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ORIGINAL ARTICLE

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The "muscular hernia sign": an original ultrasonographic sign to detect lesions of the forearm's interosseous membrane

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Abstract The total disruption of the forearm's interosseous membrane can lead to an Essex-Lopresti syndrome. The diagnosis must be done early for a better prognostic. Incomplete lesions can aggravate and an early diagnosis of incomplete lesions is a challenging problem. Magnetic resonance imaging is the gold standard but remains expensive, and is hard to obtain in an emergency. On the contrary, ultrasonography is cheap, accessible in an emergency, and dynamical tests can be performed easily. Twelve fresh frozen forearms were randomized in four groups. The membrane was divided into three parts (proximal, middle, and distal thirds). Each group was prepared with variable patterns of lesions. Two radiologists performed an ultrasonographic (US) examination of these forearms. They were blinded with respect to the lesional status of the forearms. Each examination consisted of two stages: static and dynamic. During the dynamic examination, the radiologist looked for the "muscular hernia sign". The results of their examinations were compared with the real lesional status. The static examination was very efficient in the proximal and middle parts of the membrane, and less reliable in the distal third. With the dynamical examination, no mistake occurred at the proximal and middle parts of the forearm, and there was only one at the distal part. The US examination of the interosseous membrane is very efficient to detect incomplete lesions, mostly, if dynamical tests are performed looking for a "muscular hernia sign".

Keywords Forearm, Interosseous membrane, Ultrasonography, Essex-Lopresti, Radial head fractures

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Introduction

The interosseous membrane, the radial head, and the triangular fibrocartilage complex are the three keys of forearm's longitudinal stability [3, 9, 13]. Radial head fractures may result in a longitudinal radio-ulnar instability when they are associated with a global disruption of the interosseous membrane [3, 7]. It is described as Essex-Lopresti lesions and associates wrist and elbow abnormalities with pains, and limited motions [2, 4]. Radio-ulnar disjunctions are rarely obvious. In most cases, the diagnosis is made several weeks later, which leads to poor clinical results. That is why an acute identification of the injury pattern is a real challenge. If the diagnosis of radial head fractures is easy to do with standard X-rays, the detection of interosseous membrane's disruption remains difficult. Smith [12] designed a test called the "radius pull test" to allow for an early identification of interosseous membrane's injuries. A negative "radius pull test" indicates that the membrane is able to face longitudinal loads, but it cannot make any positive statement about the whole membrane's integrity. In case of incomplete lesions, the progressive distension of the remaining membrane's fibers can allow radius proximal migration. Publications displayed the interest of magnetic resonance imaging (MRI) to study the interosseous ligament [6, 11, 15]. Axial slices T2 weighted fat-spin-echo images with fat suppression would provide the most accurate information in the middle one-third of the forearm [15]. But MRI is expensive, difficult to obtain in an emergency, and does not allow any dynamical exploration.

Some authors examined the interosseous ligament with ultrasonography [5, 10, 16]. Ultrasonography is

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much easier to obtain in an emergency, less expensive, and allows dynamical examination. Fester et al. [6] considered that there is no statistical significance between the accuracy of MRI and ultrasonography in determining complete disruptions of the central portion of the forearm interosseous membrane.

All different publications investigated mainly the middle third of the membrane, with no mention of the dynamical examination. The aim of our study is to describe a new ultrasonographic (US) dynamic test. It consists of assessing the presence or absence of a "muscular hernia sign". It would be a way to detect lesions of any part of the interosseous membrane.

Materials and methods

Specimens and preparation stage

The anatomical protocol was done using the right forearm of 12 fresh frozen cadavers (12 forearms). Both elbow and wrist regions were included in the study. All upper limbs were free from visible pathology or previous surgery. The specimens were randomized in four groups (Fig. 1). In group 1 (two specimens), the interosseous ligament was left intact. In group 2 (four specimens), the interosseous membrane was divided into three virtual parts (proximal, middle, and distal thirds). In this group, only one of the three parts was cut longitudinally with a scalpel (without any resection of the membrane). In group 3 (four specimens), the interosseous membrane was sectioned at two levels. In group 4 (two specimens), the interosseous ligament was totally sectioned. In all specimens (including the group 1), the interosseous ligament was approached through a dorso-radial incision between extensor carpi radialis longus and brachioradialis muscles. A gel was used inside the forearm to remove air bubbles, with a hermetical skin closure. All specimens had the same incision and the same muscular approach, so that it was impossible to guess the group of the forearm.

