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Preclinical and Experimental Laboratory Study

Optimization of solid needles for percutaneous needle electrolysis in invasive physiotherapy: *ex vivo* study

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ABSTRACT

Introduction: Percutaneous needle electrolysis (PNE) is an invasive physiotherapy technique that applies a galvanic current through a solid needle to treat musculoskeletal disorders. The effectiveness of the technique depends on the properties of the needle used, including its conductivity, biocompatibility, and mechanical resistance. This study explores improvements in needle design to enhance therapeutic outcomes.

Materials and Methods: The research focuses on the evaluation of different needle materials and coatings to optimize electrical conductivity and minimize tissue damage. Experimental analysis includes testing mechanical properties, corrosion resistance, and electrical performance. The results of this study can also be applied to patient safety and comfort.

Results: Findings indicate that modifications in needle material, such as the use of stainless steel with specialized coatings, significantly improve electrical efficiency and reduce unwanted oxidation. Enhanced designs result in lower resistance, improving the precision of the electrical current application. Additionally, improvements in needle flexibility and sharpness may contribute to reducing patient discomfort.

Conclusions: The study confirms that improving the material and coating of solid needles used in PNE can improve the technique's effectiveness. Specifically, stainless steel needles with specialized coatings increase electrical conductivity, reduce oxidation, and improve durability. These modifications allow for more precise current application, minimizing tissue damage and potentially reducing patient discomfort. Future studies should focus on clinical validation and further optimization to maximize safety and therapeutic benefits.

Keywords: Percutaneous needle electrolysis (PNE); Solid Needles; Invasive Physiotherapy; Electrotherapy; Needle Optimization; Galvanic Current; Musculoskeletal Treatment.

1. Introduction

The first disposable needle was manufactured in 1978. Previously, hollow reusable needles were used by acupuncturists in the United Kingdom, but the country's Ministry of Health recommended that needles be disposable following a Hepatitis B outbreak⁽¹⁾.

Currently, the use of disposable needles has spread worldwide, and they are used in an invasive physiotherapy technique called "dry needling." This technique involves inserting a needle into the body to treat trigger points (TrPs), thereby relieving symptoms⁽¹⁾. These points are responsible for causing painful symptoms, even in areas distant from the actual TrP⁽²⁾. The term "dry needling" refers to the fact that no substance is injected through the needle⁽¹⁾. After application, there is a significant reduction in pain⁽²⁾.

Another clinical use of these needles is percutaneous electrolysis (PNE: percutaneous needle electrolysis). This invasive physiotherapy technique also involves inserting the needle into the body, but in this case, it is used as a cathode to apply galvanic current, causing an electrochemical reaction at the application site. Galvanic current is a continuous flow of electrons from the negative to the positive pole. In PNE, the cathode (negative pole) is the needle applied to the target tissue. This produces two primary effects: electrophysical and electrochemical⁽³⁾. The electrochemical effect occurs because the cathode acts as an active electrode, reacting with water and electrolytes, which behave like a sodium chloride (NaCl) solution when an electric current passes through them. At the cathode, sodium hydroxide (2 NaOH) is released, immediately activating the inflammatory response to repair the altered tissue and causing liquefaction with the release of hydrogen (H₂)⁽³⁾: $2\text{Na} + 2\text{H}_2\text{O} = 2\text{NaOH} + \text{H}_2$.

The electrophysical effect causes the migration of positively charged molecules to the negative pole. Due to this movement, analgesic mechanisms and vascular responses are activated⁽³⁾. In other words, PNE first induces the inflammatory response, which removes diseased and non-functional tissue and prepares the area for the second phase, in which growth factors promote tissue regeneration. As a result, the new scar is more similar to healthy tissue⁽⁴⁾. The most widespread use of PNE for regenerative purposes is for tendinopathies. However, it is used regularly to reduce myofascial pain^(1,2).

A notable example of the clinical application of this technique was the case of tennis player Rafa Nadal. He suffered from patellar tendinopathy, a condition that often marks a turning point in the careers of many professional athletes. However, Rafa Nadal returned to play at a high level, thanks to a therapy that included PNE treatment along with the application of growth factors⁽⁴⁾.

Another reported case, although more anonymous, is that of a 42-year-old male, an occasional padel player, who was referred by his orthopedic specialist to the MV Clinic in Madrid due to elbow pain persisting for 12 months. This pain resulted from epicondylitis that had resisted all treatments and was considered a last resort before opting for surgical intervention⁽⁵⁾. The patient had previously tried conventional physiotherapy, pharmacological treatments, and two corticosteroid injections⁽⁵⁾. PNE was applied weekly, in combination with an eccentric exercise and stretching program. After four ultrasound-guided PNE sessions, the patient was discharged with significant clinical improvement. This technique allows for the specific treatment of the affected tendon area. An important fact supporting PNE as the direct cause of the improvement

is that the patient had previously undergone an eccentric exercise and stretching program without any progress, with PNE being the main difference between the two interventions⁽⁵⁾.

PNE is a very safe technique, with the most common side effect being post-electrolytic pain due to needle insertion or the application of galvanic current. However, symptoms typically disappear on their own within 12-36 hours. The fact that this therapy is recommended to be ultrasound-guided makes it much safer⁽⁶⁾. This therapy is usually performed with ultrasound assistance to selectively target the desired tissue. The aim is to deliver current only to the target tissue (e.g., TrP), not to other areas of the body. Therefore, it is essential to track the needle's movement at all times and confirm that it is acting in the correct location.

Ultrasound is also crucial for safety reasons. After all, the procedure involves inserting a needle into the body, so if the therapist is not careful enough, they could puncture a critical area. For example, performing this technique in the lung area without an ultrasound device is dangerous because the needle could puncture the pleura covering the lung, causing a pneumothorax⁽⁷⁾. There are also other areas of the body where this treatment should not be applied, such as near large blood vessels, the heart, or peripheral nerves. To avoid accidentally reaching these structures, ultrasound use is essential⁽⁷⁾.

Currently, there are three main types of needles used in invasive physiotherapy. The first type consists of dry needling or acupuncture needles. These are made of surgical steel, a material highly resistant to penetration. This alloy is rich in chromium (12-20%), molybdenum (3%), and sometimes nickel (8-12%)⁽¹⁾. A box of 100 units costs €6.95. These needles penetrate tissues easily, conduct electricity well, and are highly visible under ultrasound. However, since they are not coated, electricity stimulates all the tissues they pass through, meaning they do not conduct electricity in a specific manner. The ideal needle for the use of galvanic currents is one that only conducts electricity at the tip, is clearly visible with the ultrasound, penetrates easily and is also cheap.

