Technical Note

Ultrasound With Stress for Assessing Injuries to the Medial and Lateral Collateral Ligaments of the Knee

José Leonardo Rocha de Faria, M.D., M.Sc., Ph.D., Bernardo Crespo, M.D., M.Sc., Matheus Weihermann Guesser, M.D., João Henrique da Silva Araújo, M.D., Pedro Ênio Feitosa Bezerra, M.D., Zartur José Barcelos Menegassi, M.D., Ph.D., Sergio Augusto Lopes de Souza, M.D., Ph.D., Hélcio Mendonça Pereira, M.D., Ph.D., Alan de Paula Mozella, M.D., M.Sc., Ph.D., Robert F. LaPrade, M.D., Ph.D., and João Antônio Matheus Guimarães, M.D., Ph.D.

Abstract: Physical examination of knee ligament injuries often is considered subjective and imprecise as the result of various factors affecting its reliability. Magnetic resonance imaging is widely used but lacks information on ligament function and is costly. Stress radiography is commonly employed, but alternatives are sought because of radiation exposure and the need for a physician's presence during the procedure. Ultrasonography represents a noninvasive, rapid, and cost-effective method for assessing knee injuries. This Technical Note presents stress ultrasonography protocols for evaluating medial and lateral tibiofemoral openings in patients with posteromedial corner and/or posterolateral corner injuries. The ultrasonography examination parameters are detailed for both the medial collateral ligament and lateral collateral ligament evaluation. Studies have associated certain degrees of tibiofemoral opening with knee ligament injuries, aiding surgeons in surgical decision-making. Examination with stress ultrasonography offers a dynamic and reproducible method without adverse effects for patients, potentially expediting the diagnosis and treatment of multiligament knee injuries.

Physical examination of patients with knee ligament injuries often is regarded as subjective and imprecise. Various factors have been identified that can affect its reliability and reproducibility. These factors include the examiner's expertise, patient tolerance, and the presence of concomitant injuries.[1-3]

Magnetic resonance imaging (MRI) is extensively employed in assessing knee ligament injuries. However, being a static examination, it does not provide reliable information about the patient's ligament function. In certain situations, such as in a chronic knee injury, it may depict a ligament structure that appears normal without definitively determining its functionality.[4] Furthermore, it is important to acknowledge that MRI is costly.

Consequently, stress radiography has emerged as a widely used tool for evaluating knee ligament injuries. Given its broad availability, numerous protocols have been developed to quantify injuries and aid knee surgeons in their therapeutic decision making.[5-9] Nevertheless, because of the requirement for a physician's presence during the stress radiography procedure, the associated radiation exposure, and the need for multiple radiographic images to ensure proper femoral and tibial rotation, alternative methods for assessing tibiofemoral opening under stress in the medial and lateral compartments in the presence of injury are currently under investigation.

From the National Institute of Traumatology and Orthopedics of Brazil, Rio de Janeiro — RJ, Brazil (J.L.R.D.F., B.C., M.W.G., J.H.d.S.A., P.Ê.F.B., H.M.P., A.d.P.M., J.A.M.G.); School of Medicine from University of São Paulo — USP Riberão Preto — SP, Brazil (J.L.R.D.F.); Department of Orthopedics, School of Medicine, Federal University of Rio de Janeiro, RJ, Brazil (B.C., Z.J.B.M.); State University of Rio de Janeiro — UERJ Rio de Janeiro — RJ, Brazil (M.W.G., A.d.P.M.); Department of Radiology, School of Medicine, Federal University of Rio de Janeiro, RJ, Brazil (S.A.L.d.S.); and Twin Cities Orthopaedics, Edina, Minnesota, U.S.A. (R.F.L.).

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Address correspondence to José Leonardo Rocha de Faria, Instituto Nacional de Traumatologia e Ortopedia Jamil Haddad - Av. Brasil, 500, São Cristovão. CEP: 20940-070. E-mail: DRJOSELEONARDOROCHA@gmail.com

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Ultrasonography (US) represents another valuable tool for evaluating knee anatomical structures. It is a noninvasive, rapid, and cost-effective method. This examination can be employed to assess both acute and chronic knee injuries, serving as a complementary approach to the physical examination and readily conducted in an office setting.[10,11] Stress can be applied during the examination to analyze the opening of both the medial and lateral tibiofemoral compartments. In this Technical Note, we will delve into the application of stress US for evaluating medial and lateral tibiofemoral opening in patients with posteromedial corner and/or posterolateral corner injuries.