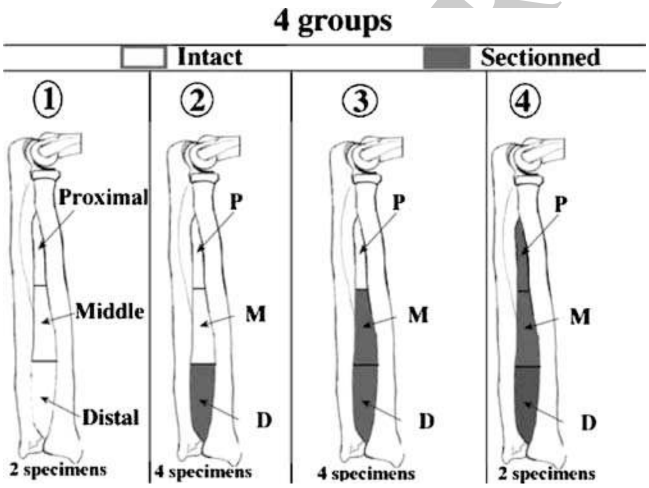

Fig. 1 Groups of specimens. Specimens were divided randomly into four groups. In group 1, the interosseous membrane was left intact. In group 2, only one level of the membrane was sectioned (proximal, middle or distal thirds). In group 3, two levels were sectioned. In group 4, the membrane was totally sectioned

Imaging techniques and US stage

Ultrasound examination of the 12 forearms was performed by two radiologists (a senior and junior), using an Aplio® (Toshiba®) sonogram. The 12–14 MHz transducer was put on the dorsal skin of the forearm in neutral rotation. Slices were axial at the proximal, middle, and distal thirds of the forearm. The examination at each level was static and dynamic. The static assessment was looking for tears of the membrane. The dynamic assessment was looking for a positive "muscular hernia sign". For each forearm, each radiologist made a lesional statement of the interosseous membrane. They had to answer the question: is the membrane intact or disrupted at this level (proximal, middle, and distal)? A total of 72 examinations were performed (3 levels×12 forearms×2 radiologists).

Statistical evaluation

The aim was to compare US diagnosis with real lesional status. The real lesional status was defined during the preparation stage of the specimens. For each level, four statistical categories of results were defined: true positive (TP), false positive (FP), true negative (TN), and false negative (FN). A TP result corresponded to an US diagnosis of rupture with a really disrupted portion. A FP result corresponded to an US diagnosis of rupture while the portion was intact. A TN result corresponded to an US diagnosis of integrity with an intact portion. A FN result corresponded to an US diagnosis of integrity with a disrupted portion. The following parameters were analyzed for each portion and for each radiologist: the sensitivity (SE), specificity (SP), predictive positive value (PPV), negative predictive value (NPV) with the following formulas: $SE = TP/(TP + FN)$, $SP = TN/(TN + FP)$, $PPV = TP/(TP + FP)$, $NPV = TN/(TN + FN)$.

Results

Description of the "muscular hernia sign"

An anteroposterior load was applied on the anterior side of the forearm, at the examinated level (Figs. 2, 3). If the interosseous ligament was intact, it was impossible for the muscles to pass through the intact interosseous membrane. If the interosseous ligament was disrupted, it was possible for the anterior muscles to pass through the tear. That motion was visible with the US dynamic examination. The "muscular hernia sign" was positive