A variation of these needles includes highly lubricated dry needling needles. These are exactly like the previous ones but with a triple layer of oil that facilitates penetration. Their price is also similar. However, they do not conduct electricity well and are not easily visible under ultrasound, possibly due to the oil layer. Therefore, they are completely useless for PNE.

The second type of needle used in PNE is coated with silicone on its entire surface except for the tip. These are also made of surgical steel and focus the current effectively. Their optimized, perfectly centered handle ensures an ergonomically comfortable grip. The handle is made of polypropylene, an extremely lightweight plastic that does not irritate the skin and is environmentally friendly. A box of 200 needles (0.25 x 30 mm) costs €11.39, with prices varying depending on size. However, they penetrate the patient's skin painfully and with great difficulty. Additionally, they are not very visible under ultrasound.

The third type of needle is the concentric electromyographic recording needle. These are uncoated, non-lubricated needles, making them highly visible under ultrasound but, as they are not lubricated, also more painful to insert. They consist of one needle inside another, separated by a thin insulating layer. The electrical current is transmitted only at the tip, making it highly specific. Each of these needles costs approximately €10. The insertion of these needles is very

painful, and this price makes them unfeasible for physiotherapy use, as 3-4 needles are typically used per patient.

For these reasons, it is imperative to design a needle that is both economically competitive and capable of penetrating tissues easily without adding extra pain during insertion. It should be easy to track under ultrasound and conduct electricity only at the tip. Then, the objective of this study is to obtain an ultrasound-visible coating that aids needle penetration and allows for the transmission of focused galvanic current. To this end, various coating components were evaluated.

2. Materials and Methods

2.1 Coating materials

Vaseline: A well-known lubricant is vaseline, whose main component is paraffin, an oil derived from petroleum. It can also originate from oil shale or coal. Paraffin is a group of alkane hydrocarbons with the general formula $C_n H_{2n+2}$. The simplest molecule comes from methane gas (CH_4). Heavier members of the series, such as octane ($C_8 H_{18}$), exist as liquids. The solid forms, known as paraffin wax, come from heavier molecules ranging from C_{20} to C_{40} ⁽⁸⁾.

To obtain paraffin, a high-temperature distillation is performed to extract heavy oils, which are then cooled to 0°C, causing paraffin to crystallize. It is separated through centrifugation or filtration. Finally, it undergoes recrystallization, acid and alkaline washing, and decolorization to purify it⁽⁸⁾.

Macrocrystalline paraffin wax is insoluble in water and an excellent electrical insulator, providing an electrical resistivity between 10^{13} and 10^{17} ohm/meter. This resistivity surpasses that of most other materials, except for some plastics. It is commonly used as an insulator in electrical conductors, making it a strong candidate for needle coating⁽⁸⁾.

Liquid paraffin, on the other hand, is a mixture of heavier alkanes⁽⁸⁾. vaseline also contains microcrystalline wax, obtained from the degreasing process during crude oil refining⁽⁸⁾. In this study, vaseline was tested in both its solid and liquid forms.

The cost of 100 ml of moisturizing vaseline was €2, while 100 ml of liquid vaseline was €4.09. These prices may vary depending on the store, brand, or current economic conditions.

Sunflower oil: In addition to these two coatings (solid and liquid vaseline) and with the intention of expanding the range of possibilities to organic materials, a third coating was chosen: sunflower oil. The oil does not conduct electricity, and a layer of oil can help with needle penetration. Many vegetable oils are used to make soaps and other skin-related products.

This oil is obtained from the seeds of the sunflower *Helianthus Annuus*. These seeds are crushed, as the oil itself is located inside the cells that make up the seed, meaning their cell walls must be broken to extract it. To separate it from other cellular elements, authorized solvents are used, with water being the most prominent⁽⁹⁾.

The next step is refining, which removes phospholipids and metals. Free fatty acids are then neutralized and eliminated. The oil is also decolorized using natural or activated clays and, if

necessary, deodorized. This process aims to reduce its acidity level. The refined sunflower oil found in supermarkets is the one used in this study⁽⁹⁾.

1 liter of sunflower oil costs €2.50. This price may vary depending on the distributor, brand, or current economic situation.

Alabaster Powder: To increase the eco-density of the coatings without modifying their insulation, all three were mixed with alabaster powder. Alabaster is a biologically neutral compound of calcium crystals ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Crystalline calcium is graphically visible and electrically insulating. Alabaster powder is miscible with other substances and therefore easily shaped into needles.

2.2 Procedure for covering needles

Single-coating material: Half of the needles were immersed in the different vehicles. The purpose of this procedure was to study the possible degradation of the vehicles due to the action of galvanic current. Only the distal half (near the tip) of each needle was coated and then the two halves (coated and uncoated) were compared to analyze possible differences.

The procedure was as follows: after cleaning the needle with 97% ethyl alcohol, the coating was applied by immersion. Subsequently, this needle was used as a cathode, recreating electrolysis with the Physio Invasiva 2.0 device. The test needle was placed as the cathode, while an uncoated needle was placed as the anode. Both were then introduced into two vials connected by a glass bridge filled with conductive agar (Figure 1).

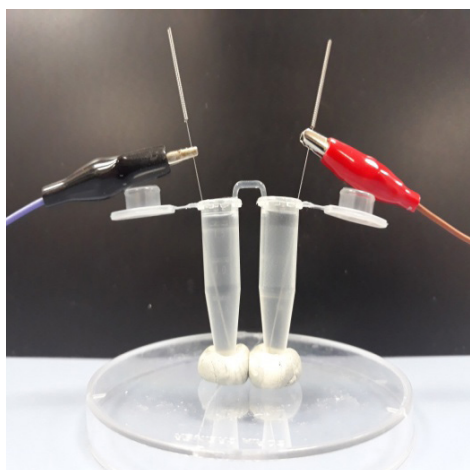


Figure 1. Electrolysis Application to the Needles. The needles acting as the anode (black) and cathode (red) were immersed in Eppendorf® vials filled with Ringer's solution⁽¹⁰⁾, NaCl 137 mM, KCl 5 mM, NaHCO_3 12 mM, Na_2HPO_4 1 mM, CaCl_2 2 mM, MgSO_4 1 mM). The cathode needle is the test needle. The two vials are connected by a glass bridge filled with conductive agar. In all cases, galvanic currents of 3 mA were applied for 3 seconds, repeated 3 times (3:3:3).

