



# Software Suite Training Tool for MSK Exploration and Botulinum Toxin Infiltration Based on Ultrasound Imaging for the Spasticity Treatment

V. Moreno<sup>1</sup> · B. Curto<sup>1</sup> · J. A. García-Esteban<sup>1</sup> · F. J. Serrano<sup>1</sup> · P. Alonso Hernández<sup>1</sup> · F. Hernández Zaballos<sup>1</sup> · J. A. Juanes<sup>1</sup>

Received: 9 January 2019 / Accepted: 8 May 2019 / Published online: 19 June 2019  
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## Abstract

Nowadays, one of the choice techniques for the spasticity treatment is the ultrasound-guided infiltration of Botulinum Toxin, because it is safe and effective. In order to medical professionals can carry out this technique, they need training and education. One of the safest and most time-free ways to facilitate the acquisition of practical medical skills is through simulators. In this paper we present an innovative technological environment, which includes an ultrasound simulator for training in muscle exploration and infiltration. The simulation platform will guide health professionals, with great realism and high degree of interactivity, in the autonomous training of all the tasks involved in the spasticity treatment procedure by infiltration of Botulinum Toxin, without the need for a real patient or costly phantoms.

**Keywords** Medical simulation · Training · Ultrasound · Spasticity · Botulinum toxin

## Introduction

Recently, clinical simulation has positioned itself as a fundamental tool for Health Sciences professionals training. Within this field, medical simulation can be seen as the use of devices, systems or environments (simulators) that reproduce conditions from real situations with the aim of carrying out a specific practice and from this, the competences acquisition achievement. Clinical simulation has been used to reproduce real experiences through properly elaborated scenarios that are carefully prepared, guided and controlled. An ideal environment for medical education will be constituted, due to the fact that the activities can be designed to be predictable, consistent, standardized, safe and reproducible. As a teaching tool, many pedagogical advantages have already been obtained and as the most relevant ones we can highlight the evaluation without risk of harming the patient, the possibility of repetition of a test and the reproduction of infrequent situations.

High fidelity clinical simulation, too, can be a tool that helps in the competencies assessment of medical students and, thus, it contributes to the goal to enable complementary support tools and instruments that add new interesting alternatives to traditional evaluation methods. For this reason, a simulation technological environment, such as the one that is presented in this paper, is very useful for the acquisition of practical skills, as well as their subsequent evaluation. Specifically, our software suite tool focuses on the technique of infiltration of botulinum toxin (BT) based on ultrasound imaging (USI) in the treatment of spasticity patients.

The ultrasound-guided BT infiltration technique is considered safe, profitable, effective and well tolerated [12], with better results than other BT infiltration techniques, such as electromyography and electrostimulation, as it achieves greater precision in the placement of the needle in the muscle. In the treatment of spasticity, the correct placement of the needle inside the selected muscular belly is a key factor for the infiltration efficacy [1, 9].

Despite being increasingly recommended, in [8] it is pointed out that the main disadvantage of USI guided infiltration is the harder learning curve required when it is compared to the rest of the techniques. Specialist must learn to position and reach a correct orientation of the probe or transducer, then, he must to interpret the obtained US images to identify

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This article is part of the Topical Collection on *Education & Training*

✉ V. Moreno  
vmoreno@usal.es

<sup>1</sup> Universidad de Salamanca, Salamanca, Spain

musculoskeletal (MSK) structures and, finally, he must to get needle orientation that lets reach the target muscle at the infiltration. To improve the learning curve, it is necessary to get a correct mental model [10].

The sonoanatomy of MSK structures differs from magnetic resonance and radiographic and tomographic images, in such a way that US images are harder to understand [4]. Relating 2D US images to a familiar 3D anatomical model is not trivial issue. This difficulty can only be overcome by training, hence practical experience becomes of fundamental relevance [7]. In USI techniques the best way to acquire a good mental model is based on the use of a simulator which can transfer the knowledge from an expert [9].

In this paper, we present a software suite tool for training which includes a virtual US simulator where the trainees will be able to acquire all the necessary knowledge about the spasticity treatment through US-guided BT infiltration. This technological learning environment includes theoretical and practical contents supported by graphics, real US images and videos, as well as a complete three-dimensional anatomical viewer.

## Materials and methods

### Conceptual design of the platform

When a specialist performs an US-guided BT infiltration, he first localizes the spastic muscle using the US probe and then proceeds to the BT infiltration. Our software suite tool makes it possible to practice with MSK exploration using a virtual