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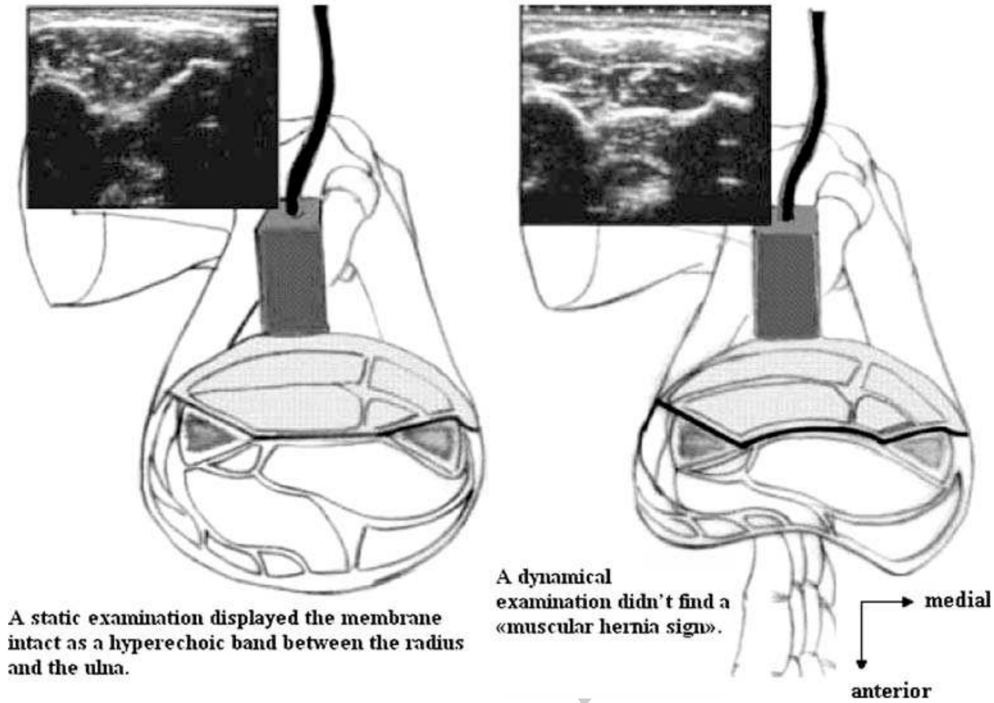

Fig. 2 Integrity of the interosseous membrane. The forearm was in neutral rotation. The transducer was applied on the dorsal skin. A static examination (figure on the *left*) displayed the membrane intact as a hyperechoic band between the radius and the ulna. A dynamical examination did not find a "muscular hernia sign" (figure on the *right*). The membrane was only curved under the anteroposterior load

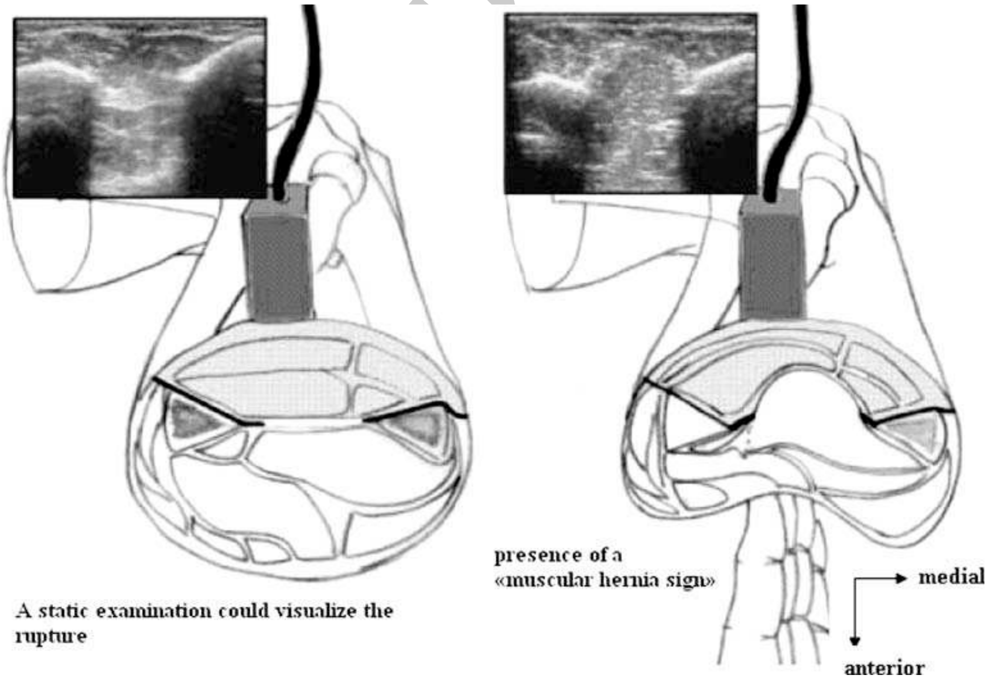

Fig. 3 Tears of the interosseous membrane. A static examination (figure on the *left*) could visualize the rupture, but it was above all the presence of a "muscular hernia sign" that defined the lesion (figure on the *right*)

when the muscular mass surpassed the "posterior interosseous line" (Figs. 4, 5). On axial slices, that line linked the middle of the posterior sides of both radius and ulna.