The parameters used were 3 mA for 3 seconds, repeated a total of 3 times. This method, when applied within a patient, does not cause any wear on the needle^(15,16).

A total of 10 needles were treated for each of the materials: liquid petroleum jelly, solid petroleum jelly, and sunflower oil.

Coating material combined with alabaster powder: The method used in this part involved mixing each vehicle (vaseline, sunflower oil) with alabaster powder. After preparing the mixture,

it was applied to the needle previously cleaned with ethyl alcohol. A total of 5 needles were prepared for each mixture.

The mixture concentration was made in equal parts of vehicle and alabaster powder. Since alabaster has a higher density than the vehicles, a well-blended mixture of liquid petroleum jelly and alabaster powder was obtained, allowing for successful needle impregnation. The same occurred with sunflower oil.

On the other hand, solid petroleum jelly was very difficult to handle. After coating an initial series of 10 needles, the resulting coating was too thick, so a second series of needles was prepared to improve the coating. For this new series, it was necessary to liquefy the petroleum jelly using a water bath. Additionally, to keep the needles warm and maintain the paraffin in a liquid state, a dry heat source (30W 230V soldering iron, Cetronic) was used. With this method, only three needles could be obtained. The mixture deteriorated prematurely as it crystallized, preventing it from blending with the alabaster.

Since this procedure was deemed inefficient for industrial-scale application, it was optimized using a thermal plate that kept the petroleum jelly liquefied, preventing it from cooling and crystallizing. The results of both series will be analyzed separately in the corresponding section.

2.3 Galvanic Current Generator

The direct current generator used in this study is an electrostimulation device (Physio Invasiva 2.0.), employed in physiotherapy treatments through the application of galvanic currents, transcutaneous electrical nerve stimulation (TENS), and microcurrents. Its design complies with European Directive 93/42/EEC⁽⁷⁾.

The current is applied using a needle holder, with a pair of needles placed at the appropriate points according to the treatment. The therapist can adjust the output current, with a maximum of 15 mA that cannot be exceeded, as well as the application time (in minutes or seconds)⁽⁷⁾.

2.4 Digital Magnifier

To get an overview of the degree of coating on the needles, the Leica DMS 1000 digital magnifier from the Rovira i Virgili University Scientific and Technical Resource Service was used. The digital binocular microscopy system guarantees magnifications of up to 300x. It comes with a built-in HDMI microscopy camera that allows real-time imaging at up to 30 fps and a resolution of 5 megapixels. This camera enables sample review on a monitor instead of through eyepieces, making it easier to capture photos⁽¹¹⁾.

2.5 Scanning Electron Microscope

In order to make a more precise assessment of the degree of coating of the needles, the FEI QUANTA 600 Scanning Electron Microscope (SEM) from the URV Scientific and Technical Resource Service was used. SEMs use an electron beam instead of light to form an image. These electrons are accelerated in an electric field to take advantage of their wave-like behavior and exit the gun to be focused on the sample by the condenser and objective lenses, aiming to keep

the beam as small as possible for higher resolution⁽¹²⁾. It has a resolution of 3 nm and a great depth of field⁽¹³⁾.

2.6 Ultrasound Machine

To ensure the degree of echoic effectiveness of the needle coating, the LOGIQ S7 XD Clear 2.0 ultrasound machine from General Electric was used. This device uses ultrasound waves to acquire images. Its operation is based on the piezoelectric effect, a property of piezoelectric crystals that, when subjected to an electric current, vibrate and produce a sound wave projected into the body. These sound waves bounce off denser regions of the body, returning to be received by sensors also made of piezoelectric crystals, where the inverse piezoelectric effect transforms this new acoustic signal into an electrical signal⁽¹⁴⁾. A single piezoelectric crystal cannot act as both an emitter and a receiver simultaneously. The obtained signal is transmitted to a computer, where it is processed and used to recreate an image of the patient's interior⁽¹⁴⁾.

2.7 Image Acquisition

Three ways of obtaining images have been used.

Digital Magnifier (Leica DMS 1000). Low-magnification images (0.72x) were obtained for the entire needles, and higher magnification images (4.5x) were taken for further reconstruction.

Scanning Electron Microscopy (SEM). Imaging was performed at 230x magnification, with a voltage of 10 kV and a pressure of 0.68 Torr. The coating thickness in the first series of petroleum jelly with alabaster was excessive for the magnifications used, so imaging was adjusted to 138x to capture the full thickness⁽¹⁶⁾.

Ultrasound Imaging. Finally, to confirm the smooth insertion of the needles and their visibility under ultrasound, they were inserted into chicken breasts. Chicken breast is an excellent model that closely mimics human tissue and does not require harming laboratory animals. This technique was performed by an expert sonographer from BrumaClinic in Tarragona. Ultrasound imaging of the inserted needles was performed using a longitudinal scan, aligned with the longitudinal axis, at a 45° angle. This method was chosen to obtain a complete view of the needle in the ultrasound scan. The ultrasound machine parameters used were a sweep frequency of 12 Hz and a depth of 4 cm.

For each tested needle, two photographs were taken—one during insertion and one afterward—to confirm that no alabaster residues remained. Additionally, a video was recorded documenting the entire insertion process (some have been posted in complementary data).

3. Results and interpretation

3.1 Petroleum Jelly

Microphotographs. The pure petroleum jelly coating covered the needle's applied region almost uniformly (Figure 2.A, 2.B center, and 2.C center). Scanning electron microscope images at high magnification show that the coated area is clearly uniform. Additionally, as observed, the needle tip was not covered by petroleum jelly, remaining completely exposed (Figure 2.B right

and 2.C right). Although the needle will penetrate the patient well, in addition to the tip, these uncovered regions will transmit electricity during application, reducing the focalization of the galvanic currents.