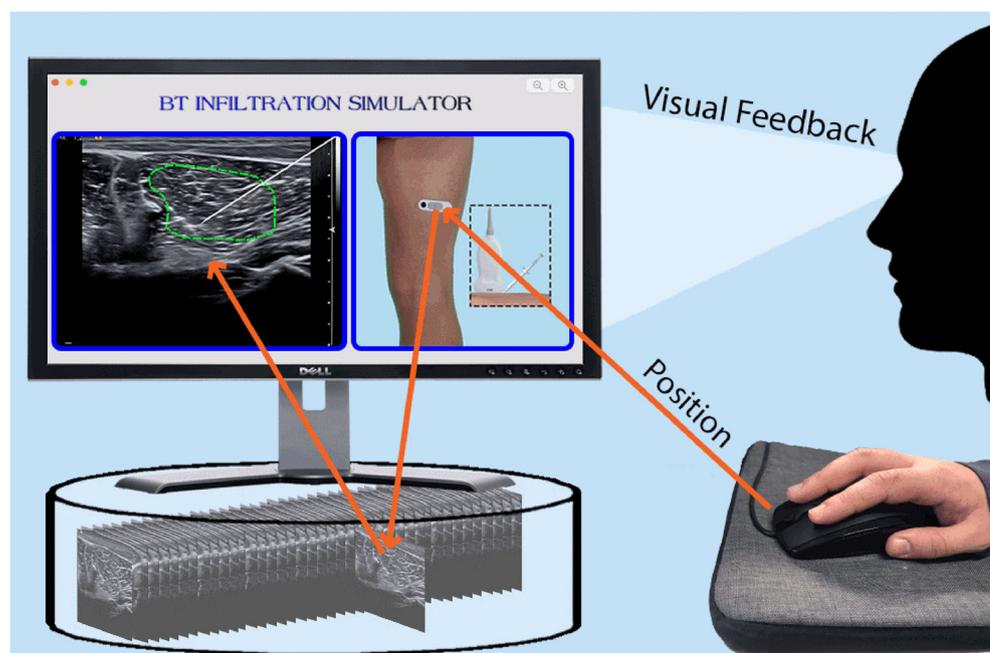
probe to locate the infiltration points and, then, a BT infiltration into the spastic muscle using a virtual needle. A simulator of BT infiltration that replicates the movement of rotation (inclination) and displacement of the syringe and needle assembly also is provided.

The US exploration simulator includes a virtual probe represented over a human model image in the same plane on the screen (Fig. 1). While the virtual probe is moved with the mouse over the model, a set of previously recorded images from the scanning area is displayed. A team of rehabilitation, radiologists, traumatologists and anesthesiologists have designed a set of practical cases. The simulator includes a virtual syringe that is represented perpendicular to the model. If the syringe is clicked with the mouse by the trainee, it is possible to change its inclination respect to the model and, in the following, the needle can be inserted into the model.

### Images repository

The person that has acted as model is a 46 years old male. US images and photos on the right side of the software environment were obtained from the individual without any spastic disorder, which was informed and signed his consent. The real US images were obtained through a Mylab 25 Gold equipment from ESAOTE. The transducer consists of a variable band linear array, model L4 523, that operates in a frequency range from 5 to 12 MHz. US videos were recorded showing a path over the infiltration muscle and voluntarily muscular movements or contractions were made by the model-patient. Doppler videos at the infiltration area were also recorded.

