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ORIGINAL ARTICLE

Comparative morphometry of the antebrachial and crural interosseous membranes: preliminary study for the use of the crural interosseous membrane in the surgical repair of the antebrachial interosseous membrane tears

Driss Elamrani · Aurélien Aumar · Guillaume Wavreille · Christian Fontaine

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Abstract

Introduction Traumatic tears of the antebrachial interosseous membrane (AIOM) on its whole length are difficult to treat, particularly in the Essex-Lopresti syndrome. The number of ligamentoplasty techniques described in the literature witnesses the difficulty of its reconstruction and the absence of reliable and satisfying procedure. The aim of this study was to explore a new way of treatment, which consists in replacing the AIOM by the crural interosseous membrane (CIOM), harvested from the same patient.

Materials and methods A morphometric study of the AIOM and CIOM has been conducted on both sides of 15 formalin preserved corpses (i.e. 30 AIOM and 30 CIOM). Studied data were: length of forearms and legs, length and width (at different locations) of the membranes, in situ and after harvesting, and orientation of their fibers. The thickness of membrane was also measured but only after harvesting.

Results Concerning the AIOM, the mean length was 13.3 cm in situ and 12.8 cm after harvesting. Its width was maximal at the union of middle and distal thirds with an average value of 1.7 cm in situ and 1.45 cm after harvesting. Mean thickness was 1 mm. Anterior fibers were oblique distally and medially (20.5° ± 0.95°), and posterior fibers were oblique distally and laterally (40° ± 3.4°). Concerning the CIOM, the mean length was 24.75 cm in situ and 23.9 cm after harvesting. Its width was maximal at the union of proximal and middle thirds with an average value of 2.3 cm in situ and 1.85 cm after harvesting. Mean thickness was 0.5 mm. Obliquity of its fibers was reverse of that of the AIOM: the anterior fibers were quite oblique distally and laterally (13° ± 2.6°), and the posterior fibers oblique were oblique distally and medially (24.2° ± 2.48°).

Discussion From these results, one may conclude that the largest length and width of the CIOM allow its use as substitute for the injured AIOM. The orientation of its fibers should necessitate either its reversal while using the same side or the use of the CIOM of the opposite side; its relative sharpness could signify that its biomechanical properties could be worse. A biomechanical study is necessary to evaluate how this new way of replacing the AIOM could resist to the strains imposed on the forearm.

Keywords Antebrachial interosseous membrane · Crural interosseous membrane · Ligamentoplasty · Radioulnar instability

D. Elamrani
Institute of Anatomy, Faculty of Medicine and Pharmacy, University of Caddi Ayad, Marrakech, Morocco

D. Elamrani · A. Aumar · G. Wavreille · C. Fontaine
Institute of Anatomy, Faculty of Medicine Henri Warembourg, University of Lille 2, PRES Nord de France, Place de Verdun, 59045 Lille Cedex, France

G. Wavreille · C. Fontaine (✉)
Department of Orthopedics, Roger Salengro Hospital, University Hospitals of Lille, rue du Pr Émile Laine, 59037 Lille Cedex, France
e-mail: christian.fontaine@chru-lille.fr

Introduction

Traumatic tears of the antebrachial interosseous membrane (AIOM) on its whole length are really difficult to treat, particularly its extended forms, such as the Essex-Lopresti syndrome, especially at the late stage when diagnosis has been delayed.

Ligamentoplasty techniques described in the literature are numerous: using a lip of calcaneus tendon [24], bone-patellar tendon-bone (BPTB) on-lay allograft [22], the pronator teres tendon [4], the semitendinosus tendon [19], the flexor carpi radialis [1–3, 18, 22], palmaris longus, [22], synthetic material [16], etc. The number of techniques witnesses the difficulty of its reconstruction and the absence of reliable, reproducible, and satisfying procedure.

The authors would like to explore a new way of treatment, which would consist in replacing the AIOM by the crural interosseous membrane (CIOM), harvested from the same patient.

The aim of this study was to assess through an anatomical study the following questions, to determine the feasibility of this new technique: (1) is the AIOM long, wide, and thick enough to be used as a substitute of the CIOM? (2) Does the fiber orientation of the AIOM fit with that of the CIOM?

