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ORIGINAL ARTICLE

Morphodynamic study of the corona mortis using the SimLife® technology

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Abstract

Purpose Open book pelvic ring fractures are potentially life-threatening, due to their instability and major hemorrhage risk. During the open reduction and internal fixation, the pelvic approach remains a technical challenge, as the surgeon wants to prevent any iatrogenic damage of the vascular loop located in the retro-pubic area called corona mortis (CMOR). Recently, the cadaver perfused SimLife® technology has been developed to improve the surgeon training, out of the operating room. This study aimed to compare two models of cadaveric dissection, to assess the interest of the perfused SimLife® in providing dynamic aspect of anatomy in the identification of CMOR and its topography.

Methods Twelve human cadaveric pelvises have been dissected, following two protocols. 12 hemi-pelvises of the dissections were performed without perfusion (Model A), whereas the 12 other hemi-pelvises have been prepared with the SimLife® pulsatile perfusion (Model B). The prevalence and morphologic parameters determined: length, diameter and distance between the CMOR and the pubic symphysis.

Results The CMOR has been found in 66.67% of the cases. The length, the diameter, and the distance between the CMOR and the pubic symphysis were significantly higher in model B (respectively $p=0.029$, $p=0.01$, and $p=0.022$).

Conclusion These results suggest that the CMOR is easier to identify and to dissect with the SimLife® perfusion. As part of the surgical training of any trauma surgeon, this model could help him to keep in mind the CMOR topography, to improve the open book lesion management.

Keywords Surgery and vessel injuries · Training · Cadaveric perfusion · Corona mortis · Pelvic fracture management

Introduction

Open book pelvic ring injuries are rare, with an incidence between 0.3 and 8.2% of all fractures [1], but Day et al. found 1–3%, and around 60% of them occur in men [2]. They are associated with significant morbidity and mortality [3, 4]. Recently, a French epidemiological study described in France described the acetabular and pelvic fractures as 1.5% of all adult fractures, and 2 to 5% of them required a hospital admission, with an increasing incidence possibly due to the

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population growth [5]. High energy fractures of the pelvic ring often result from motor vehicle collisions, crush injuries or falls from a height [2].

Among them, open book injuries are due to anteroposterior impacts [6]. Management is based on the patient's physiological status, fracture classification, and associated injuries [7].

The two most basic classification systems commonly used for pelvic ring injuries are those described by Tile [3, 8] and Young-Burgess [3, 9]. The Tile classification system is based on the stability of the pubic ring and mechanism of injury [10], and it helps predict the need for operative repair [4]. However, Young-Burgess classification is depending on injury mechanism and main vector of energy impact [9], and it helps predict the chance of associated injuries and mortality risk [4].

Diastasis of the symphysis pubis or wide displacement of pubic ramus fractures associated with open book pelvic ring fractures is potentially life-threatening. It is due to their instability and major hemorrhage risk. A pelvic belt could initially control the bleeding, but the definitive treatment is a screwed plate [2]. Yet, the 2.5 cm threshold of pubic diastasis often leads the surgeon to choose an open reduction and internal fixation (ORIF) [3, 11] with a symphyseal plate as definitive management [2, 8], whereas the posterior pelvic arch is usually stabilized by screws [7].

For this purpose, various surgical approaches have been used: in 1900, Pfannenstiel described a low transverse abdominal incision to prevent incisional hernia used [12]. It is an incision of choice in gynecology. And nowadays, it is used in orthopedic surgery for open book lesions [12, 13]. The anterior ilio-inguinal approach was described by Letournel in 1961 with 3 "working windows" (medial, middle and lateral) [14]. The Stoppa procedure is very safe repair of bilateral inguinal hernia, but it requires a learning period to achieve optimal results [15]. Tannast et al. confirmed that modified Stoppa approach is performed for safe and efficient management of acetabular fractures involving the anterior column [16]. However, the modified Stoppa–Cole's approach avoids dissection in inguinal canal, the femoral nerve, and the external iliac vessels as seen in the "second window" of the ilioinguinal approach and has thus been shown to be less invasive than the ilioinguinal approach [17, 18].

The most difficult part of the dissection relies on the ilio-pectineal fascia disinsertion from the ilio-pectineal eminence for plate implanting [19], as there is a risk of corona mortis (CMOR) vascular injury [20], leading to uncontrolled hemorrhages [7]. First described by Friedrich Fürer's in 1857 [21], the so called "Corona mortis" (CMOR) refers to the vessel anastomoses of the obturator branch and the inferior epigastric artery at the pecten pubis. The CMOR shows multiple arterial and venous anatomic variations. Farabeuf described the supra-pubic vascular arch as sometimes single, sometimes double. Underlying its small caliber, he compared it to ''a dressmaker's needle" [22].

