identifying needle placement during infiltrative treatments. A retrospective analysis was conducted involving 5,376 patients where procedures were performed under ultrasound guidance from January 2014 to January 2022. While the needle tip was successfully visualized in 7% of cases, the Jet sign facilitated accurate localization in 368 instances. This technique capitalizes on the creation of a high-pressure fluid flow, enabling real-time monitoring and precise targeting of the therapeutic agent while minimizing complications. The findings underscore the effectiveness of the Jet sign in enhancing procedural accuracy and suggest its incorporation into clinical practice to optimize outcomes in ultrasound-assisted infiltrative therapies.

Key Words: Power Doppler; ultrasound-guided percutaneous infiltrative procedures; Jet sign.

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In recent decades, outpatient percutaneous interventional procedures in the field of musculoskeletal disorders have taken on an increasingly important role in the treatment of numerous joint and extra-articular pathological conditions. The rationale for infiltrative therapy is based on the ability to effectively utilize the specific pharmacological action of the substance employed, both on the painful symptoms and on the pathogenetic mechanisms of the disease. To achieve greater effectiveness and, consequently, a stronger therapeutic effect, the main objectives to pursue are the correct identification of the site of pathology and the precise targeting of the therapeutic agent.

The traditional infiltrative technique relies on the manual identification of superficial anatomical landmarks, depending on the experience and skill of the operator to reach the target.

Ultrasound guidance in infiltrative procedures is progressively replacing traditional blind injections, having demonstrated greater accuracy in the execution of infiltrative treatment, as it allows real-time control of the entire procedure, from target identification to drug injection.[1,2]

The technical and methodological advantages of ultrasound-guided infiltrative procedures are represented by the recognition and monitoring of the needle throughout its course through the tissues, from the entry site to its correct positioning within the target structure. This allows for maximum injection accuracy and helps to identify and avoid critical structures such as vascular and nerve bundles, minimizing the occurrence of potential local complications or side effects.[3]

In addition to these considerations, intrinsic advantages of the ultrasound method align perfectly with the literature data, including: i) absence of ionizing radiation, making procedures safe and repeatable for both the operator and the patient; ii) ubiquitous distribution in outpatient settings; iii) low management costs.

Ultrasound-guided percutaneous interventional procedures are executed through two modalities. In the ultrasound-assisted infiltrative treatment, needle insertion is performed freely with a coaxial or lateral approach to the transducer. This mode allows for variations in the course and angle of needle insertion during the infiltrative act. Typically, the ultrasound operator and the therapeutic operator are the same person. With the ultrasound-guided infiltrative treatment, needle insertion occurs in a fixed manner through a guiding device placed on the short side of the probe, maintaining a constant angle of inclination and insertion, which is electronically visible on the ultrasound monitor via specialized software. This mode usually requires two operators, and the ultrasound operator and therapeutic operator typically do not coincide.

The most frequently encountered error during the execution of ultrasound-guided and ultrasound-assisted percutaneous interventional procedures is the inadequate or poor identification of the needle tip, leading to a lack of verification of its correct placement. This can depend on various factors such as excessive insertion speed, angle of insertion error, lack of coordination between monitor visualization and needle insertion, and needle size.[4]

To facilitate the visualization of the needle or its tip, several techniques are commonly employed, such as moving the needle itself, shifting the needle's mandrel back and forth, making slight oblique movements of the probe to better position the needle within the ultrasound beam plane, injecting a small amount of sterile saline; or inoculating a minimal amount of air.[5]

Considering these techniques and based on our personal experience and the literature, the aim of this work is to verify whether the use of Power Doppler ultrasound can provide significant assistance in accurately locating the needle tip and to suggest the incorporation of such technical adjustments in clinical practice, especially in cases where the inability to identify the needle tip does not allow certainty regarding its position and placement within the target structure.[6]

Materials and Methods

Between January 2014 and January 2022, 5,376 patients (2,043 men and 3,333 women) underwent ultrasound-guided infiltrative procedures for musculoskeletal disorders at the Sergio Mantia Research and Care Institute in Palermo. The average age of the patients was 60.2 years, with an age range from 47 to 72 years.