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All examinations were performed with a Butterfly US device (Butterfly NetWork, Burlington, MA) through medial and lateral access of the knee to visualize the joint space at rest and after valgus or varus stress using a linear transducer with a length of 40 mm and frequency of 17 MHz and maximal depth of 4.0 cm (Fig 1). Stress US examinations were conducted exclusively by the designated researcher, adhering to the parameters in the sections that follow.

Medial Collateral Ligament (MCL) Evaluation

The examination uses the ButterFly US device, which conveniently connects to a smartphone. A linear transducer with a frequency range of 17 MHz is employed (Fig 1).[12] The patient assumes a seated position with the proximal half of the thigh resting on the center of a conventional examination table (Fig 2 A and B). The knees are flexed at a precise angle of 90°, while the feet find support on the second (last) step of a specially designed ladder intended for clinical settings (Fig 2A). US transmission gel is evenly distributed on the transducer's surface, after which it is connected to the examiner's smartphone, enabling immediate access to the predefined US imaging mode.

Positioned laterally to the knee being examined, the examiner places their own foot on the ladder's second step, using their own knee as a pivotal point for applying valgus stress (Fig 3A). The examiner finds the joint line of the knee (Fig 3B).

The examiner advises the patient to relax and allow the limb under examination to rest in a loose state. With one hand, the examiner secures the ankle of the examined limb and proceeds to execute a complete knee extension (Fig 3A). With the other hand, the transducer is longitudinally positioned on the medial and distal aspect of the femur, facilitating the identification of the medial epicondyle and the proximal fibers of the MCL. Subsequently, the probe is further directed to the joint space, allowing for the identification of the distal femur, its medial articular surface,

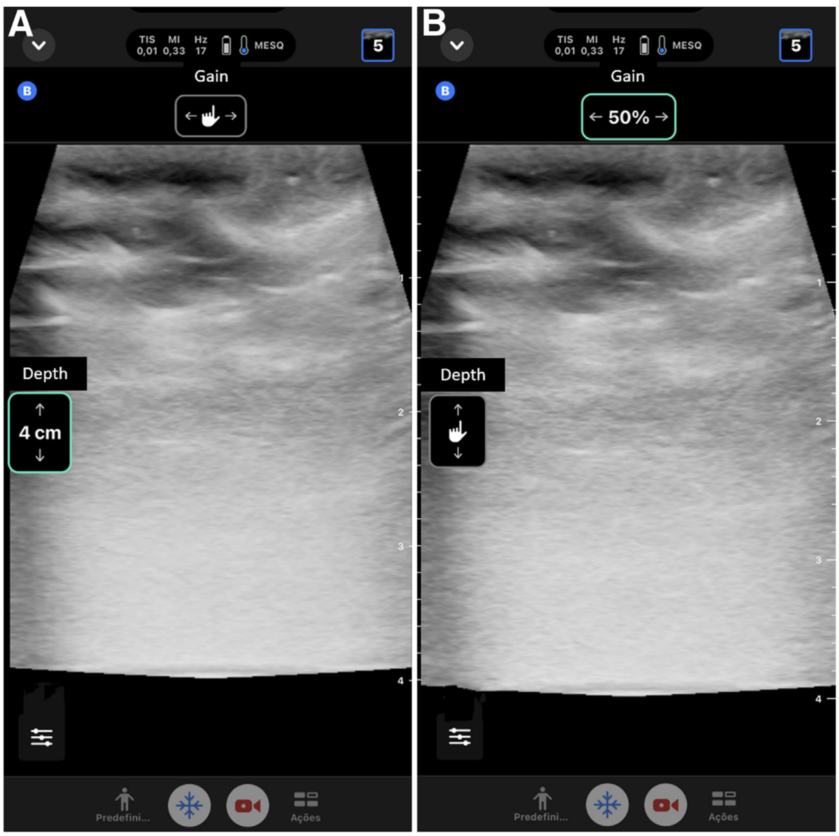

Fig 1. (A) We demonstrate the depth setting of 4 cm for which the Butterfly US should be configured. (B) The gain should be set at 50%. US performed in the right knee.