Static examination (Tables 1, 2)

At the proximal third level, the junior radiologist did one mistake (SE = 100%, SP = 83%, NPV = 100%, PPV = 86%). The single mistake at this level corresponded to a FP. The senior radiologist made no mistake (SE = 100%, SP = 100%, NPV = 100%, PPV = 100%).

At the middle third level, the junior radiologist did two mistakes (SE = 100%, SP = 67%, NPV = 100%, PPV = 75%). The senior radiologist did one mistake (SE = 100%, SP = 83%, NPV = 100%, PPV = 86%). The three mistakes corresponded to FPs.

At the distal third portion, the junior radiologist did one mistake (SE = 100%, SP = 83%, NPV = 100%,

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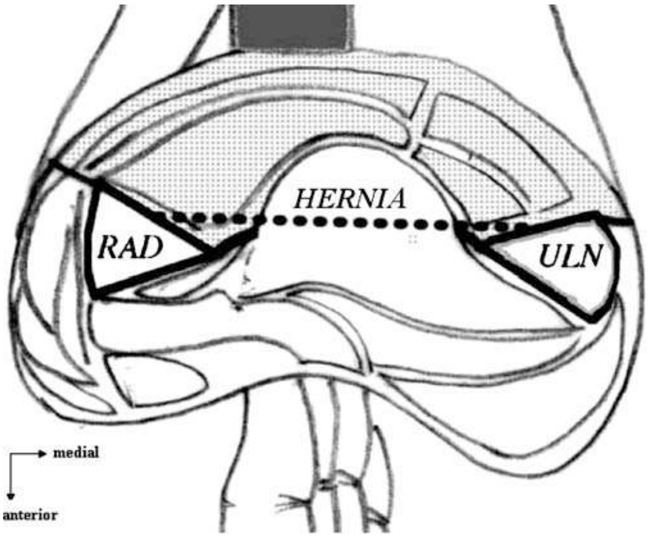

Fig. 4 The "muscular hernia sign" was positive if the hernia surpassed the interosseous posterior line (displayed as a discontinuous line)

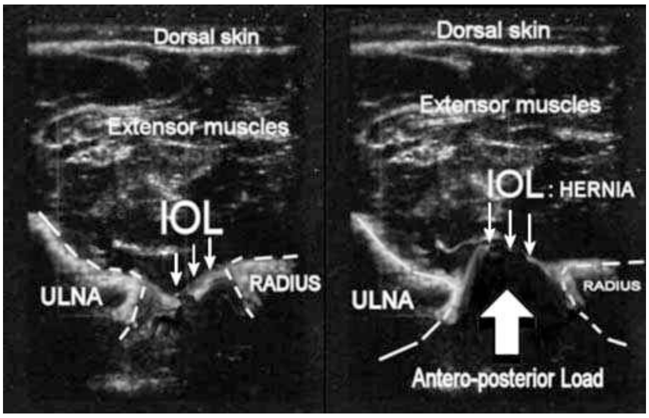

Fig. 5 Ultrasonographic (*US*) axial slices of the forearm. On the left, the interosseous membrane was disrupted. On the right, the "hernia muscular sign" could be observed: an anteroposterior load was applied and the anterior muscles passed through the membrane's tear

PPV = 86%), and the senior did three mistakes (SE = 100%, SP = 50%, NPV = 100%, PPV = 67%). Every mistake was FP.

Dynamic examination ("muscular hernia sign") (Tables 1, 2)

At the proximal and middle third levels of the forearm, both radiologists always made good diagnosis (SE = 100%, SP = 100%, PPV = 100%, NPV = 100%). At the distal third level, the senior radiologist made no mistake while the junior did one wrong evaluation (SE = 100%, SP = 100%, PPV = 86%, NPV = 83%), which corresponded to a FP.