The data collection was conducted prospectively during ongoing clinical treatments.

Needles of 21 Gauge (G) and 23 Gauge (G) were used, with lengths varying from 40 mm to 90 mm. For ultrasound guidance, two different ultrasound machines, MyLab 70 XVG and MyLab 90 EXP Esaote, were utilized, both equipped with a multifrequency linear probe (3-15 MHz) and a color Doppler and Power Doppler module.

The use of two different ultrasound machines was considered in the evaluation of the results, to avoid potential variables that could affect the accuracy of the localization.

The Power Doppler module allows for the representation of the fluid dynamic field in the selected anatomical area through the application of a color detection box. The ultrasound evaluation parameters considered included: visualization of the needle along its path; identification of the needle within the context of the predetermined target structure; and creation and assessment of the Jet Sign using the Power Doppler module.

To recreate the fluid dynamic effect, a 10 ml syringe containing a solution of 5 ml composed of 4 ml of saline (NaCl 9%) and 1 ml of lidocaine at 1% was used. The recruited patients were not allergic to this substance. All procedures were performed by a specialist physician with twenty years of experience in musculoskeletal ultrasound.

Before proceeding with the study, informed written consent was obtained from the participants after reading the information provided. The authors declare that the presented study was conducted in accordance with the ethical standards established in the Declaration of Helsinki, and that informed consent was obtained from all participants prior to their enrollment in the study.

Results

Out of a total of 5,376 ultrasound-assisted percutaneous infiltrative procedures, it was not possible to identify the exact location of the needle tip in the target structure in 375 cases (7% of the total). Of these 375 cases, 45% were infiltrations of the sacroiliac joint, while 34% were intra-articular infiltrations of the glenohumeral joint performed under ultrasound guidance with a subcoracoid approach. Among the remaining procedures, 14% were intra-articular infiltrations of the hip, and 7% were intra-articular infiltrations of the ankle. In all these cases, the Jet Sign phenomenon (Figure 1) was used, which allowed for the identification of the needle tip position in 368 cases (Figure 2, Figure 3, Figure 4), while in the remaining 7 cases, no phenomenon was observed (Figure 5).

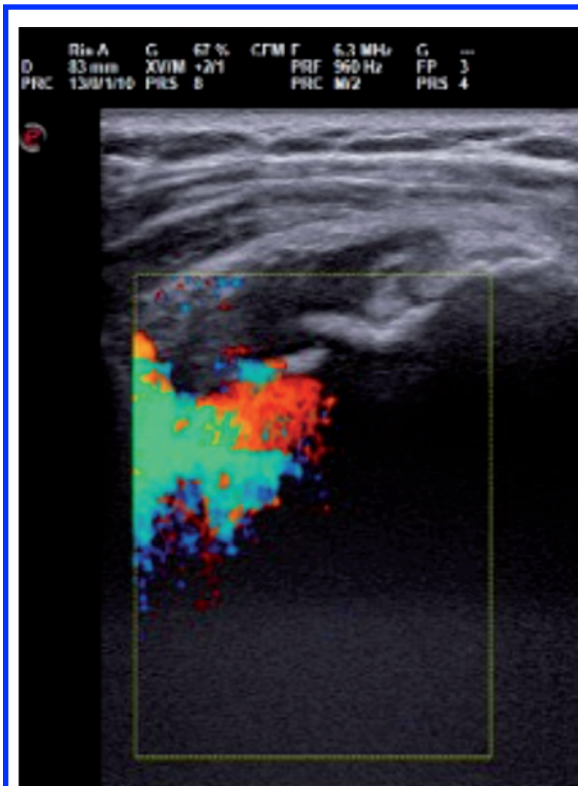

Figure 1. Reproduction of the Jet Sign. The introduction of a mixture composed of saline solution and 1% lidocaine, injected at a relatively high speed, is identified as a flow from the identification box.

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None of the treated patients experienced post-procedural complications.