Materials and methods

Fifteen formalin-preserved corpses (7 males, 8 females), mean age 71 years (57–86) were used in this anatomical study. Two corpses had been previously injected with colored latex.

A comparative morphological study was conducted on the antebrachial and crural interosseous membranes of the four limbs of each cadaver (i.e. 30 AIOM and 30 CIOM).

Each interosseous membrane was approached both on its anterior (volar) and posterior (dorsal) aspects; the vascular relationships and limits of the muscular insertions on both aspects were recorded.

The fiber orientation of the interosseous membrane on both anterior and posterior aspects was carefully recorded after cleaning the membrane from any muscular insertion (Figs. 1, 2, 3, 4); the precise angles of orientation were measured on photographs according the longitudinal axis of the ulna and fibula, the straighter bones of forearm and leg. Dimensions of the interosseous membrane were first measured in situ between the interosseous borders of the radius and ulna, or the tibia and fibula: its length thanks to a millimetric millimeter ruler and its width with a manual caliper at different locations: (1) proximal border, where the posterior interosseous neurovascular bundle crosses the upper border of the AIOM and where the anterior interosseous vascular bundle crosses the upper border of the CIOM; (2) union between the middle and proximal thirds; (3) union between the middle and distal thirds of the distance between proximal and distal radioulnar joints (AIOM) or articulation of the fibular head and tibiofibular syndesmosis (CIOM).

The interosseous membrane was then harvested and pinned on a board (Fig. 5). Dimensions of the interosseous membrane were then measured once more according the same criteria as in situ. The thickness of each IOM was

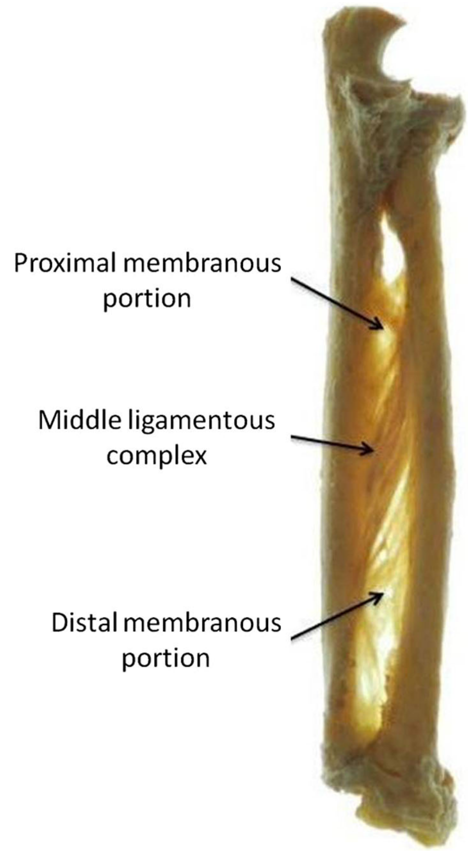

Fig. 1 Anterior view with transillumination of the left forearm skeleton and the AIOM, showing the three parts of the AIOM and the orientation of its anterior fibers oblique medially and distally. Please note the maximal thickness of the AIOM at the level of the central band at its middle part and the relative sharpness at the level of its distal part

measured at the level of the radial border of the central part (AIOM) or at the level of the tibial border of the middle part (CIOM).

All data were then collected on two Excel tables, enabling calculation of average values and standard deviations.

Results

The recorded measurements are displayed in Tables 1 and 2.

Dimensions

Ratio between length of the CIOM and length of the AIOM was 1.51–2.22 (mean 1.9). Ratio between length of the AIOM and length of the CIOM was 0.45 (45 %) to 0.66 (66 %) (mean value 0.57).

The width of the CIOM at the level of its proximal border was about twice that of the AIOM at the level of its