Discussion

In our study, the "muscular hernia sign" that we designed, was able to diagnose correctly lesional status at every level of the interosseous membrane. Disruption of the membrane: importance of an early and quantitative diagnosis

The diagnostic of a total rupture of the interosseous membrane is rarely possible on standard X-rays, if a proximal ascension of the radius is visualized. This migration can be spontaneous or induced by dynamical tests like the "radius pull test" [12]. This ascension exists only in the case of rupture of the whole interosseous membrane. In the acute period, lesions of the membrane are incomplete with the persistence of intact fibers. As a result, no proximal migration of the radius is displayed on standard X-rays. Under the action of muscles (flexor digitorum, pronator teres...), a progressive stretching of these remaining fibers can occur. That phenomenon is illustrated by the frequent radius proximal migration following radial head resections [1, 4, 8]. In case of late diagnoses, the treatment gives poor results [14]. So, it is important to detect early incomplete lesion of the interosseous membrane. In anatomical studies, the interosseous membrane is classically divided into proximal, middle, and distal parts [9].

Hotchkiss et al. [9] identified a central band, approximately twice the thickness of the membrane. Mechanical studies stated that this central band was responsible for 71% of the longitudinal stiffness of the interosseous membrane after the radial head excision [9]. But proximal and distal parts of the membrane are not insignificant. It seems necessary to evaluate separately the status of each level for two reasons. Firstly, if the tear's size is important, the remaining fibers will be less efficient to prevent from a radius ascension in the acute period. The radial head resection will increase the stretching of the remaining fibers. Thus, a large membrane lesion should be an indication for a longitudinal stabilization of the forearm (ligamentoplasty of the interosseous membrane for example). Secondly, the "standard" evolution of membrane tears is not exactly known. If the membrane seems unable to heal spontaneously [5], no predictive factor of partial tears' progression exists. Are there stable lesions? Is there a minimal size for the tear to predict aggravation of the longitudinal instability? A reproducible method of quantitative evaluation of the membrane's lesions is necessary. The possibility to evaluate separately each level of the membrane should permit a classification and a follow-up of these lesions.

Disruption of the membrane: ways of diagnosis

The MRI is considered as the "gold standard" to investigate the interosseous ligament [6, 11, 15] but it is an expensive, and difficult to obtain in an emergency. MRI is hardly compatible with a dynamic assessment of

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Table 1 Results of senior's examination (resident's examination)

Specimen	Group	Proximal/middle/ Distal third	Static examination	Dynamical examination (hernia sign)	Real status
1	2	P	I (I)	I (I)	I
1	2	M	R (R)	R (R)	R
1	2	D	I (I)	I (I)	I
2	1	P	I (R)	I (I)	I
2	1	M	I (I)	I (I)	I
2	1	D	I (I)	I (I)	I
3	2	P	I (I)	I (I)	I
3	2	M	I (I)	I (I)	I
3	2	D	R (R)	R (R)	R
4	2	P	R (R)	R (R)	R
4	2	M	I (I)	I (I)	I
4	2	D	I (I)	I (I)	I
5	3	P	R (R)	R (R)	R
5	3	M	R (R)	R (R)	R
5	3	D	R (R)	I (R)	I
6	3	P	I (I)	I (I)	I
6	3	M	R (R)	R (R)	R
6	3	D	R (R)	R (R)	R
7	3	P	R (R)	R (R)	R
7	3	M	R (R)	I (R)	I
7	3	D	R (R)	R (R)	R
8	4	P	R (R)	R (R)	R
8	4	M	R (R)	R (R)	R
8	4	D	R (R)	R (R)	R
9	1	P	I (I)	I (I)	I
9	1	M	I (I)	I (I)	I
9	1	D	R (I)	I (I)	I
10	2	P	I (I)	I (I)	I
10	2	M	R (R)	R (R)	R
10	2	D	R (I)	I (I)	I
11	4	P	R (R)	R (R)	R
11	4	M	R (R)	R (R)	R
11	4	D	R (R)	R (R)	R
12	3	P	R (R)	R (R)	R
12	3	M	I (I)	I (I)	I
12	3	D	R (R)	R (R)	R

In group 1, the membrane was intact. In group 2, only one third of the membrane was sectioned. In group 3, two thirds were sectioned. In group 4, the membrane was totally sectioned
I intact, *R* rupture

the membrane. Moreover, metallic implants (plates or screws) are often used in these patients and can interfere with MRI. That is why ultrasonography (US) was proposed [5, 10, 16] as an alternative. It can be performed during the acute phase, it is less expensive than MRI, and allows the dynamical examination of the forearm. Interferences with metallic implants are minimal. According to Fester, MRI and US would be equivalent for the diagnosis of lesions of the interosseous membrane [6]. The main problem of US is that the accuracy of the diagnosis is experience-related. In Fester's study [6], the US images were read only by the radiologists. This explains why we aimed to develop an easy US test to minimize the experience factor.