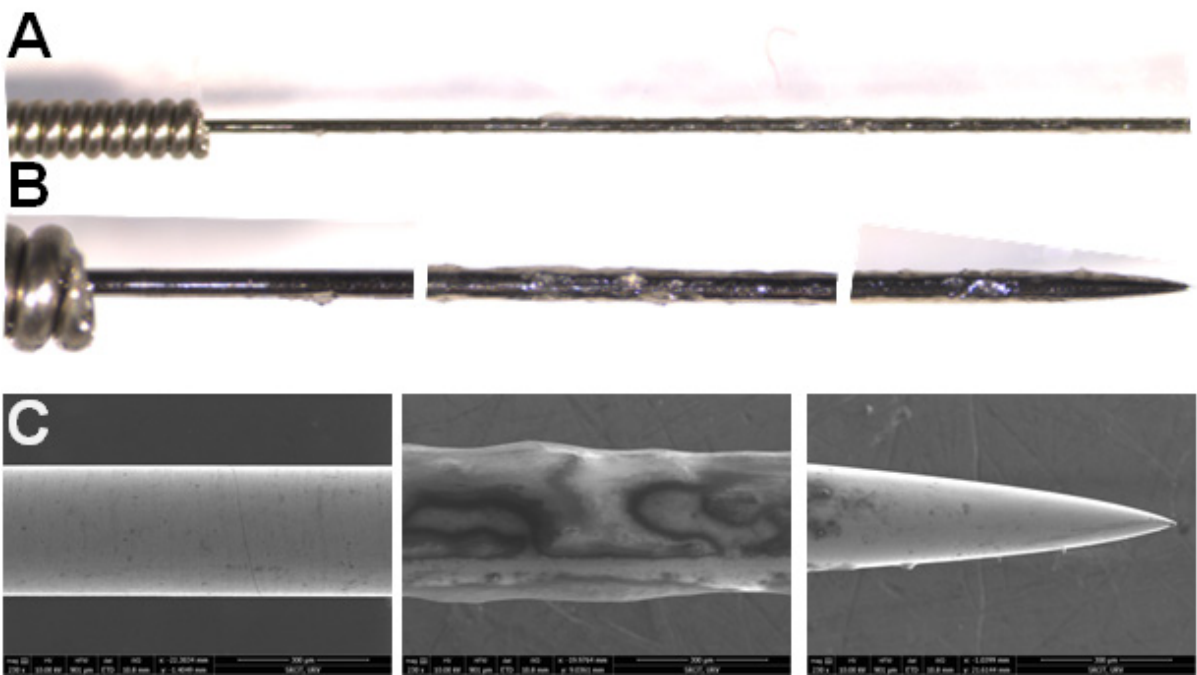


Figure 2. Example of a Needle Coated with Petroleum Jelly. A: Image obtained with a magnifier at 0.72x magnification. B: Images obtained with a magnifier at 4.5x magnification. C: Images obtained with a scanning electron microscope at 230x magnification. In B and C, the three images correspond to: The base, near the handle (left image); The central part of the needle (center image); and image of the needle tip (right).

Ultrasound Imaging. In all ultrasound images, the entire needle can be seen (Figure 3.B). This indicates that the ultrasound waves are reflecting off the needle's surface, allowing for full tracking of the needle (Table 1). Since petroleum jelly is not echodense, it is understood that there are either uncovered areas or layers thin enough to be echogenic. vaseline with thick alabaster (Series 1).

Penetration: With this pure coating, the needle will penetrate effectively, but the current will not be properly concentrated.

Table 1. Visualization of needles inserted into chicken breasts with ultrasound.

Ultrasound Image	Liquid Petroleum Jelly	Paraffin + alabaster Series 1	Paraffin + alabaster Series 2	Oil	Oil + alabaster	Paraffin	Liquid Petroleum Jelly + alabaster
Only the Tip	80%	100%	100%	50%	25%	-	40%
Entire Needle	20%	-	-	50%	75%	100%	40%
Not Visible	-	-	-	-	-	-	20%

Ultrasound Image: Part of the needle seen with ultrasound. Series 1: First series of needles coated with petroleum jelly, which turned out to be very thick. Series 2: Series made with a thinner, more liquefied petroleum jelly. The percentages are relative to all needles evaluated with each coating.

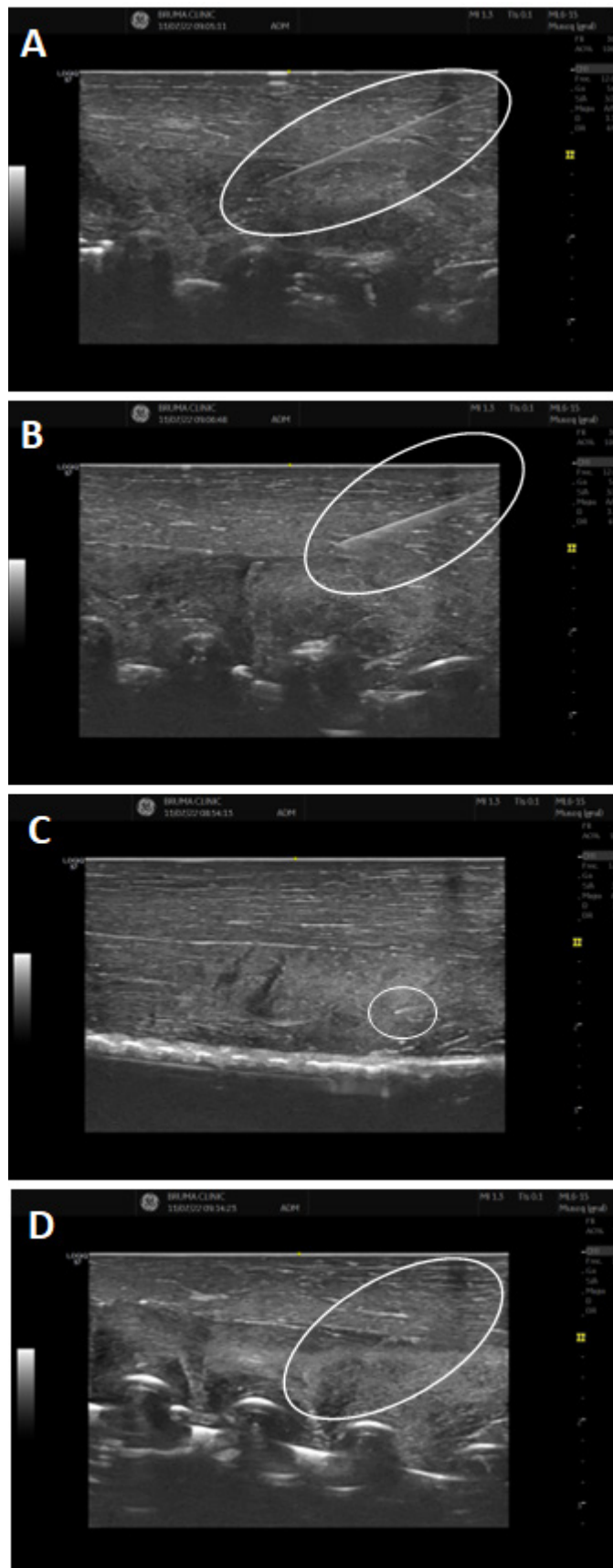


Figure 3. Examples of ultrasound images. Each of the needles studied has been inserted into chicken breast. A, Ultrasound recording of a control needle uncoated by anything. B, Typical image of a needle coated with a vehicle, e.g., paraffin. The needle is somewhat blurred by the vehicle, but clearly identifiable. C, In this example, only the tip of the needle is visible (white circle). D, Typical image of a needle coated with a vehicle (white ellipse), e.g., alabaster oil. The needle can be seen, although with difficulty.