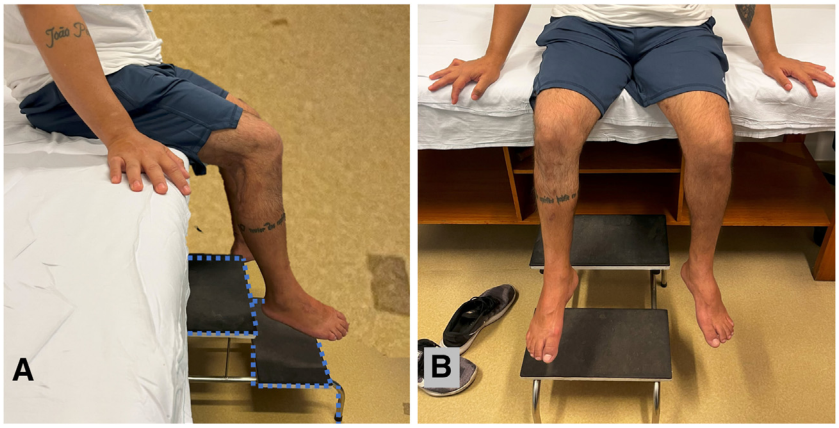

Fig 2. (A-B) We position the patient sitting on a physical examination table, and a 2-step stool is placed under the patient's feet.

the medial meniscus, and the medial tibial plateau (Video 1). Maintaining this probe placement, valgus stress is applied by employing the examiner's knee as a fulcrum on the lateral aspect of the femur's mid-third, while maximum force is exerted on the ipsilateral ankle of the examined limb through the examiner's hand. We teach the patient how to freeze the screen pressing the freezing button (Fig 3 C-E). The resulting medial opening is visualized and then frozen on the smartphone screen (Fig 4 A and B). Subsequently, the examiner discontinues the stress application and proceeds to employ the US device's software to measure the distance between the most medial and distal points of the distal femur, as well as between the most medial and proximal points of the tibial plateau (Fig 4B).

These aforementioned steps are replicated with the patient's knee flexed at a precise angle of 30°, ensuring accurate measurements of the forces applied during valgus stress and the space between the femur and tibia (Fig 4 C and D). Both stages are also conducted on the unaffected knee, thereby facilitating a comparative analysis to ascertain the extent of increased medial opening within the injured knee.

Lateral Collateral Ligament (LCL) Evaluation

The patient assumes a seated position with the proximal half of the thigh resting on the center of a conventional examination table.[12] The knees are flexed at a precise angle of 90°, while the feet find support on the second (last) step of a specially designed ladder intended for clinical settings.

Positioned medially to the knee being examined, the examiner places their own foot on the ladder's second step, using their own knee on the medial aspect of the femur's mid-third as a pivotal point for applying varus stress (Fig 5A). US transmission gel is evenly distributed on the transducer's surface, after which it is connected to the examiner's smartphone, enabling immediate access to the predefined US imaging mode.

The examiner advises the patient to relax and allow the limb under examination to rest in a loose state. With one hand, the examiner secures the ankle of the examined limb and proceeds to execute a complete knee extension (Fig 5A). With the other hand, the transducer is longitudinally positioned on the lateral and distal aspect of the femur, facilitating the identification of the lateral epicondyle and the proximal fibers of the LCL (Video 1). Subsequently, the probe is further directed to the joint space, allowing for the identification of the distal femur, its lateral articular surface, the lateral meniscus, and the lateral tibial plateau. Maintaining this probe placement, varus stress is applied by employing the examiner's knee on the medial aspect of the femur's mid-third as a fulcrum, while maximum force is exerted on the ipsilateral ankle of the examined limb through the examiner's hand. The resulting lateral joint opening is visualized and then frozen on the smartphone screen (Fig 5A). Subsequently, the examiner discontinues the stress application and proceeds to employ the US device's software to measure the distance between the most lateral and distal points of the distal femur, as well as between the most lateral and proximal points of the tibial plateau (Fig 5B).