Discussion

Percutaneous infiltrative therapeutic treatments represent an increasingly widespread method in outpatient specialty settings for the treatment of numerous musculoskeletal disorders, as they are relatively simple and low-cost procedures. For years, these procedures were performed based on the manual identification of anatomical landmarks and the operator's personal experience. Numerous studies have evaluated the effectiveness and accuracy of this technique, defined as blind, highlighting generally high probabilities of therapeutic failure due to poor injection precision.[7,8] The literature is now unanimous in considering ultrasound particularly suitable for guiding percutaneous infiltrative therapeutic treatments. In particular, it has documented the superior effectiveness of ultrasound-assisted and ultrasound-guided infiltrations compared to blind infiltrations in improving clinical outcomes.[9,10]
This superiority in effectiveness is based on the inherent

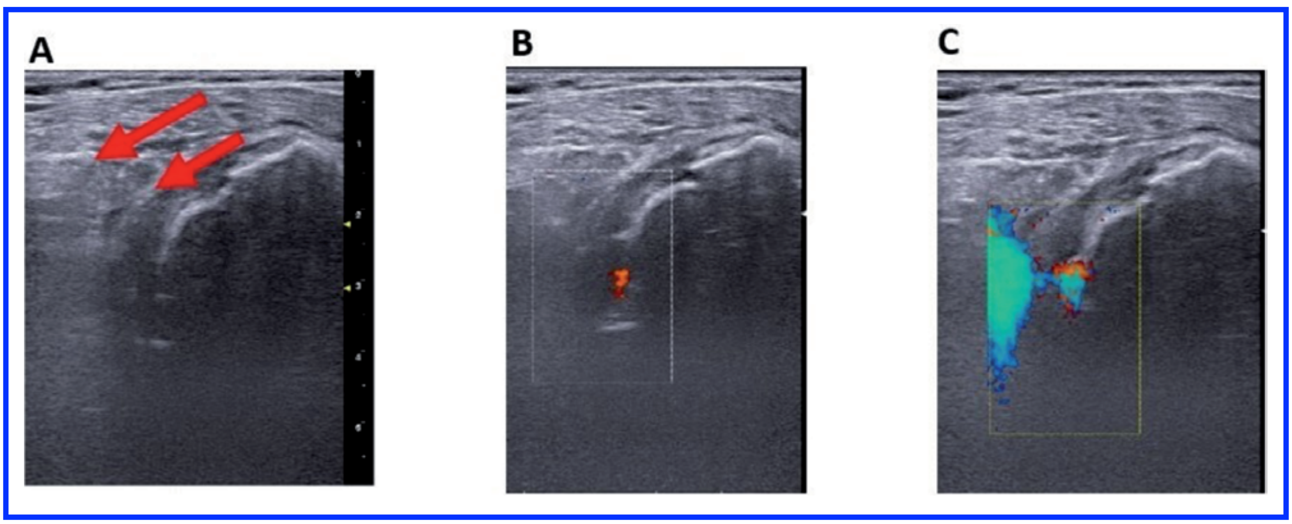

Figure 2. A) Infiltration of the shoulder joint capsule. Possible needle position (red arrow); B) Jet Sign identifying the location of the needle tip intra-articularly; C) Jet Sign demonstrating the incorrect localization of the needle tip and the potential spread of the injected substance into the surrounding tissues.