3.2 Thick Vaseline and Alabaster Coating (Series 1)

Microphotographs: The first type of vaseline and alabaster coating produced shows uniform coverage across the entire applied surface. Although clearly visible under magnification (Figure 4. A and B), the electron microscope confirms that a thick, uniform layer has formed (Figure 4. C). It is important to note that the tip remains uncovered. Due to this coating, only the tip will transmit the current, as intended. This coating allows the currents to be focused. Due to its thickness, it was decided to repeat this test, further liquefying the vaseline.

Ultrasound Imaging: All ultrasound scans show only the needle tip (Figure 4.C; Table 1). This is because the alabaster mixture is very echo-dense and does not reflect ultrasound. This coating allows the needle to be ultrasound-guided by visualizing the needle tip.

Penetration: The alabaster petroleum jelly coating is unable to adhere to the needle during puncture, remaining outside the breast during the process. While it meets the expectations of being insulating, it minimizes the possibility of insulating against currents. Furthermore, if more than one insertion is required, the same needle cannot be used. This problem could perhaps be solved with an additional polymer coating, which covers the surface and aids penetration. This problem must be solved to achieve a functional coating.

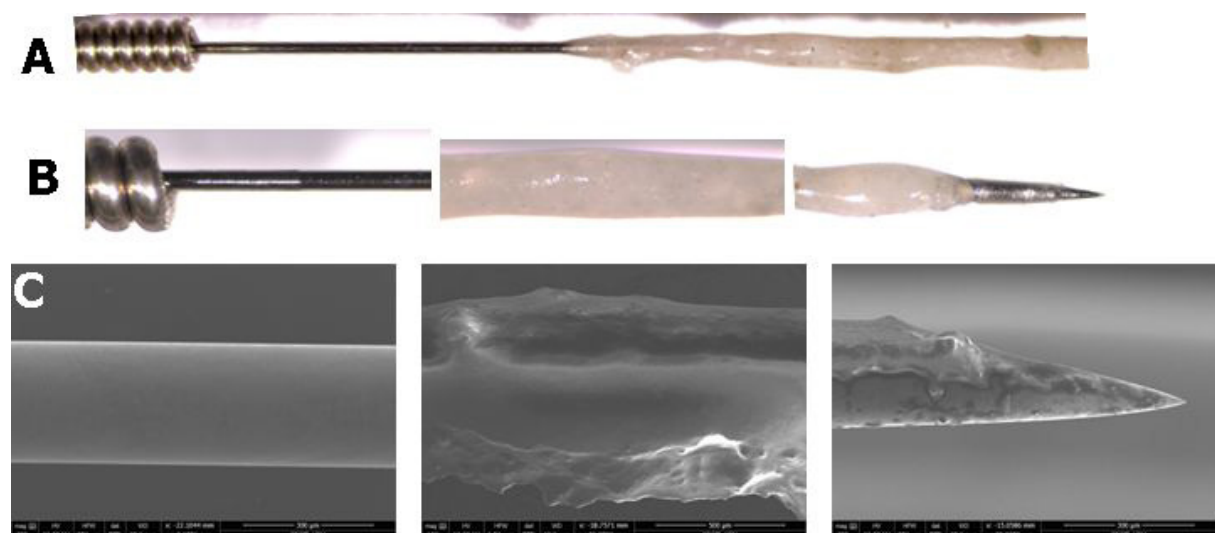


Figure 4. Example of a needle coated with vaseline and alabaster. Series 1. A, Image obtained with a magnifying glass at 0.72x magnification. B, Images obtained with a magnifying glass at 4.5x magnification. C, Left and right images obtained with a scanning electron microscope at 230x magnification. Central image obtained at 138x magnification. In B and C, the three images correspond to: Base, near the handle (left image); image of the central part of the needle; and image of the needle tip (right).

3.3 Vaseline with Fine Thickness Alabaster (Series 2)

Microphotographs. The second coating of vaseline and alabaster is also evenly applied. This is not only evident in the images taken with a magnifying glass (Figure 5.A and 5.B) but is also confirmed by the electron microscope (Figure 5.C). The coated surface will be completely insulated and will not conduct current. Since the vaseline was able to be liquefied more effectively than in the previous experiment, its thickness has been reduced. This coating will serve as a good current focalizer.

Ultrasound Imaging: The second coating of vaseline and alabaster provides ultrasound images in which the needle tip is visible (Figure 3.C; Table 1). The coating remains echodense, preventing the ultrasound from providing a clear image of the coated area. However, since the tip is uncoated, it is clearly visible. This coating allows the needle to be ultrasound-guided.

Penetration: The second coating of vaseline and alabaster shares the issue of poor adhesion to the needle's surface, rendering the coating ineffective. The use of polymers is once again considered as a potential solution to address this difficulty. It is necessary to resolve this issue to make the coating functional.