These aforementioned steps are replicated with the patient's knee flexed at a precise angle of 30°, ensuring accurate measurements of the forces applied during varus stress and the space between the femur and tibia (Fig 5 C and D). Both stages are also conducted on the unaffected knee (Fig 6 A-D), thereby facilitating a comparative analysis to ascertain the extent of increased lateral opening within the injured knee.

Discussion

Stress US is a valuable tool for assisting surgeons in diagnosing ligament injuries that require surgical intervention. This noninvasive method eliminates the need for radiation exposure. When performed under a standardized protocol and following the

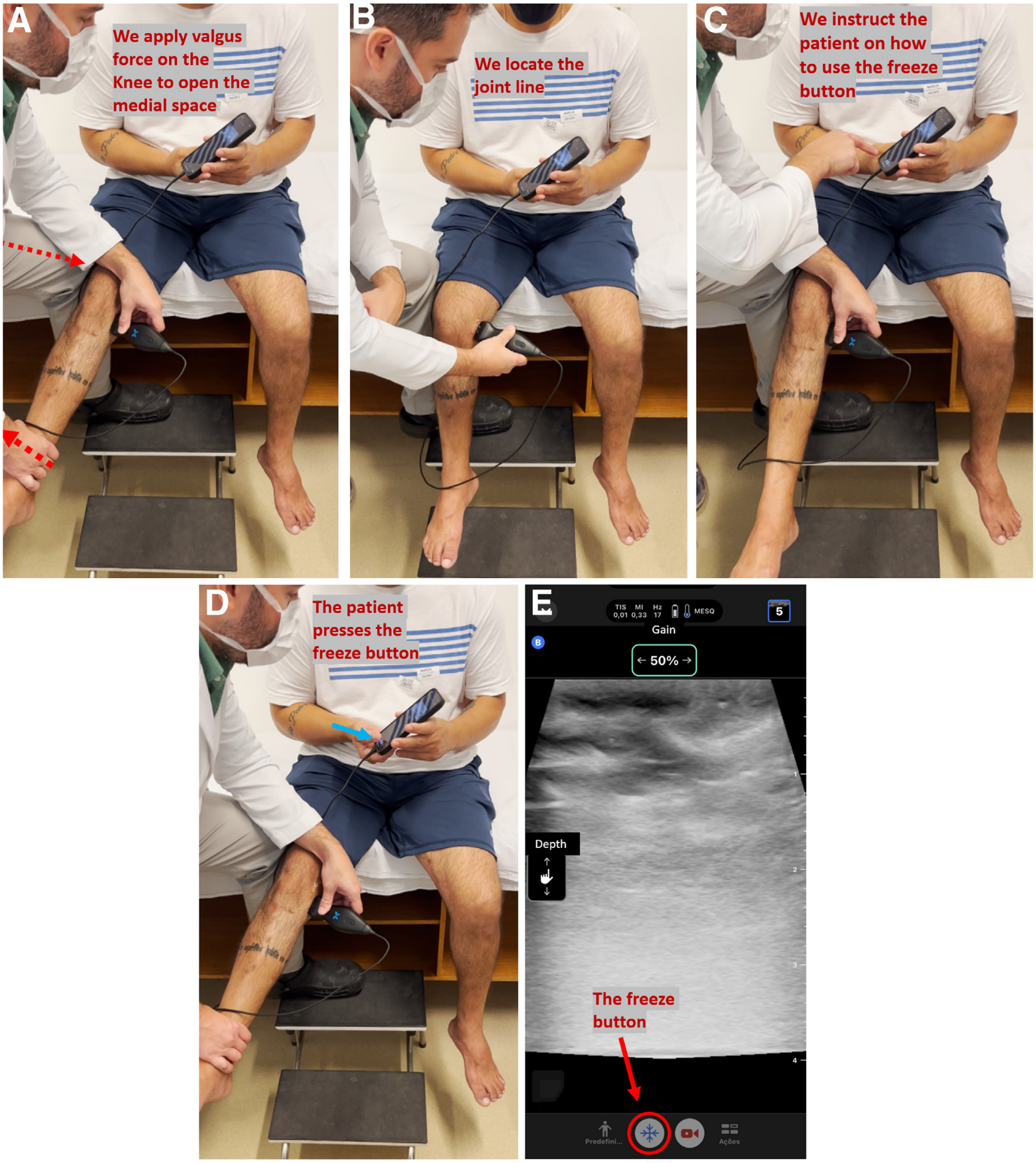

Fig 3. (A) We apply a valgus force on the knee to open the medial space; the patient holds the cell phone, displaying its screen to the examining physician. (B) We locate the joint line with the ultrasound. (C) We instruct the patient on how to use the freeze button. (D) The patient presses the freeze button. (E) We observe the cell phone screen displaying the Butterfly app, with a red circle around the freeze button. US image taken of the right knee.

aforementioned sequential steps, it offers several advantages. First, it provides a relatively accessible and noninvasive approach for assessing ligament stability, making it both a safe and rapid diagnostic test. The enhanced diagnostic accuracy and the capability for dynamic assessment stand out as some of the method's most significant advantages. Pearls and pitfalls of the stress US are described in Table 1.

A recent systematic review evaluated reference radiographic measurements for stress radiography in diagnosing knee ligament injuries, highlighting its accuracy and reproducibility despite methodologic