**Fig. 1** An illustrative diagram of the exploration and infiltration simulator



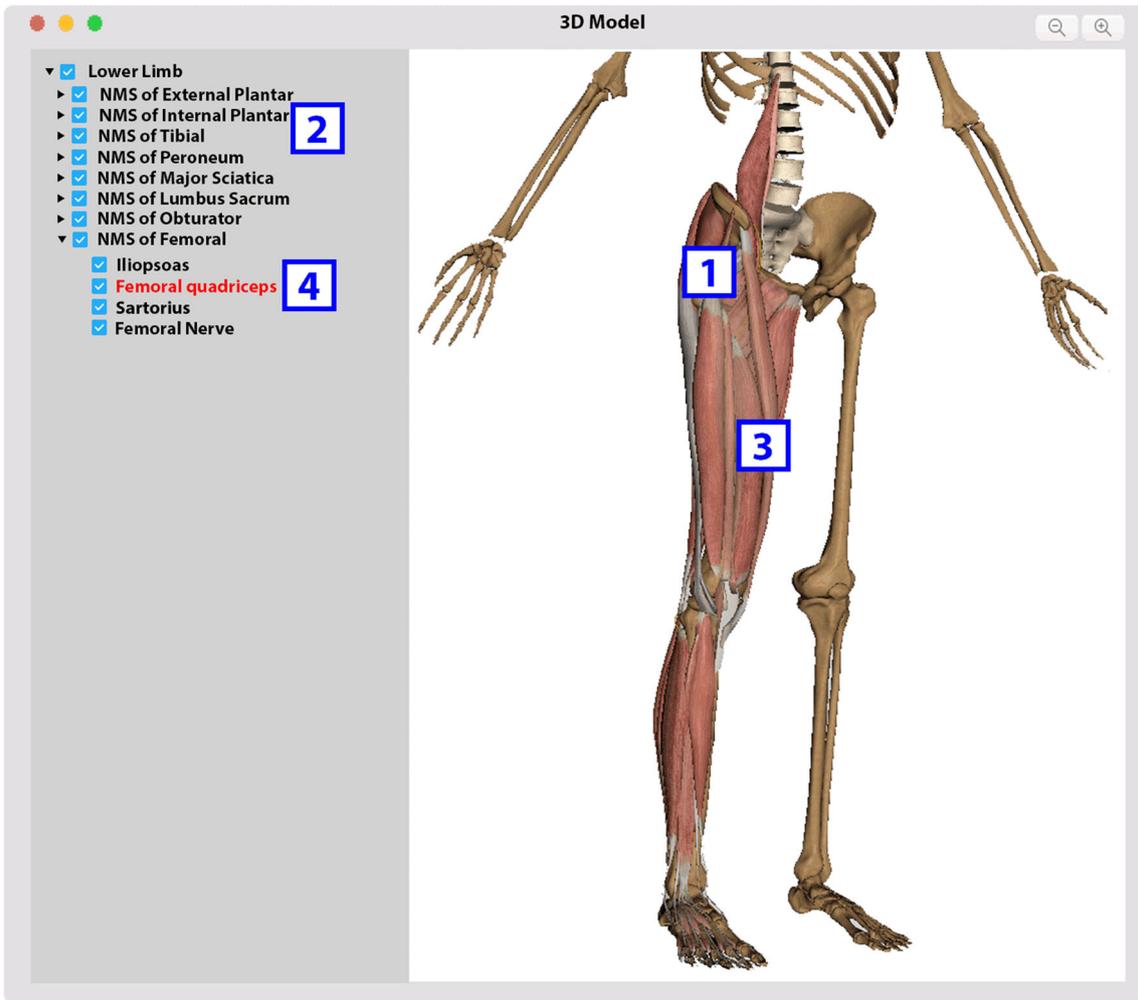


Fig. 2 3D model with a selected muscle

Fig. 3 The human model window with probe

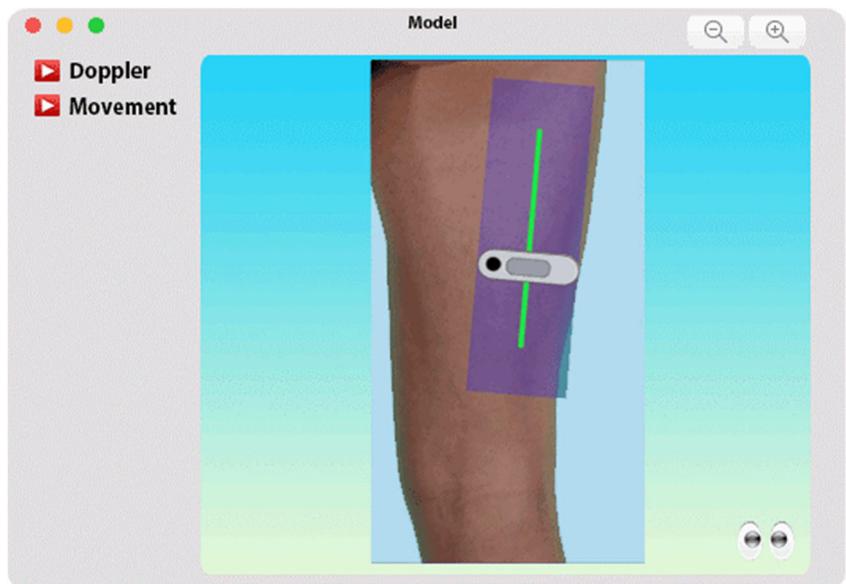
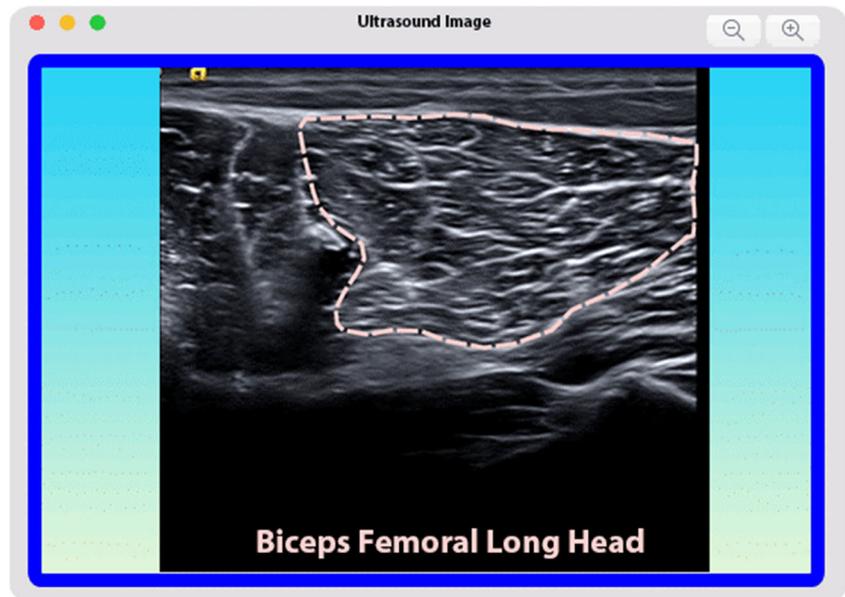


Fig. 4 Real US image window



### Development of the exploration and infiltration simulator

The software suite tool has been developed using C++ programming language and Qt, a cross-platform framework which has different widgets to create graphical interfaces. In order to provide a flexible definition capability for practices, a data model based on XML (eXtended Mark Language) is used, which allows to add, modify or delete practices without the need of software modifications. At XML files, all the necessary resources for each of the infiltration practices are configured.