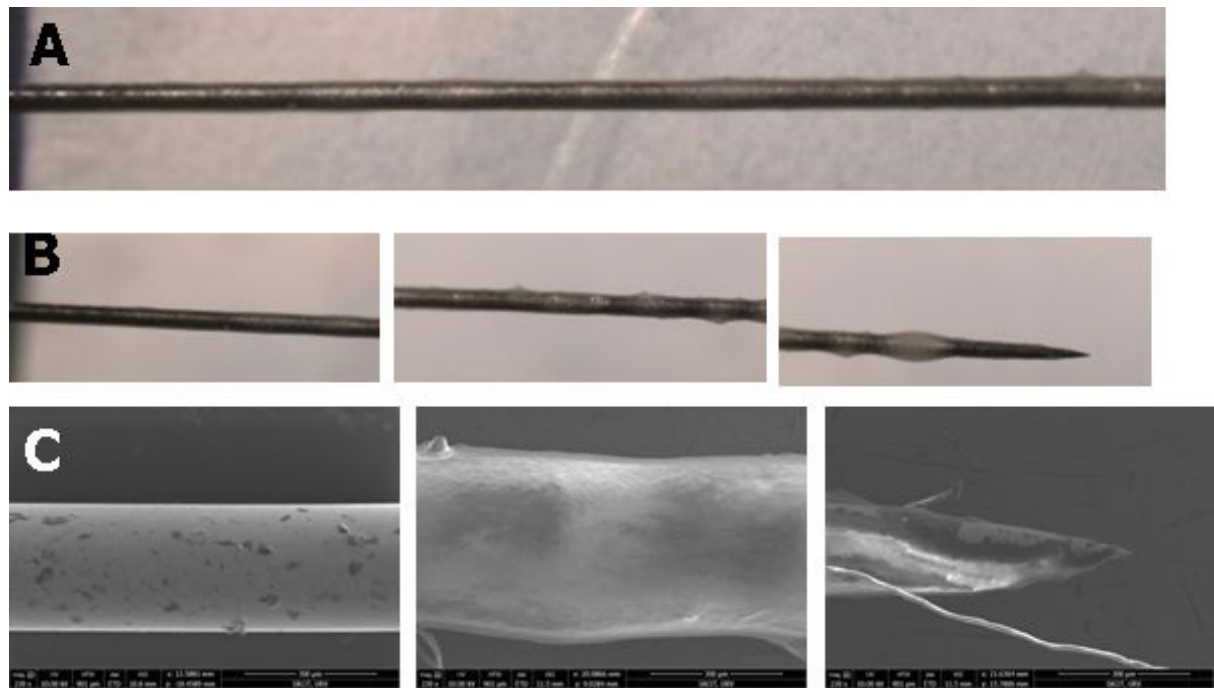


Figure 5. Example of a needle coated with vaseline and alabaster. Series 2. A, Image obtained with a magnifying glass at 0.72x magnification. B, Images obtained with a magnifying glass at 4.5x magnification. C, Images obtained with a scanning electron microscope at 230x magnification. In B and C, the three images correspond to: Base, near the handle (left image); image of the central part of the needle; and image of the needle tip (right).

3.4 Sunflower Oil

Microphotographs: The sunflower oil coating does not uniformly cover the surface of the needle. Small isolated black areas can be observed where the oil has remained on the surface (Figure 6.C, center), while the rest of the surface appears gray, similar to areas where no oil has been applied (Figure 6.C, left and right). These uncovered areas will conduct electricity, preventing current focalization. This coating will not focus the current.

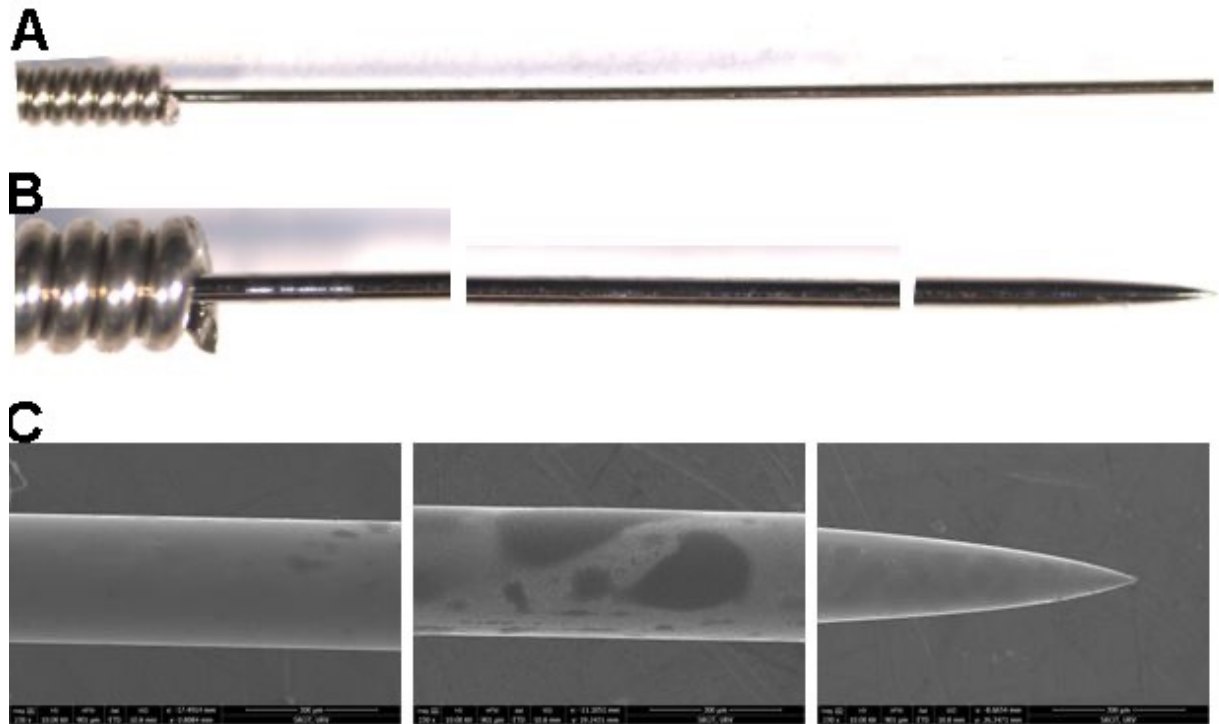


Figure 6. Example of a needle coated with sunflower oil. A: Image obtained with a magnifying glass at 0.72x magnification. B: Images obtained with a magnifying glass at 4.5x magnification. C: Images obtained with a scanning electron microscope at 230x magnification. In B and C, the three images correspond to: Base near the handle (left image), central part of the needle (center image), and needle tip (right image).

Ultrasound Imaging. Half of the ultrasound images of this coating show only the tip, while the other half shows the entire needle (Table 1). The ultrasound waves reflect off the oil, but it is not always spread widely enough to cover the entire application surface. No similar experiments have been documented so far. It is possible to obtain ultrasound-guided needles using this coating.

Penetration: With this pure coating, the needle will penetrate effectively, however the current will not be properly concentrated at the top.

3.5 Sunflower oil with alabaster

Microphotographs. The sunflower oil coating uniformly covers the needle's surface, as clearly seen in images obtained via magnifying glass and electron microscope (Figure 7). The coating surface exhibits protrusions (Figure 7.C, center) that may cause discomfort during insertion. Note that in this case, the tip is also coated (Figure 7.C, right), meaning it will not conduct current at all.