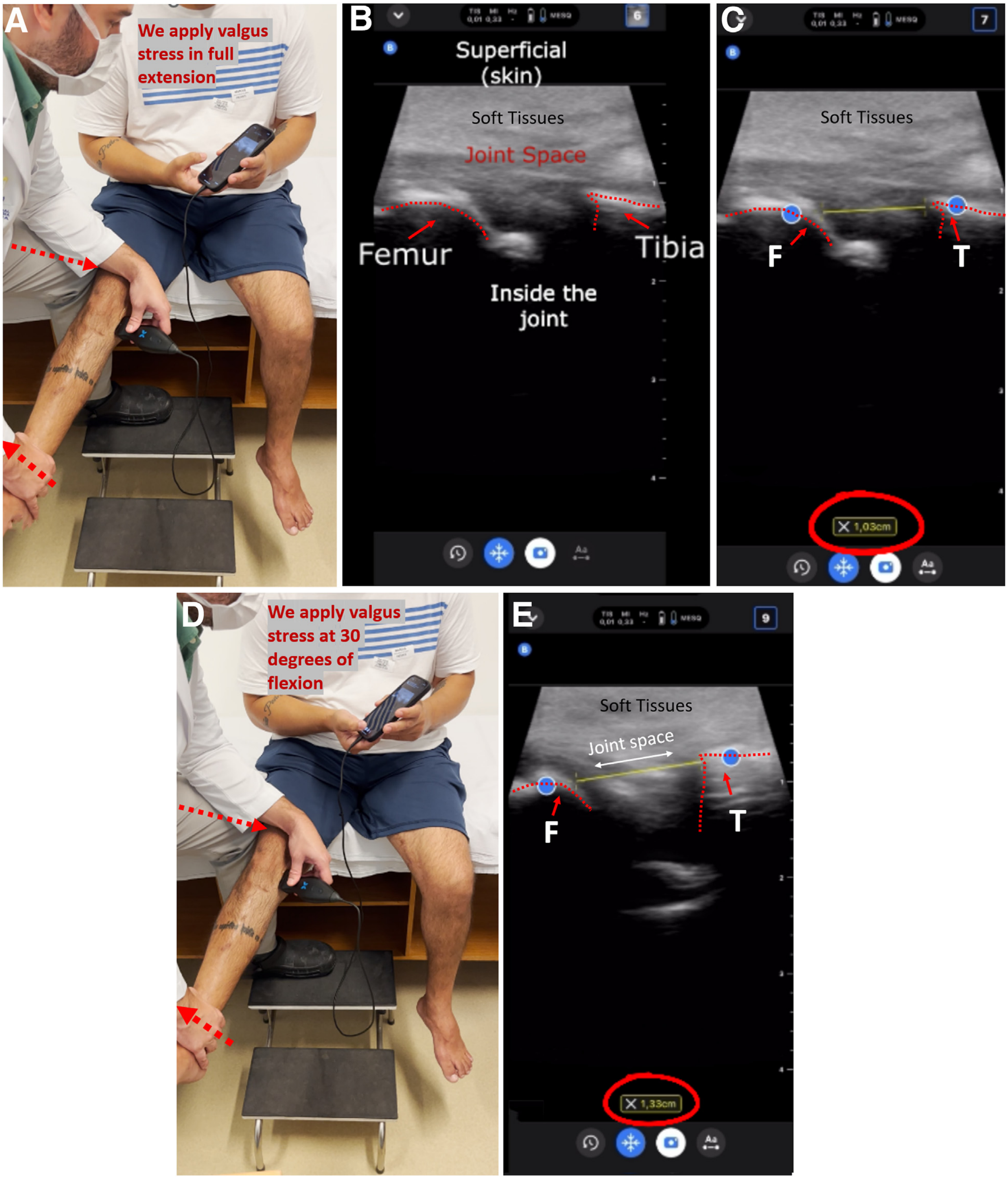

Fig 4. (A) We apply valgus stress in full extension. (B) We observe the femur (red arrow), the tibia (red arrow), the joint space, within the joint, and the superficial region of the skin. (C) We measure a medial joint space opening of 1.03 cm using the ultrasound software. (D) We apply valgus stress at 30° of flexion. (E) We observe a medial opening of 1.33 cm. US image taken in the medial side of the right knee.

heterogeneity among studies.[13] In addition, other studies emphasize stress radiography's role in precisely assessing instability in multiligament knee injuries[14,15] and its advantage in comparing with the healthy contralateral side, reinforcing its diagnostic value.[5,15]

LaPrade et al.[8] have reported that during varus stress, a lateral opening greater than 2.7 mm suggests a lateral