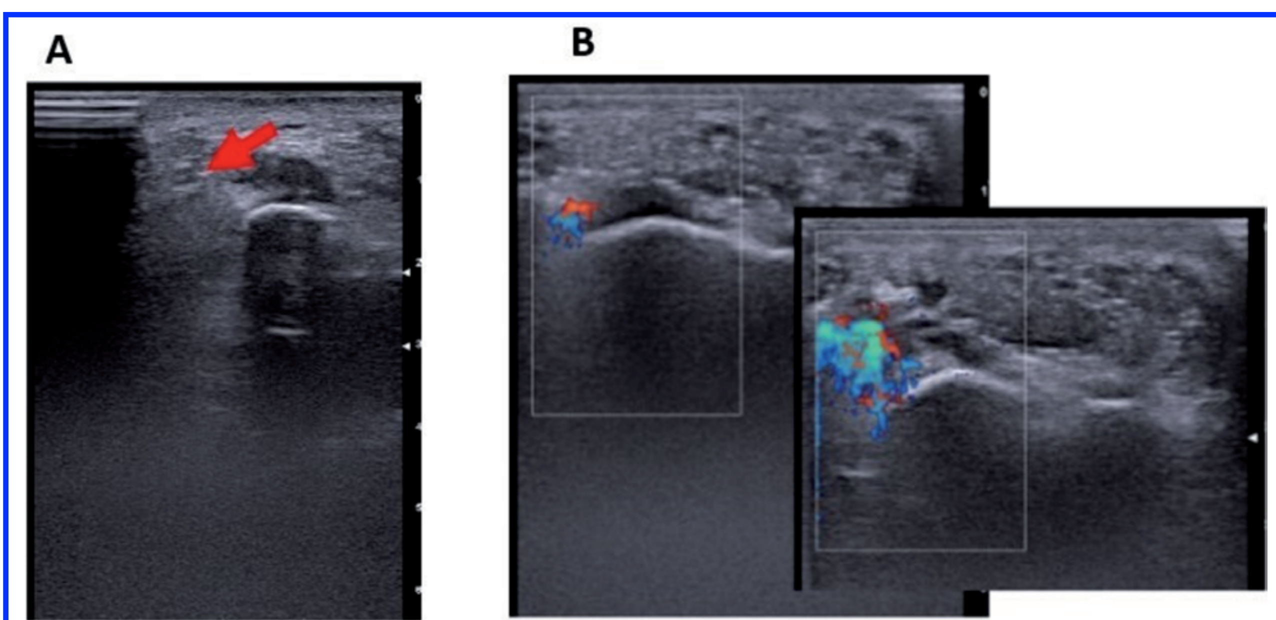

Figure 3. A) Plantar fascia infiltration. Possible needle position (red arrow); B) Jet Sign indicating the location of the needle tip within the fascial area.

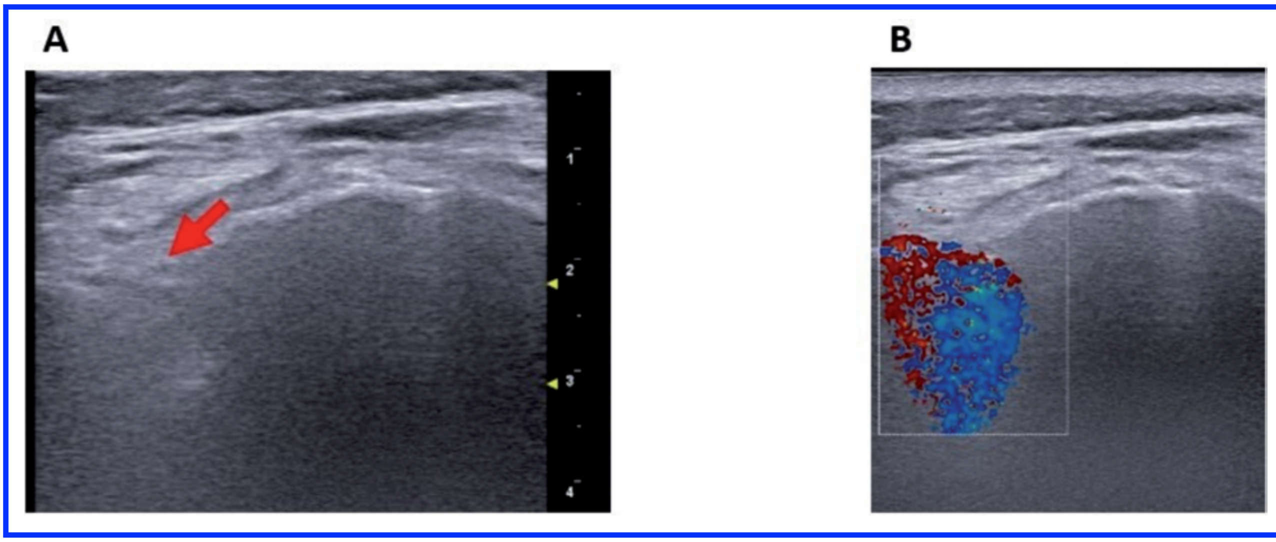

Figure 4. *A) Infiltration of the sacroiliac joint. Possible needle position (red arrow); B) Jet Sign indicating the location of the needle tip within the intra-articular space.*

characteristics of the ultrasound method (low costs, absence of ionizing radiation, widespread availability in outpatient settings, and high diagnostic accuracy), and especially on the capability for real-time multiplanar dynamic visualization of the target organ, as well as real-time monitoring of the entire infiltrative procedure—from needle insertion to substance injection—thereby preserving critical structures such as vascular and nerve bundles, reducing risks, minimizing potential undesirable side effects, and increasing patient comfort.[11,12]