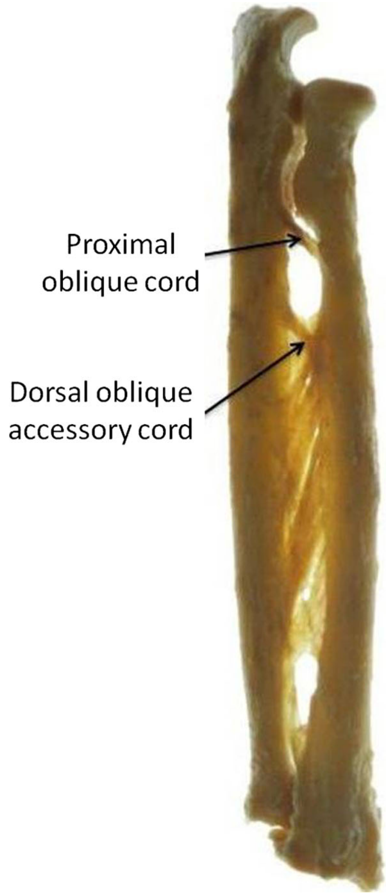

Fig. 2 Posterior view with transillumination of a right forearm skeleton and the AIOM, showing the orientation of its posterior fibers oblique laterally and distally

Fig. 3 Anterior view with transillumination of a leg skeleton and the CIOM, showing the orientation of its anterior fibers oblique laterally and distally. Please note the different thickness between the center (*thin*) and the tibial and fibular borders (*thick*)

proximal border. At the union between proximal and middle thirds, the width of the CIOM was 1.38–2.3 times that of the AIOM. At the union between middle and distal thirds, the CIOM was always less wide than that the AIOM.

The thickness of the AIOM was not homogeneous (Fig. 1). Its mean value was 1.06 mm. It was thin at its distal part and not as large at its median part that on its radial and ulnar insertions, especially on the radial side, where it was maximal, corresponding to the radial insertion of the central band.

The CIOM was thinner at its center than at its tibial and fibular borders (Fig. 3). Its mean thickness was 0.54 mm, i.e. half that of the AIOM.

Fiber orientation

The AIOM presented two crossed layers: (1) an anterior layer, whose fibers ran oblique distally and medially and which is composed of three parts; a central tendinous band and two membranous parts, proximal and distal (accessory bands); (2) a posterior layer whose fibers ran oblique distally and laterally and where one could distinguish two main bands: the oblique string of Weitbrecht and the proximal band. Fibers of the central band made an angle of 20.5° (SD 0.95) with the axis of ulna. Those of the posterior layer made an angle of 40° (SD 3.4) with the axis of ulna.

The CIOM presented two crossed layers, whose obliquity was inverse of those of the AIOM: (1) an anterior layer whose fibers ran oblique distally and laterally; (2) a posterior layer whose fibers ran slightly distally and medially (quite vertical) at the level of the proximal half and of fibers oblique distally and medially at the distal half. Fibers of the anterior layer made an angle of 13° (SD 2.6) with the axis of fibula. Those of the posterior layer made an angle of 24.2° (SD 2.48) with the axis of fibula.

Discussion

Clinical background

According to the updated literature [9, 20, 21], the radio-ulnar unit can be considered as the association of three

Fig. 4 Posterior view with transillumination of a left leg skeleton and the CIOM, showing its posterior layer made of fibers running slightly distally and medially (*quite vertical*) at the proximal half and of fibers oblique distally and medially at the distal half

Fig. 5 Anterior views of both AIOMs (*top*) and of both AIOMs (*bottom*) harvested from the same cadaver and pinned on a board

"bolts": (1) a proximal one: the proximal radioulnar joint; (2) a distal one: the distal radioulnar (DRU) joint; and (3) a middle one: the AIOM, which is really a middle radioulnar joint or radioulnar syndesmosis. The AIOM plays many roles, out of which uniting firmly both bones of forearm and transferring strains from the radius to the ulna seem the most important ones.

Osteoligamentous forearm injuries can be considered of progressive severities, according to the number and location of injured "bolts" [20, 21]. The most severe consists in an injury of the three "bolts" in the Essex-Lopresti syndrome, which associates a radial head fracture (generally comminuted), a DRU joint dislocation and a tear of all the radioulnar ligaments, including the AIOM [5, 20].

Stabilization of the forearm in this last instance is very difficult to obtain, both in emergency and particularly secondarily, and needs the AIOM reconstruction. If the AIOM is not repaired, forearm stability and pronation–supination movements are much compromised [5, 9].

Spontaneous healing of the AIOM in Essex-Lopresti syndrome seems difficult because of muscular interpositions and repeated contractions of muscles mobilizing the radioulnar unit, such as biceps brachialis [5, 9]. In such instances, the restitution of the radioulnar unit needs repairing the AIOM.