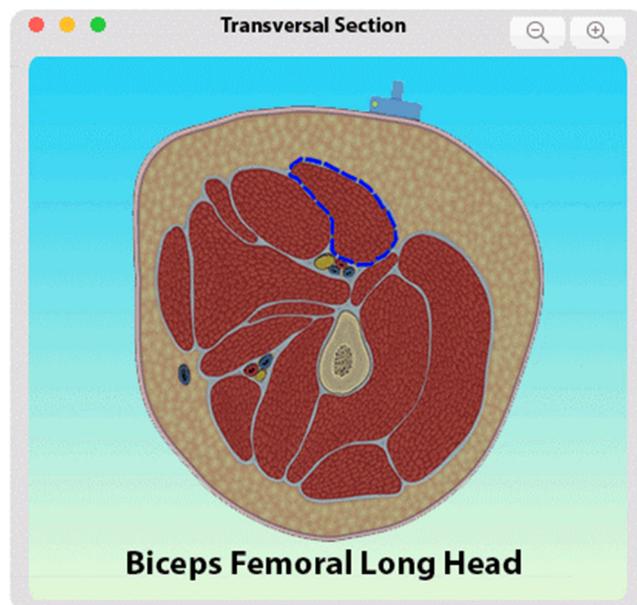


Fig. 5 Window of sectional anatomical image

### Results

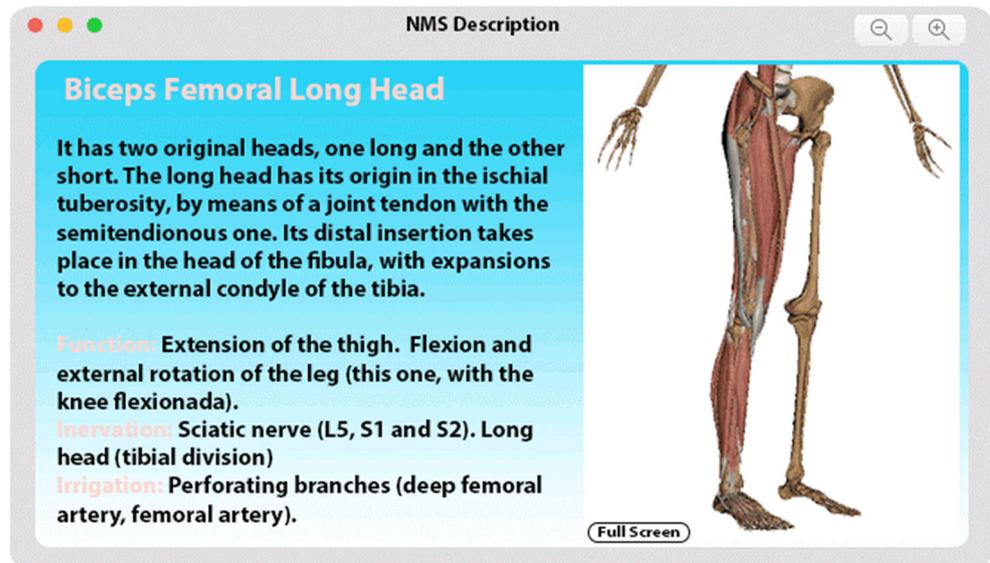
The aim of this technological training environment is to allow medical students to carry out a correct infiltration of botulinum toxin by means of USI, at their professional work in different healthcare teams. Under this platform, the student receives training, both from a theoretical and practical point of view, for the spasticity integral treatment. The available set of theoretical contents on the learning platform constitutes the basis that the student needs to start practicing this kind of treatments. In addition, our e-learning platform integrates a 3D anatomical viewer of the entire human body (Fig. 2). Also, it includes a set of practices where the students will learn, in a visual and interactive way, how to position a virtual probe to visualize the correct US image. To learn how to identify the MSK structures visible in the US exploration, a sectional anatomical image will be exposed where the most significant structures are visually related to the US image.

### Simulator of exploration based on US imaging

In the theoretical modules devoted to the study of spasticity patterns, the student will be able to practice on different MSK systems from the upper and lower limbs. In order to facilitate the student's development of practical skills, the e-learning platform includes a simulator of exploration based on US imaging. At the design, the virtual exploration platform was distributed into four main windows.