Ultrasound Imaging - Table 1 shows that 25% of the needles display only their tip in the ultrasound (see an example in Figure 3.C), while the rest show the entire needle (an example is shown in Figure 3.B). The mixture does not appear to be sufficiently echodense to block the ultrasound waves, which is curious because the pure version of this coating showed more results where only the tip was visible. Furthermore, as mentioned earlier, in this case, some tips are also coated. This coating allows the needle to be ultrasound-guided without any issues. These results suggest that alabaster has little influence on the ultrasound beyond its amalgamating properties.

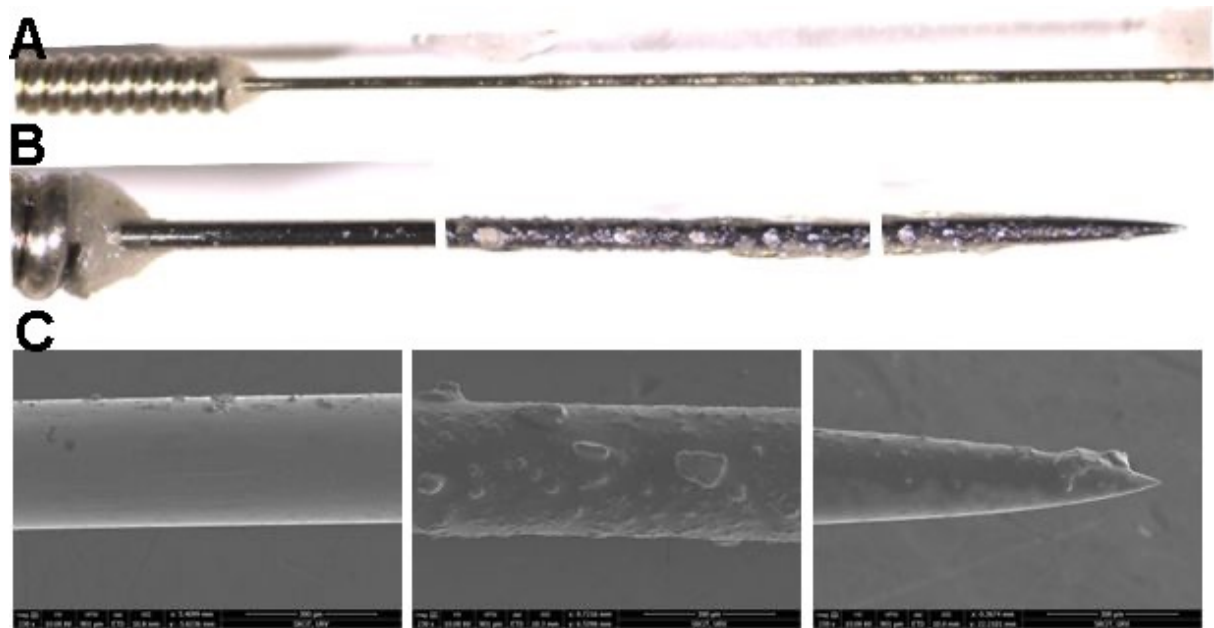


Figure 7. Example of a needle coated with sunflower oil and alabaster. A: Image obtained with a magnifying glass. B: Images obtained with a magnifying glass at higher magnification. C: Images obtained with a scanning electron microscope. The three images correspond to: Base near the handle (left), central part of the needle (center), and coated tip (right).

Penetration: This coating will effectively focus currents as long as the tip remains unblocked and can penetrate painlessly once the surface protrusions are sanded down.

3.6 Liquid vaseline

Microphotographs: The liquid petroleum jelly coating does not evenly cover the needle surface. It can be seen that the coated black areas leave gray areas uncovered (Figure 8.C center), as do the areas where it is not applied (Figure 8.C left and right). Because it is not evenly coated, it will transmit current into these uncovered areas. This coating is unable to adequately focus currents.

Ultrasound Imaging. As can be seen in Table 1, the needle tip can be seen in most ultrasounds of this coating (Figure 3.C), although the entire needle is visible in some (Figure 3.B). Liquid petroleum jelly does not reflect ultrasound and does not transmit images, but because the tip is uncovered, it is visible. This coating allows the needle to be ultrasound-guided.

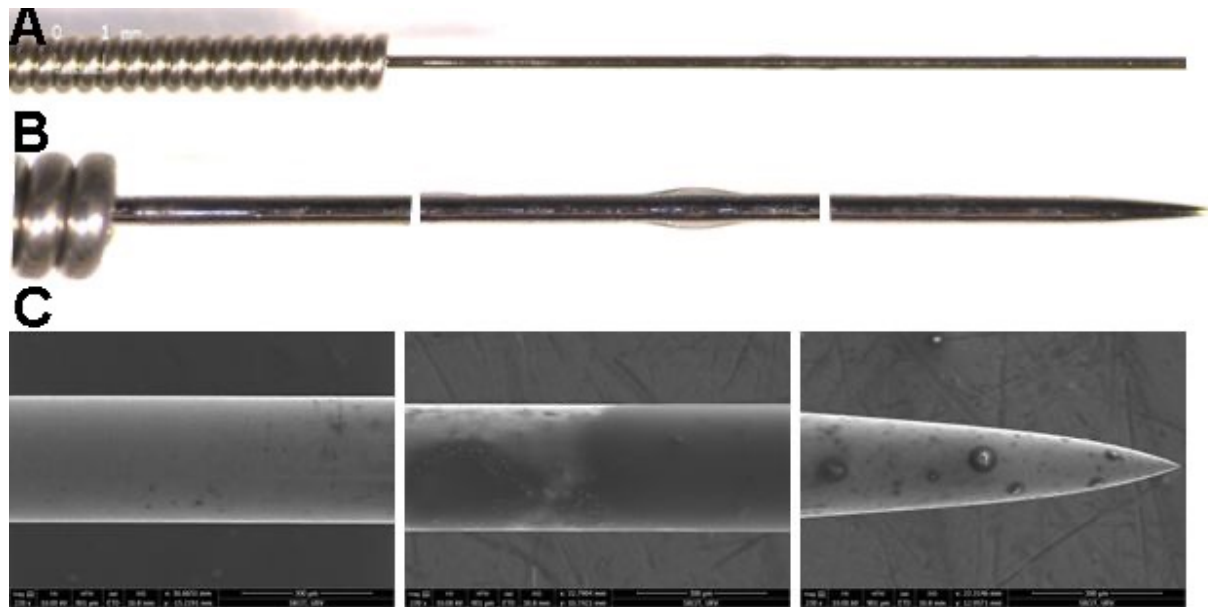


Figure 8. Example of a needle coated with liquid petroleum jelly. A, Image obtained with a magnifying glass at 0.72x magnification. B, Images obtained with a magnifying glass at 4.5x magnification. C, Images obtained with a scanning electron microscope at 230x magnification. In B and C, the three images correspond to: Base, near the handle (image on the left); image of the central part of the needle; and image of the needle tip (right).