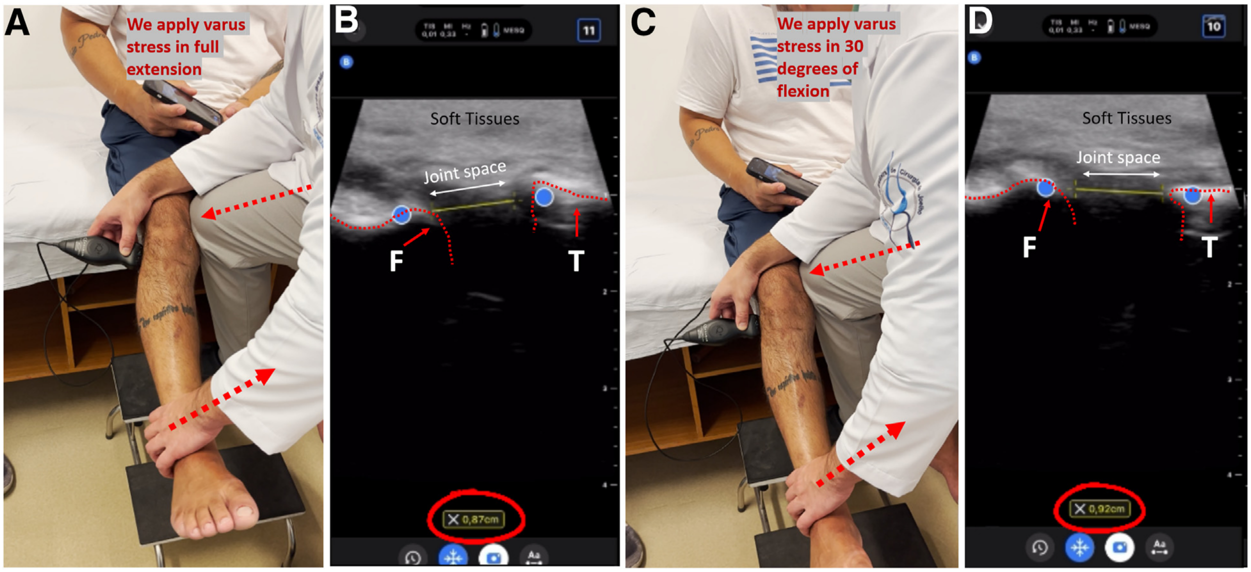

Fig 5. (A) We apply varus stress in full extension. (B) We observe the femur (red arrow), the tibia (red arrow), the joint space, within the joint, and the superficial region of the skin. We measure a lateral joint space opening of 0.87 cm using the ultrasound software. (C) We apply varus stress at 30° of flexion. (D) We observe a lateral opening of 0.92 cm. US image taken in the lateral side of the right knee.

collateral ligament injury. If the opening exceeds 4.0 mm, there is an associated complete posterolateral corner injury. Similarly, during valgus stress, LaPrade et al.[9] associated an opening greater than 3.2 mm, compared with the contralateral knee, with a medial collateral ligament injury. In these cases, manual maximum force applied by the same examiner was used to assess the opening.