The fiber orientation of the AIOM and the importance of the mechanical strains that the AIOM has to face make the direct suture fragile [20]. Several ligamentoplasties using various transplants have been proposed in the literature: using the palmaris longus tendon [22], the flexor carpi radialis tendon [1–3, 18, 22], the patellar tendon [22], the calcaneus tendon [24], the semimembranosus tendon [19], and a synthetic ligament [16], but none of these techniques is totally satisfying.

Complexity of the AIOM and its reconstruction

The AIOM is more complex than its central band. It is made of two layers, anterior and posterior, the directions of which are opposite; AIOM is also longer than its central band. Reconstructing only its only central band, oblique distally and medially, can be seen as a simplification of its

Table 1 Measurements performed on the antebrachial interosseous membranes (AIOM)

Corpse (both sides)	Length (cm)		Width (cm)						Thickness of the AIOM after harvesting (mm)
	AIOM in situ	AIOM after harvesting	AIOM in situ			AIOM after harvesting			
			Proximal border	Union proximal and middle thirds	Union middle and distal thirds	Proximal border	Union proximal and middle thirds	Union middle and distal thirds	
1	14	13.5	1.1	1.8	2.5	0.9	1.5	1.8	1.2
2	11	10.5	1	1.3	1.5	0.7	1.1	1.4	1
3	13.5	13.2	1.1	1.6	2.1	0.8	1.2	1.8	1
4	13.5	13	1	1.2	1.5	0.9	1	1.3	1.4
5	14	13.8	1	1.5	1.6	1	1.4	1.5	1.2
6	16.5	15.5	1	1.2	1.5	0.8	1	1.2	1
7	14	13.5	1	1.5	1.8	0.9	1.2	1.5	1
8	13	12.5	0.9	1.1	1.5	0.5	0.6	1.3	1
9	14	13.5	1.1	1.2	1.4	0.7	1	1.1	0.9
10	13.5	13	1	1.2	1.5	0.9	1	1.4	1
11	17	16.5	0.6	1	1.2	0.5	0.9	1	1
12	12	12	1.2	1.4	1.8	1	1.2	1.6	1.3
13	15	15	1.2	1.4	1.6	1.1	1.2	1.5	1
14	12	11.5	1	1.2	1.5	0.8	1	1.3	1
15	13	12.5	1.1	1.3	1.5	0.9	1.2	1.4	1
Average	13.3	12.8	1.02	1.32	1.7	0.82	1.1	1.45	1.06

Table 2 Measurements performed on the crural interosseous membranes (CIOM)

Corpse (both sides)	Length (cm)		Width (cm)						Thickness of the CIOM after harvesting (mm)
	CIOM in situ	CIOM after harvesting	CIOM in situ			CIOM after harvesting			
			Proximal border	Union proximal and middle thirds	Union middle and distal thirds	Proximal border	Union proximal and middle thirds	Union middle and distal thirds	
1	23	22	2	2.5	1.3	1.8	2.2	1	0.5
2	22.5	22	2	2.5	1.4	1.1	1	0.6	0.6
3	30	30	2.2	2.7	1.8	1.6	2.2	1.5	0.7
4	25.5	25	1.8	2.1	1.5	1.3	1.7	1.2	0.5
5	29	29	1.8	2.4	1.4	1.6	2.1	1.1	0.5
6	25	25	2.1	2.6	2	1.9	2.2	1.6	0.6
7	23.5	23	1.6	1.9	1.3	1.4	1.7	1.1	0.5
8	26	25.5	2	2.3	1.6	1.4	1.8	1.1	0.7
9	20	20	1.1	1.2	0.9	0.9	1	0.7	0.5
10	22	21	2.1	2.3	1.6	1.8	2	1.5	0.5
11	26	25	1.5	1.8	1.2	1.2	1.7	1	0.5
12	22	21.5	2	2.2	1.7	1.5	1.5	1.1	0.4
13	26	26	2.2	2.6	1.5	2	1.8	1.3	0.5
14	22	21.5	2	2.1	1.5	1.8	2	1.3	0.5
15	24	23	2.1	2.4	1.8	1.9	2.1	1.6	0.6
Average	24.75	23.9	1.91	2.3	1.5	1.64	1.85	1.18	0.54

structure, even though the central band is its thicker and stiffest part [27]. Reconstructing both layers, anterior and posterior, both useful, and the whole length of AIOM seems preferable, because control of pronation–supination implies both layers [9, 25]. Using the CIOM could allow achieving these aims.