Table 2 Statistical parameters according to the level of the membrane and the type of examination: sensitivity (SE), specificity (SP), predictive positive value (PPV), negative predictive value (NPV)

Level of assessment of the membrane	Statistical parameters	Static examination		Dynamic examination	
		Junior radiologist (%)	Senior radiologist (%)	Junior radiologist (%)	Senior radiologist (%)
Proximal third level	SE	100	100	100	100
	SP	83	100	100	100
	PPV	86	100	100	100
	NPV	100	100	100	100
Middle third level	SE	100	100	100	100
	SP	67	83	100	100
	PPV	75	86	100	100
	NPV	100	100	100	100
Distal third level	SE	100	100	100	100
	SP	83	50	100	100
	PPV	86	67	86	100
	NPV	100	100	83	100

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Static US examination

The noninjured central third of the interosseous membrane is seen in an ultrasound as a thick, continuous, and highly hyperechoic structure that connects the ulna to the radius [5, 16]. The intact membrane thickness ranged from 1 to 3 mm with ultrasound data quantification [5]. The central band region can be well-localized, with a thickness of 1.5–1.8 mm, in contrast to the thinner distal part of the membrane, which had a thickness of approximately 0.8 mm. These ultrasonic data were confirmed by direct measurement of the dissected membrane [16]. The membrane structure is double-layered, with a 0.5 mm space between palmar and dorsal layers. A section of the membrane would be revealed with a 6 mm ultrasound gap between the cut edges [5]. Disruption of the membrane is defined as a lack of visualization of this continuous hyperechoic band taut between the radius and ulna through a region of at least 2 cm in length [5].

Ultrasound evaluation may be useful in association with conventional radiography, in acute cases since it is relatively inexpensive, portable, and can provide both static and dynamic images of the integrity of the interosseous membrane [16]. In our study, the interosseous ligament was easy to visualize. In only two specimens, air bubbles interfered with the US evaluation but were not a major problem. The procedure was not performed under saline water as in other studies, but the gel was sufficient enough to keep away air bubbles, which did not alter the quality of the protocol [10, 16]. The distal third of the membrane was the most difficult part to assess. In an anatomic study, Jaakola et al. [10] reported an accuracy of 96% for diagnosis of interosseous ligament's ruptures with ultrasonography. They studied only the middle third level. Even if the middle part corresponds to the "central band", we think the whole membrane should be analyzed because of possibly aggravated tears with time. Our results are similar and confirm that a static examination has an excellent accuracy, overall in the proximal, and middle parts. But our results emphasize the fact that the quality of the static US examination depends on the radiologist's ability. In our protocol, the transducer was put on the dorsal skin, like in other studies [5]. Jaakola et al. [10] preferred the palmar ultrasound approach. The posterior approach is easy to perform with a small thickness of the soft tissues on axial slices. The decreased distance between the transducer and the membrane improved the image resolution. In our experience, a neutral rotation position of the forearm allowed a better US examination of the interosseous space.

Dynamic US examination: "muscular hernia sign"

Jaakola et al. [10] used a dynamic examination protocol, which consisted in rotating the forearm. Our dynamic examination is different. The interosseous membrane is flexible and curves under anteroposterior loads. When the ligament is disrupted, anterior muscles pass through the tear, and reach the posterior compartment of the forearm. Tears of the membrane are easier to detect with this dynamic test for two reasons. Firstly, muscles passing through the tear enlarge it. Secondly, the global mass of anterior muscles in motion is easily visualized with ultrasonography. The anterior muscles cannot be in the posterior compartment of the forearm if the interosseous membrane is intact. If they do it, it is an indirect and pathognomonic sign of membrane's disruption. With that sign, it is paradoxically not necessary to see the membrane, which is useful in clinical practice. The distal third of the membrane is thin and hardly detectable. Anatomical studies do not include trauma-related factors (post traumatic hematomas, edema, and soft tissue bruises...) with possible attenuation of the ultrasound beam [10].