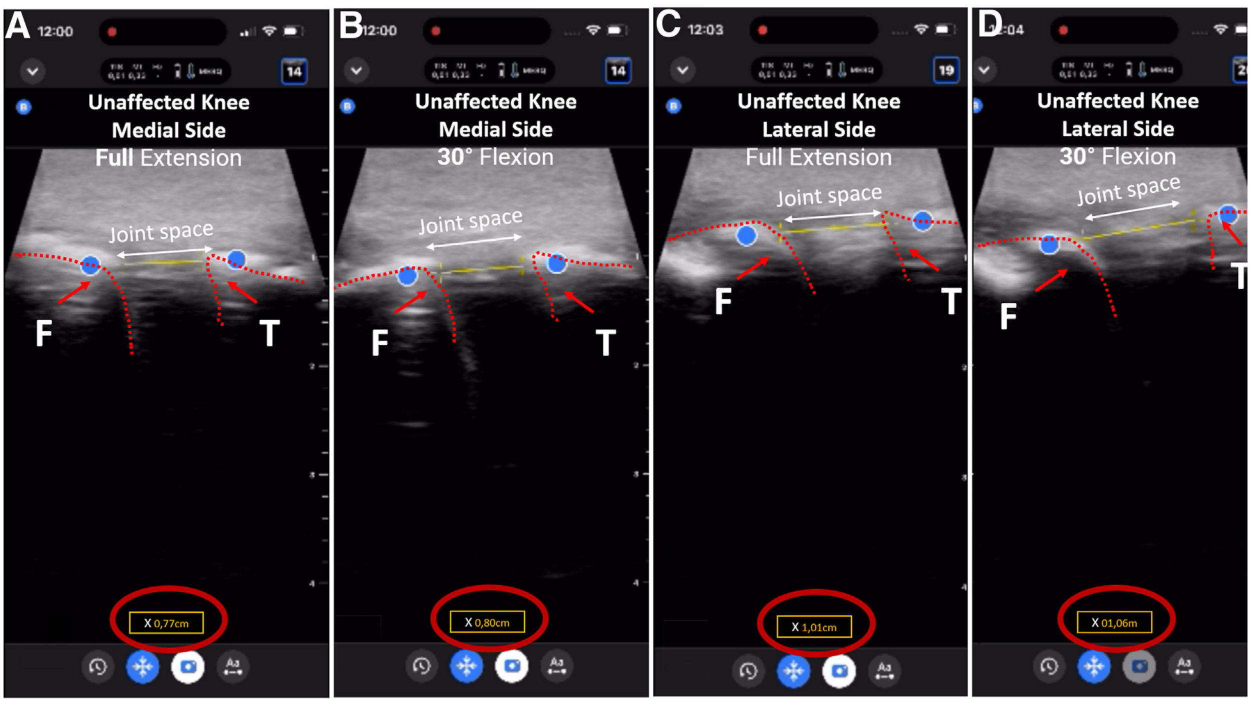

Fig 6. (A) We observe the femur (red arrow), the tibia (red arrow), the joint space, within the joint. At unaffected knee medial side full extension, we observe an opening of 0.77 cm. (B) At unaffected knee medial side at 30° flexion, we observe an opening of 0.80 cm. (C) At unaffected knee lateral side full extension, we observe an opening of 1.01 cm. (D) At unaffected knee lateral side at 30° flexion, we observe an opening of 1.06 cm. US images of the left knee.