- Model window (Fig. 3). The student can move the virtual probe with the computer mouse over a photo of the human model to locate, by exploration, the most effective point for the infiltration of BT. A black circle indicates the orientation of the probe. As an example, the

**Fig. 6** Window with explanatory information on anatomical structure

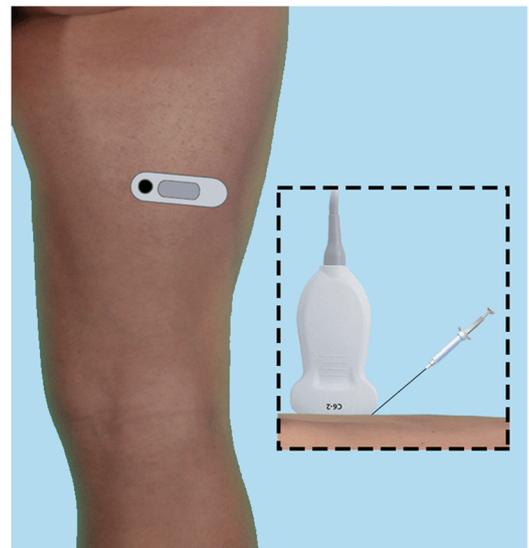
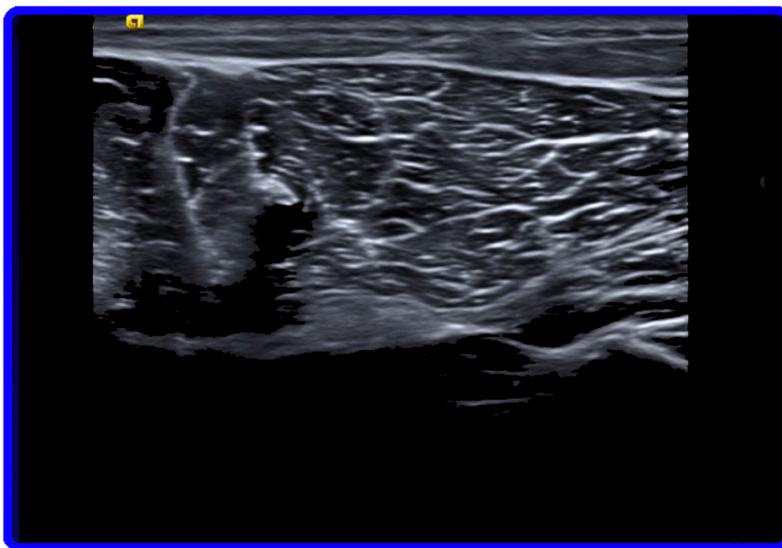


practice on the Biceps Femoral Long Head is shown in the Fig. 3. As an aid to learning, it is possible to show the user the exploration path (purple rectangle with green line) to be followed. It also includes a video in Doppler mode that allows you to identify the veins and arteries in the area. Another illustrative video shows the movement or contraction by the patient of the muscle to infiltrate, which will allow the student to identify the muscular area where the BT has to be infiltrated.

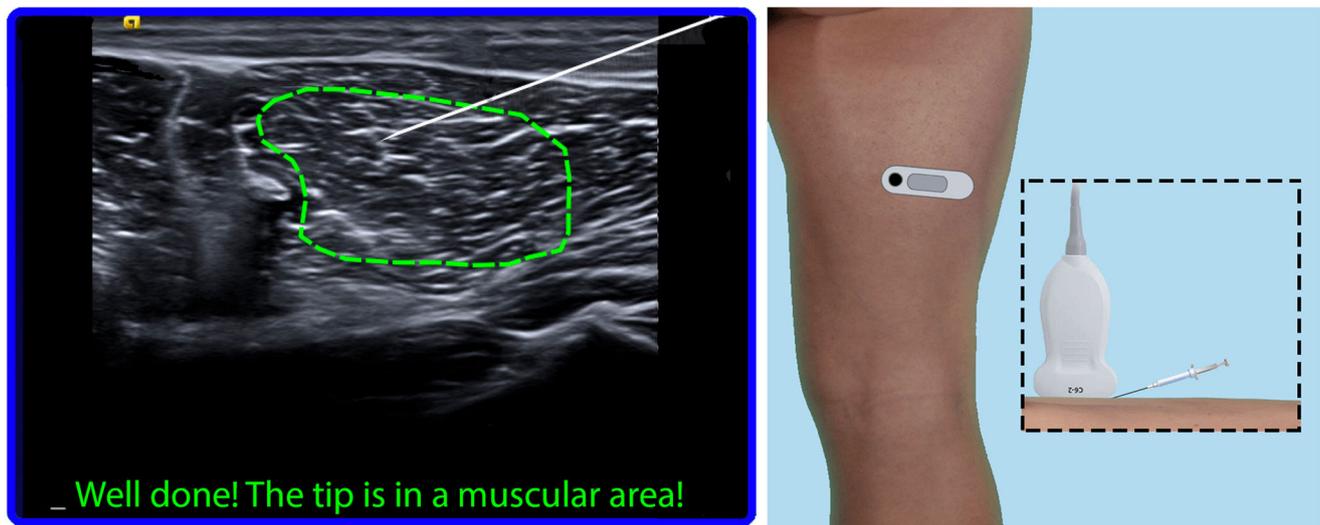
- US image window. When the student places the virtual probe close to the target area, real images of the muscle group where he is working are displayed in the window (Fig. 4) as the mouse is been moving. As a learning aid,

as the student moves the virtual probe, the edges of the US viewer will change color (red, yellow and blue) to indicate if it is far away, near or over the exploration area. When the mouse passes over the US image, the anatomical structures are identified with a discontinuous line and a descriptive text.