Conclusion

Our anatomical study confirms that the "muscular hernia sign" is very efficient to detect lesions of the interosseous membrane of the forearm. It allows an easy, quantitative, and reproducible evaluation of lesions. It should be useful in an emergency for patients with suspected lesions of the interosseous membrane. It would be an objective examination to discuss a longitudinal stabilization of the forearm. In the future, it could permit to study the natural history of membrane partial lesions.

References

1. Broberg MA, Morrey BF (1986) Results of delayed excision of the radial head after fracture. J Bone Joint Surg Am 65:669–674
2. Curr JF, Coe WA (1946) Dislocation of the inferior radioulnar joint. Br J Surg 34:74–77
3. Duparc F, Tobenas AC, Dujardin F, Thomine JM (1999) Fractures de la tête radiale: données anatomiques et biomécaniques. In: Duparc F, Katz D (eds) Fractures de la tête radiale. Monographies du GEEC. Sauramps medical, Montpellier, pp 15–27
4. Essex-Lopresti P (1951) Fractures of the radial head with distal radio-ulnar dislocation: report of two cases. J Bone Joint Surg Br 33:244–247
5. Failla JM, Jacobson J, van Holsbeeck M (1999) Ultrasound diagnosis and surgical pathology of the torn interosseous membrane in forearm fractures/dislocations. J Hand Surg Am 24:257–266
6. Fester EW, Murray PM, Sanders TG, Ingari JV, Leyendecker J, Leis HL (2002) The efficacy of magnetic resonance imaging and ultrasound in detecting disruptions of the forearm interosseous membrane: a cadaver study. J Hand Surg Am 27:418–424
7. Geel CW, Palmer AK (1992) Radial head fractures and their effect on the distal radioulnar joint. A rationale for treatment. Clin Orthop 275:79–84
8. Goldberg I, Peylan J, Yosipovitch Z (1986) Late results of excision of the radial head for an isolated closed fracture. J Bone Joint Surg Am 68:675–679

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9. Hotchkiss RN, An KN, Sowa DT, Basta S, Weiland AJ (1989) An anatomic and mechanical study of the interosseous membrane of the forearm: pathomechanics of proximal migration of the radius. J Hand Surg Am 14:256–261
10. Jaakkola JI, Riggans DH, Lourie GM (2001) Ultrasonography for the evaluation of forearm interosseous membrane disruption in a cadaver model. J Hand Surg Am 26:1053–1057
11. Nakamura T, Yabe Y, Horiuchi Y, Yamazaki N (1999) Three-dimensional magnetic resonance imaging of the interosseous membrane of forearm: a new method using fuzzy reasoning. Magn Reson Imaging 17:463–470
12. Smith AM, Urbanosky LR, Castle JA, Rushing JT, Ruch DS (2002) Radius pull test: predictor of longitudinal forearm instability. J Bone Joint Surg Am 84:1970–1976
13. Soubeyrand M, Oberlin C, Dumontier C, Belkheyar Z, Lafont C, Degeorges R (2006) Ligamentoplasty of the forearm's interosseous membrane using the semitendinous tendon: anatomical study and surgical procedure. Surg Radiol Anat (publication in progress)
14. Sowa DT, Hotchkiss RN, Weiland AJ (1995) Symptomatic proximal translation of the radius following radial head resection. Clin Orthop 317:106–113
15. Starch DW, Dabezies EJ (2001) Magnetic resonance imaging of the interosseous membrane of the forearm. J Bone Joint Surg Am 83:235–238
16. Wallace AL, Walsh WR, van Rooijen M, Hughes JS, Sonnabend DH (1997) The interosseous membrane in radio-ulnar dissociation. J Bone Joint Surg Br 79B:422–427

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2 7 6 | Journal ID | 1 0 0 | Article ID | B | Dispatch: 2.3.06 Journal: 276 No. of pages: 7 | Author's disk received ☑ Used ☑ Corrupted ☐ Mismatch ☐ Keyed ☐