Based on these considerations, it should be emphasized that infiltrative procedures performed under ultrasound guidance require a thorough understanding of anatomy and specific ultrasound training. This means maintaining visibility of the needle for its entire length during the procedure and accurately locating the tip even when using smaller gauge needles. In clinical practice, there is a tendency to use the smallest possible gauge needle in relation to the pharmaceutical product used, in order to reduce discomfort for the patient during the infiltrative procedure. However, the use of small gauge needles, combined with other objective factors such as the patient's physical constitution, deep target localization, and technical factors like excessive needle insertion speed, angle of insertion errors (the needle remains consistently visible only if it stays within the plane of the ultrasound beam), and lack of coordination between monitor visualization and needle insertion, can make it difficult to localize the tip of the needle during ultrasound visualization and thus its exact placement.

The proposed technical and methodological solutions to address these issues are numerous and may include the use of needles equipped with echogenic markers (located both on the tip of the stylet and on the cannula) or needles with straight tips (up to 85% straighter than standard sharpened needles, eliminating unwanted distal deviations). However, their higher costs and limited availability prevent widespread use in outpatient settings.

As previously described, some technical and methodological solutions can be utilized to address the problem of failing to

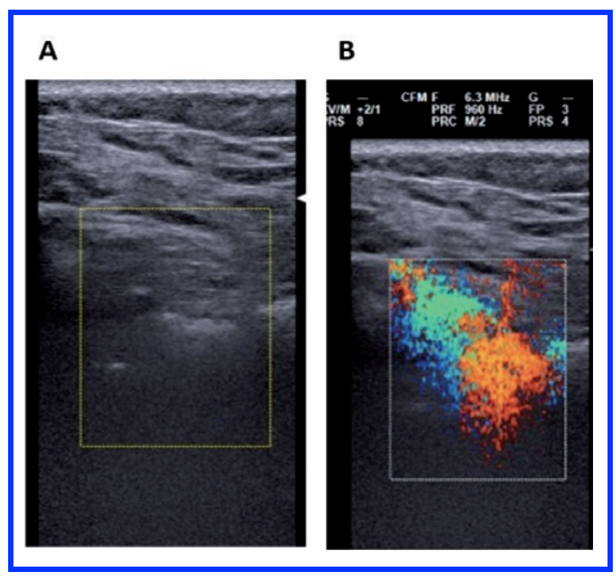

Figure 5. *A) Ultrasound-guided infiltration of the sacroiliac joint: Failure to identify the needle. The arrow indicates the potential location of the needle tip. The identification box for the color signal, after the injection of a mixture of saline solution and 1% lidocaine, does not show the presence of the Jet Sign. Sacro (S) - Iliac (I) joint. B) Repetition of the injection of lidocaine + saline solution with greater pressure compared to the first injection. The identification box for the color signal clearly highlights the presence of the 'Jet Sign.*