Penetration: This pure coating allows an effective penetration. However, it won't focus the currents properly at the top of the needle.

3.7 Liquid vaseline with alabaster

Microphotographs. The liquid petroleum jelly coating has a smooth surface, as can be seen in the images obtained using a digital magnifying glass and electron microscope (Figures 9.B and 9.C), ensuring that no current is transmitted. The coating also covers the tip in this case (Figure 9.C right), so no electricity is transmitted, and has a rough surface (Figure 9.C center) that could cause pain to the patient during penetration. This coating insulates the entire needle, preventing it from conducting electricity, but if the tip is left free, it will focus properly.

Ultrasound Imaging. As can be seen in Table 1, 20% of the needles are not visible on ultrasound (Figure 3.D), while in the remaining samples, half only show the tip (Figure 3.C) and the other half show the entire needle (Figure 3.B). In the case of the needles that show nothing, they must be those in which the tips were accidentally coated, preventing their visualization with the ultrasound. This finding, together with the other coating samples in which only the tip appears, together with the data from the normal petroleum jelly, reinforce the idea that an accident occurred during the preparation of the remaining needles, allowing ultrasound to penetrate the coating. These needles can be directed by ultrasound without any problem, as long as the tips are not covered.

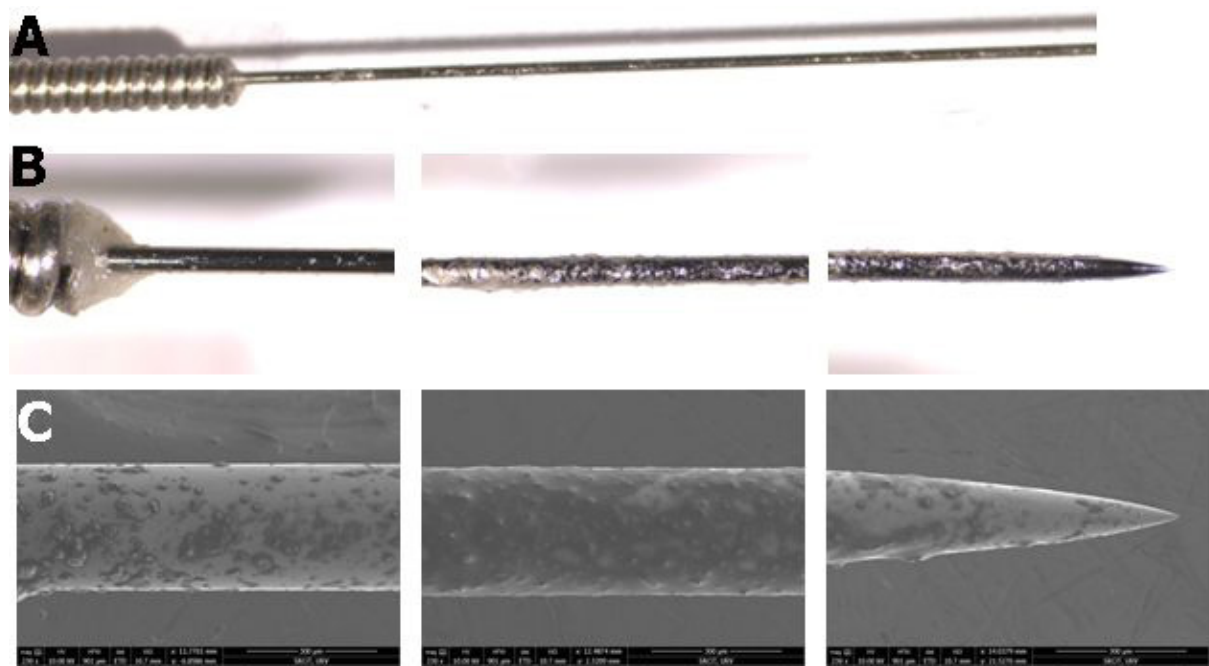


Figure 9. Example of a needle coated with petroleum jelly and alabaster. A, Image obtained with a magnifying glass at 0.72x magnification. B, Images obtained with a magnifying glass at 4.5x magnification. C, Images obtained with a scanning electron microscope at 230x magnification. In B and C, the three images correspond to: Base, near the handle (left image); image of the central part of the needle; and image of the needle tip (right).

Penetration: The coating has a rough surface that could cause pain to the patient during penetration. Once the roughness is sanded down, it will penetrate painlessly.

4. Conclusions

Pure coatings fail because they cannot guarantee the focusing of the galvanic current. However, this objective is successfully achieved by alabaster coatings, thanks to the latter's amalgamating properties. Furthermore, solid vaseline with alabaster performs quite well on ultrasound, allowing the needle to be guided into the target tissue during insertion. The adhesion problems of solid vaseline with alabaster would need to be resolved for it to be fully functional. However, if the polymer solution for solid vaseline proves feasible, a suitable coating would be obtained.

Although the study did not aim to use pure coatings as such, solely as a vehicle for alabaster, relevant results were obtained: They do not coat the needle homogeneously; The solid vaseline coating best coats the needles; They do not allow current focusing; They allow ultrasound identification.

The alabaster coating mixture was expected to provide greater echodensity, allowing for good visualization of the needles without conducting galvanic currents. However, alabaster has been a good amalgamator of the fatty coatings: The needles are uniformly coated; They focus the currents well; alabaster itself does not appear to prevent ultrasound from reaching the needle; The needles are often visible on ultrasound; liquid vaseline and sunflower oil present surfaces that appear aggressive to penetration; Both solid vaseline series do not adhere adequately to the needles during penetration; Both solid vaseline series present the same results on ultrasound; An additional polymer coating could help the vaseline stay on the needle.

The combined results of this study pave the way for an optimal needle use in PNE, ensuring good insertion, good ultrasound tracking, and good current focusing, at a competitive price.

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Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

Manel M Santafé is an Associate Editor of IPMM. This manuscript was handled by another editor, and he was not involved in the peer review or the editorial decision. The other author declares no conflicts of interest.

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