- Sectional anatomical image window (Fig. 5). When the student has placed the probe over the correct exploration area, an anatomical illustration of an axial cut of the corresponding **MSK** is displayed. The student can identify on the US image, when the mouse passes over them, the anatomical structures that will appear surrounded by a discontinuous line in both images.



**Fig. 7** Window for infiltration training



**Fig. 8** The needle is inserted over a muscle area with a specific orientation

Same situation happens when the student passes the mouse over the sectional anatomical image.

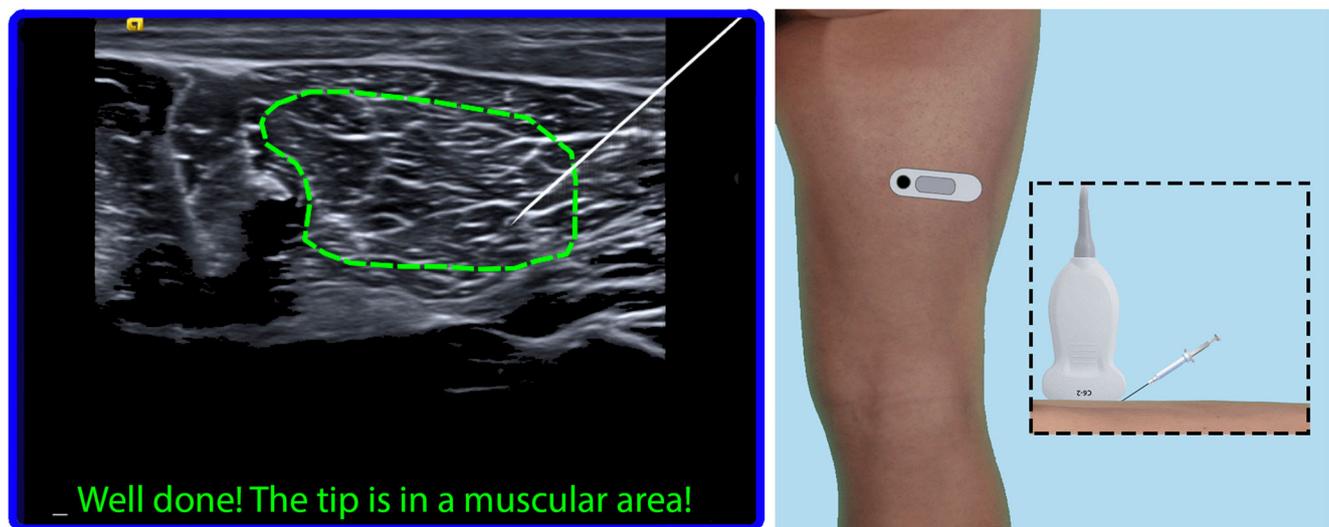
- Descriptive information window (Fig. 6). Its function consists of the display of a theoretical description of the involved muscles, nerves, etc. when they are selected with the mouse.

### Simulator of BT infiltration

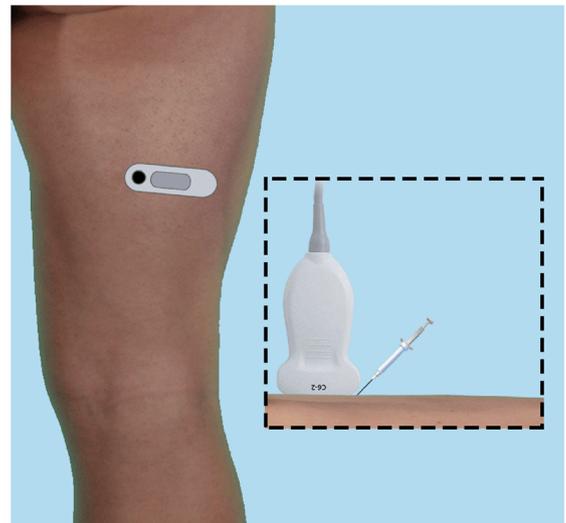
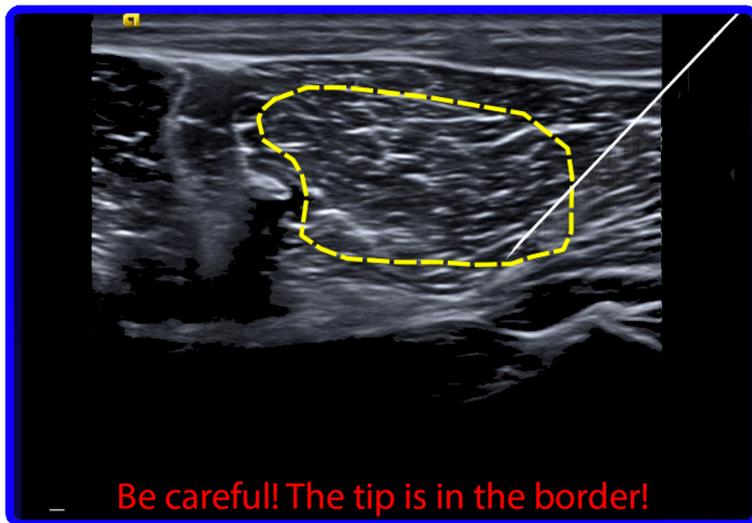
Each of the practices includes an instance of the BT infiltration simulator. Through a virtual syringe, the student can perform infiltrations guided by an US image. In this way, he will learn, in each examination area, which is the muscular area or areas to perform the puncture and infiltrate BT and where are