identify the needle during its course, especially regarding its positioning at the desired target.
Our retrospective study highlighted that during the execution of an ultrasound-assisted infiltrative treatment, which requires careful monitoring of all its phases, there is a percentage of cases (7%) in which it was not possible to visualize the tip of the needle via ultrasound. In all these cases, we optimized the ultrasound image acquisition parameters to reliably identify the needle's location concerning the target structure, using the Power Doppler application, which allows the construction of images based on the Doppler effect (first described by the Austrian physicist Christian Johann Doppler in 1842). This was associated with the rapid administration of 5 ml of a mixture composed of saline solution (NaCl 9%) and 1% lidocaine, specifically aiming to create and identify a characteristic sign that reproduces the presence of a relatively high-pressure hemodynamic flow (Jet sign), which has already been extensively utilized in some pathological conditions related to the heart and other organs.[13,14]
Power Doppler, unlike traditional color Doppler, allows for the visualization of even relatively slow flows, enabling better visualization of small caliber vessels at the expense of directional and speed information typical of color Doppler. In Power Doppler, there is no distinction of colors as in color Doppler; it uses a thermal color scale, transitioning from black to red to orange to yellow as power increases. This mode, exclusively used in the context of musculoskeletal pathologies, has become truly effective only after an increase in sensitivity in ultrasound devices introduced in recent years.[15]
The literature has extensively demonstrated the possibility of using Power Doppler to recognize non-hematologic flows. In particular, its application in evaluating urethral flow in the bladder is documented, where the result of peristaltic emptying of the ureters translates into a thin high-pressure flow of intravesical urine known as urethral jet or Jet sign.[16,17] The Jet sign is based on the formation of a physical phenomenon in fluid dynamics that occurs when a high-pressure fluid passes into a low-pressure area through a narrowing, resulting in the formation of an area of sudden turbulence (Bernoulli's principle).[18,19] In our experience, administering a solution composed of saline (NaCl 9%) and 1% lidocaine through a needle mounted on a syringe, combined with the application of Power Doppler ultrasound, allowed for the identification of the flow's origin (jet) and therefore the tip of the needle through the formation of a dynamic color image generated by the easily identifiable high-pressure injected flow (Figure 1).[20-22]
Therefore, the failure to identify this sign, in our personal experience (7% of treated cases), is related to insufficient injection speed and thus the failure to create the Bernoulli effect at the site of injection of the saline solution and lidocaine (Figure 5a). It was sufficient to retry the procedure with greater pressure to recreate the Jet sign, avoiding a second needle insertion (Figure 5b).

Conclusions

To date, a large number of minimally invasive percutaneous treatments are performed quickly and safely under ultrasound guidance, both in outpatient settings and at the patient's bedside or in the operating room by the same clinical specialist. The integration of ultrasound in percutaneous infiltrative treatments allows for optimal use of the specific pharmacological action of the substance employed, addressing both pain symptoms and the etiopathogenetic mechanisms of the disease.
When performing these procedures, it is crucial to plan the path of the needle in such a way as to reduce the risk of damaging critical structures such as vessels, nerves, and tendons (the needle tip acts in tissues like a small scalpel). In this regard, one might consider opting for a longer but safer needle path by introducing the needle diagonally relative to the axis of the probe. The injection of the drug should only be performed when there is certainty about the correct positioning of the needle at the desired therapeutic target.
The use of small gauge needles makes their ultrasound visualization difficult, as previously highlighted, which poses a significant problem for injection accuracy, particularly when trying to ensure absolute precision, as well as for the effectiveness of the treatment itself.
Based on our years of experience, we can thus state that to correctly identify the tip of the needle, especially in cases where exact visualization and localization are not possible, the high-pressure injection of a solution composed of saline and 1% lidocaine, applied with the Power Doppler function of ultrasound to create an artificial Jet sign, allows for the immediate identification of the area where the tip of the needle is positioned. This demonstrates that the use of the Jet sign can serve as an easy and immediate aid in the ultrasound-assisted infiltrative technique, effectively contributing to enhancing the therapeutic effectiveness of this method.

List of abbreviations

US, ultrasound
G, Gauge
NaCl, sodium chloride
MHz, megahertz
Ml, millilitre
PwD, power doppler

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article. All authors have reviewed the manuscript and approve its content. No financial or personal relationships with individuals or organizations have influenced the work reported in this study.

Ethics approval

Ethical approval: No. 1/2014-14.01.2014 Ethics Committee of the University of Palermo. The study is conformed with the Helsinki Declaration of 1964, as revised in 2013, concerning human and animal rights.

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Contributions

AB, PC, conceptualization; MT, data curation; AB, formal analysis; EMI, investigation; AI, methodology; AI, PC, supervision; FM, writing – original draft; FM, AI, writing – review & editing.

Informed consent

All patients participating in this study signed a written informed consent form for participating in this study.

Patient consent for publication

Written informed consent was obtained from a legally authorized representative(s) for anonymized patient information to be published in this article.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

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