Morphometry of AIOM and CIOM

The aim of our study was to know if the CIOM, harvested in the leg of the same people, could take a place in the treatment of AIOM tears.

Our results about the AIOM fit perfectly with those of the literature [9–11, 14, 17, 20, 25].

The literature about the CIOM is quite poor and the rare papers devoted to the CIOM do not give precise morphometric data. Conversely, the orientation of its fibers has been studied extensively by some authors and their results are in agreement with ours [13].

Our results show that the length of the CIOM is large enough to using it to replace the AIOM. Nevertheless, one could be afraid of destabilizing the tibiofibular joint, and so the ankle joint, while harvesting the distal quarter of the CIOM, and it seems preferable respecting this distal quarter during the CIOM harvesting [6, 23, 26]. Even in this instance, the length of the proximal three quarters of the CIOM is largely sufficient: it represents 1.5–2 times the length of the AIOM in the same people.

The width of the CIOM is large enough to use it as a substitute to the AIOM, especially if one harvests only its proximal three quarters, whose width is 1.3–2 times that of the AIOM.

The orientation of the CIOM needs to reverse the membrane if harvested in the same side, or using that of the contralateral leg.

The CIOM is half less thin than the AIOM. One could think that its biomechanical properties could be worse than those of the AIOM, even though some articles have shown that the CIOM is very resistant and little extensible [12]. Its resistance and its biomechanical performances should be carefully evaluated and compared with those of the AIOM from the same bodies. It will be the subject of our next work.

To the best of our knowledge, the fiber orientation of the CIOM has never been measured. The orientation of the posterior layer of the CIOM % (24.2° ± 2.48°) was close to that of the anterior layer of the AIOM (20.5° ± 0.95°) in our study and to 21° found by Skahen et al. [17].

Donor site morbidity

One could be afraid of donor site morbidity, especially on tibiofibular stability. The distal third of the CIOM is too narrow compared to the width of the interosseous space of forearm at its proximal third; so should it be let in place in the leg. The authors think that preserving the distal quarter of the CIOM and the anterior and posterior tibiofibular ligaments would be sufficient not to destabilize the ankle joint [6].

Harvesting the upper two-thirds does not seem biomechanically deleterious:

- When performing a muscular transfer (Tibialis posterior ± Flexor digitorum longus) through the CIOM, the surgeon resects the distal third of the CIOM and severs its middle third to give transfer the most direct course, without any donor site morbidity.
- Vascular surgeons divide the CIOM to get the anterior tibial artery from posterior approach without any mentioned drawback [7].
- After performing a vascularized free fibular graft, the CIOM has no more fibular insertion; suppressing the fibula does not seem bringing biomechanical drawbacks [23]. While harvesting the CIOM upper two-thirds, the whole fibula, the tibiofibular joint and syndesmosis are kept intact; this should be enough to help the fibula partially unloading the tibia.

Reconstructing the whole AIOM should sever all the anastomoses between the anterior and posterior interosseous arteries [15]. It seems not to be deleterious, because such sections are already done when harvesting a posterior interosseous flap, without any known vascular complication.

Technical details of ligamentoplasty

It is too early to detail the operative technique of the replacement of AIOM by the CIOM. The authors propose using a dorsal approach, such as described by Jin et al. [8] for radioulnar synostosis, using the CIOM from the opposite leg to fit fiber orientation and suturing the CIOM to the AIOM remnants in case of middle disruption, or using bony anchors in one of the forearm bones on case of osseous desinsertion.

Conclusion

This comparative morphometric study about the AIOM and CIOM has shown that the CIOM exhibits:

- Some advantages for its possible future use as a substitute for the CIOM: its length and its width, large enough, and the possibility of reproducing the plane, thin and fan-shape structure of the AIOM, more than are able the nowadays available techniques.
- One detail: the orientation of their fibers needs an artifice to mimic the orientation of AIOM: reversing that of the ipsilateral leg or using that of the contralateral leg.

– One drawback: its relative thinness.

This work needs a complementary throughout a comparative histological study of both membranes and, overall, a comparative biomechanical study to evaluate the ability of the CIOM to resist the stains imposed on the AIOM.

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