Table 1. Pearls and Pitfalls of Stress Ultrasonography

Pearls	Pitfalls
Noninvasive	Requires specialized training
Cost-effective	Examiner's dependence
Dynamic assessment under stress conditions	Complex intra-articular lesions may require complementing with magnetic resonance imaging
Low cost, quick, and safe without radiation exposure	Pain during stress may limit assessment in acute injuries
	Check the rotation of the limb when you are applying stress to the medial and lateral compartments. You can do this by ensuring that the patella faces directly upward, and also by checking the orientation of the foot

Table 2. Comparative Advantages and Disadvantages Between Physical Examination, MRI, Stress Radiography, and Stress Ultrasound

Method	Advantages	Disadvantages
Physical examination	Can be performed in a doctor's office Integral part of clinical assessment requiring examiner expertise and patient tolerance	Often considered subjective and imprecise
MRI	Provides detailed images of soft tissues of the knee Widely used for assessing knee ligament injuries Aids in identifying concomitant injuries	Does not provide information on ligament function May not definitively determine ligament functionality
Stress radiography	Broad availability and protocols developed for quantifying injuries Assists in assessing knee instability under stress Comparisons with the healthy contralateral side can be made	Requires a physician's presence during the procedure Radiation exposure is a concern Multiple radiographs often needed for proper evaluation
Stress ultrasound	Noninvasive, quick, and cost-effective. Can be performed in a doctor's office and involves no radiation Allows dynamic assessment Complements physical examination and can expedite diagnosis and treatment	Requires a specialized ultrasound device to visualize musculoskeletal structures Reproducibility depends on examiner's skill and training Pain in acute injuries may limit medial or lateral opening In complex intra-articular lesions, it may need to be complemented with MRI

MRI, magnetic resonance imaging.

Although there are established parameters and values in the literature, there is still no consensus on the best measurement method and instrument to use for reproducing stress.[5] In addition, multiple radiographs are often required for a proper evaluation. It is important to consider that stress radiography exposes the patient to radiation, even with the use of protective lead aprons. In addition, the physician performing the stress is also not entirely free from radiation exposure.

Studies that evaluate the knee through US mostly do not associate valgus and varus stress for assessing tibiofemoral opening. Rather, these evaluations focus on assessing the integrity of ligament fibers.[10,16] For knee surgeons, it is crucial to determine the degree of tibiofemoral opening because this is the primary way to quantify the extent of ligamentous injury.

Sekiya et al.[17] published a study defining the degree of opening in millimeters to determine lateral collateral ligament injuries. A lateral joint space opening of 10.5 mm or greater during US examination with a varus stress reported a sensitivity of 83% and specificity of 100% for lateral collateral ligament and posterolateral corner injuries, with a positive predictive value of 100%, negative predictive value of 75%, and an accuracy of 88%. A medial joint space opening was determined by Lee et al.[18] In this study, grade I MCL injuries were determined to have an opening of 0 to 5 mm in the tibiofemoral distance, grade II had an opening of 5 to 10 mm, and grade III had an opening greater than 10 mm, all compared to the healthy contralateral side.[18]

In 2017, Espregueira-Mendes et al.[19] described a study using MRI with stress to assist in the diagnosis of ACL injuries, focusing on anterior translation and rotational instability. However, it remains a method that is not widely reproducible outside of research centers.

We compare advantages and disadvantages between physical examination, MRI, stress radiography, and stress US in Table 2. Limitations and challenges of the method include the necessity for a US device capable of visualizing musculoskeletal structures and measuring distances between points specified by the physician. Another issue is reproducibility, which is examiner dependent and thus requires adequate training for accurate identification of structures and distances, thereby ensuring technical competence. In cases of acute injuries, patients may experience pain during stress testing, which could limit medial or lateral opening. Finally, for complex intra-articular lesions, US may need to be supplemented with MRI.[14]

In conclusion, we believe that US examination can aid in the diagnosis of multiligamentous knee injuries, providing a low-cost, dynamic, and reproducible method without adverse effects for patients. It has the potential to expedite the diagnosis and subsequent treatment of patients.

Disclosures

The authors report the following potential conflicts of interest or sources of funding: J.L.R.D.F. reports personal fees from Sintegra Surgical Sciences, outside the submitted work. R.F.L. reports other from Arthrex, Ossur, Smith & Nephew, Elsevier, Linvatec, outside the submitted work. All other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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