located the veins, arteries and nerves whose puncture should be avoided. The training window was divided into two main sections:

- Left section. The US images corresponding to the probe position on the model are displayed (Fig. 7). When the infiltration area is reached, a video that shows the active exploration with a real US scanner is reproduced. By hovering the mouse over the image, the student will be able to identify the muscle areas, veins, arteries, nerves or bones, which will be highlighted with polygons of discontinuous green, blue, red, yellow or white lines, respectively. In addition, they will see an identifying text in the same colors.
- Right section. A virtual syringe (Fig. 7) appears on the model for an approach in plane. The student will be able to move the syringe using the mouse to change its



**Fig. 9** The needle is inserted over a muscle area with a different orientation



**Fig. 10** The needle is inserted over the limit of the correct muscle area

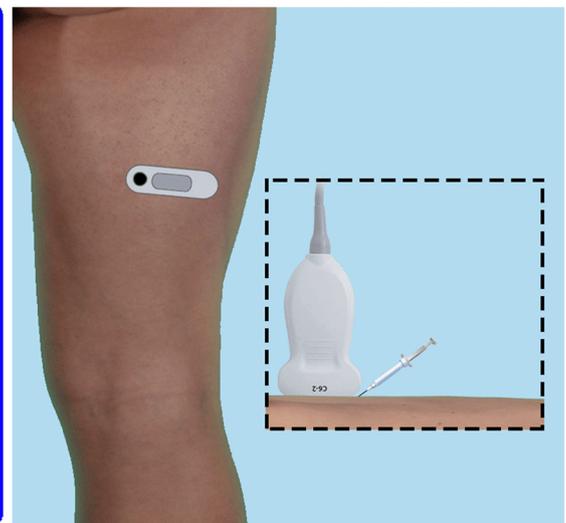
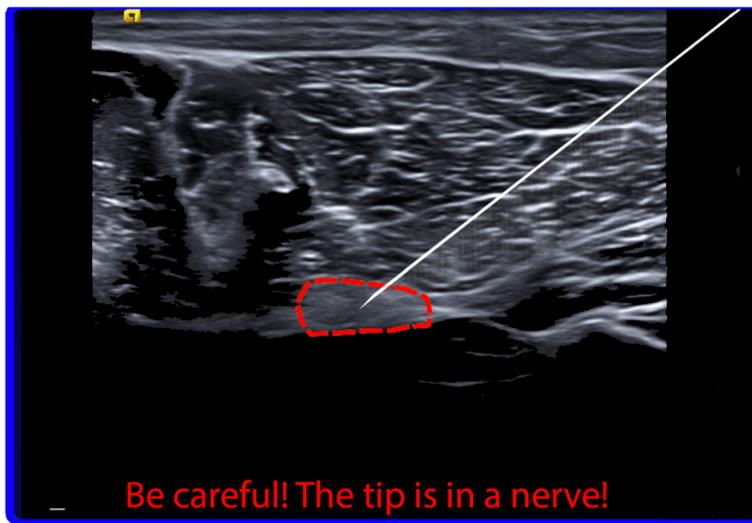
orientation (taking the probe as a reference) before performing the puncture. Afterwards, he can move it, keeping the orientation, to simulate the puncture.

Then the needle starts to be displayed on the US video, so the trainee will be able to direct it towards the target muscle to infiltrate the drug (Fig. 8) with different orientations (Fig. 9). He must always prevent the needle from passing through or touching a vein (Fig. 10), artery, nerve (Fig. 11), or bone (Fig. 12). During the puncture, students will be instructed on the image itself, using a green colored text indicating that the procedure is being performed correctly, when it is a muscle area (Figs. 8 and 9) or red if it is a vein, an artery, a nerve (Fig. 11) or a bone (Fig. 12). Depending on the type of area of the human body at which the puncture is to be performed, the

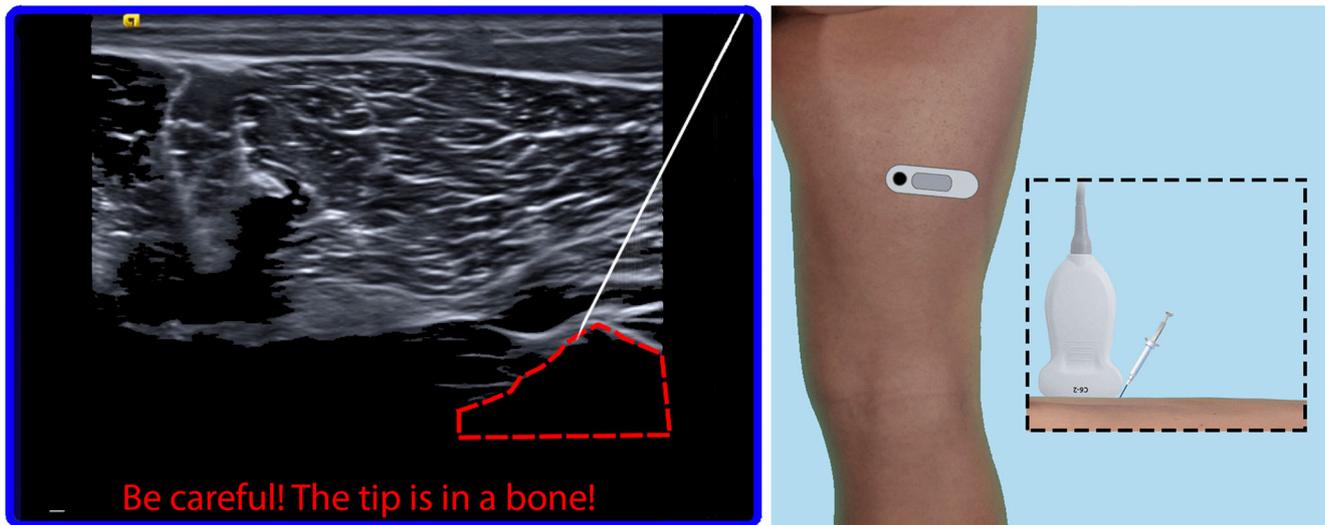
simulator will allow to perform it from the right or left side. Also, cases where it can be performed from both sides are including, so the student can choose which one he prefers. Once the spastic muscle to be infiltrated is reached, the infiltration is simulated by right clicking on the syringe. The US image shows a halo similar to that can be seen in a real procedure.

### Discussion and conclusions

Learning and training based on software simulators allows the acquisition of knowledge and the development of practical skills autonomously, remotely at any time without the need for patients, free of pressure and without ethical issues [2].



**Fig. 11** The needle is inserted over a nerve



**Fig. 12** The needle is inserted over a bone

Among the simulators for training in USI-based needle insertion techniques, an approach is based on the use of cadavers, animals or organs to practice insertions with a real US scanner, but in addition of the ethical considerations, logistical problems appear [2]. Another widely used alternative is to practice with medical phantoms, that consist on realistic models designed to mimic the acoustic characteristics of the human tissues and organs. However, medical training with phantoms requires the use of real US scanners, that still are expensive devices. In addition, each phantom is designed to practice the echo-guided insertion on a particular zone of the human body, which makes necessary to have different types that involves a prohibitive cost [3]. Some low-cost phantoms are built with different materials such as tubes, gelatin, latex, etc., with the desirable acoustic characteristics for the training to be performed [11]. However, they have durability problems with a prolonged usage, due to deterioration of materials, and many times special conservation tasks are needed.

On the contrary, haptic simulators considers replicas (for US probe and syringe) from which the movements made by trainees are captured. These simulators use robotic arms or orientation and position sensors (PCIBirds) to obtain the movements made by the trainees in order to be able to represent the corresponding US images [2]. The images that will appear at these kinds of simulators can be generated through mathematical models [6] or by overlapping previously generated and recorded images from real patients and the needle with different positions and orientations [12]. Main drawback of the US image generation comes from the huge computational cost related with this process [5].

With our training platform, students can perform autonomous learning in this speciality from anywhere, at any time, with great realism and without using a real US scanner. This is achieved because it is based on advanced software development technologies and theoretical content is built using

multimedia material: presentations, traditional anatomical illustrations, real patient videos that show spasticity patterns, ultrasound videos with real muscle paths or eco-Doppler videos. It is a set of resources that allows the trainee to work with a high degree of interactivity. Thanks to our US scanning simulator design and to the 3D anatomical viewer, students can visually and interactively relate the anatomical structures that appear in the US image to those of a transverse anatomical slice of the same area and to three-dimensional objects.

Regarding with the infiltration simulator, it recreates, as the inclination of the syringe is modified, with great realism the positioning of the needle within the human tissues. In this way, the simulator helps trainees to construct a mental model that allows them to direct the needle to correctly apply the corresponding dose of BT on the muscular areas.

Although in our approach it seems unnecessary to use a real US machine, we think that the training of professionals should always require to finish the practice with an ultrasound machine with real patients. However, as it is a question of learning how to perform a puncture on a patient, our training platform allows the professional that already have practical skills before facing an infiltration on a person.

## Compliance with Ethical Standards

All the authors declare that they have not conflict of interest. Ethical approval: this article does not contain any studies with human participants performed by any of the authors.

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