We did not study the ethnic prevalence of the CMOR [21], but regarding the explorations methods, most studies were based on:

– Dissections: Cloquet (1817) [23], Hesselbach (1819) [24], Schlobig (1844) [25], Quain (1844) [26], Hoffmann (1878) [27], Hartmann (1881) [28], Pfitzner (1889) [29], Jastschinski (1891)[30], Dwight (1894) [31], Lipshutz (1918) [32], Adachi (1928) [33], Pick et al. (1942) [34], Braithwaite (1952)[35], Letournel (1993)[36], Teague et al. (1996) [37], Tornetta (1996) [38], Gilroy et al. (1997) [39], Sarikcioglu et al. (2003) [40], Okçu et al. [41], Rusu et al. (2010)[42], Stavropoulou-Dei and Anagnostopoulou et al. (2013) [43], Rajive and Pillay (2015) [44], Bargoria (2015) [45], Al Talalwal (2016) [46], Cavaillié (2019) [47] and Heichinger (2022) [21];
– Surgical dissection: Berberoglu et al. 2001) [48];
– Surgery: Letournel (1993)[49], Ates (2016) [50];
– Laparoscopy: Pungpapoung (2005) [51], Lee et al. (2013) [52],
– Angiography: Karakurt (2002) [53];
– Radiology: Wada et al. (2017) [54], Duenas-Garcia et al. (2017) [55], Steinberg et al. (2017) [56] and Perandini et al. (2018) [57].

Nevertheless, the CMOR must be introduced in the specific surgical steps that include preoperative planning, patient positioning and setup, a Pfannenstiel incision, superficial and deep dissection, development of the Retzius space and retraction of the bladder, exposure of the superior pubic ramus and ilio-pectineal eminence, dissection and ligation of a potential corona mortis [58]. It will be noticed over the superior pubic ramus, on the medial part of ligamentum teres uteri, where it enters in the inguinal canal [58]. Apart from its iatrogenic lesion, the CMOR injury can be caused by the fracture itself during the accident [19].

Rusu et al. considered that CMOR is at risk in groin or pelvic surgeries and the failure to ligate these vessels will be followed their retraction in the obturator canal after being injured [42].

Heichinger et al. have noted that CMOR can lead to death in the worst-case scenario if injured [21].

For avoiding the death, the angiography of angio CT scan is necessary in emergency. However, in the absence of active bleeding it can provide a false result. The hematoma can be the simple factor revealing the vessel injury, and it is difficult to differentiate from the hematoma related to the pubic disjunction. And, when an injury to the corona mortis is suspected, embolization of the involved obturator and inferior epigastric branches may be necessary to achieve hemostasis [59].

Coil embolization of the internal iliac artery branches is very effective in managing hemorrhage due to pelvic fractures, but variations in the origin of the obturator artery from internal or external iliac artery may be additional sources of bleeding [60]. Thus, the interventional radiology with injected multidetector CT scan might be helpful for the CMOR diagnosis and its embolization [60]. In the same way, Marsman et al. recommended considering the aberrant origin of the obturator artery during embolization to avoid failure [61].

Thus, for any anterior pelvic and hip approach, the knowledge of vascular mapping of the inguinal region is so important. Accurate anatomical knowledge of CMOR may aid in reducing the incidence of surgical complications and improving the outcome of pubic surgical procedures [62].

Rusu et al. insisted that the surgical relevance of the vascular relations of the superior branch of pubis (in trauma, orthopedic, approaches, hernia repair, embolization and intra-arterial infusions) recommends a detailed knowledge of the morphological and topographical possibilities of the crown of death and the individual evaluation of this risky anatomical structure [42].

Sanna et al. in a meta-analysis conducted the prevalence and the morphology of CMOR with surgical implications of the abdominal wall and pelvis, which have been listed in the hemi-pelvises, respectively, a high prevalence of CMOR (49.3%), venous CMOR more prevalent than arterial (41.7% versus 17.0%), more prevalent in Asia (59.3%) than in Europe (42.8%) and North America (44.3%) [62].

Surgical training of the pelvic approach is obviously based on dissections of fresh human cadaveric models. But, the perfused SimLife® model has been developed by Simedys© as a dynamic model places the learner in an almost real situation of an anesthetized patient in the operating room, we decided to use it for our study [63]. However, it has never been used for pelvic dissection training. For that, we promote the SimLife® technique to include laparoscopy in the management strategy of laparoscopic hernia repair [42, 51]. Thus, Marolleau et al. described a novel laparoscopic approach to treatment of pelvic ring fractures [64].

Due to the challenging dissection of the ilio-pectineal fascia in those approaches while avoiding iatrogenic vascular damages, keeping in mind the potential iatrogenic vascular damages, we hypothesized that a perfused SimLife® (Simedys©) cadaver model could improve the surgeon training by helping him (her) to identify the CMOR [65] thanks to the restored pulsatile perfusion [63].

Methods

Twelve human pelvises from fresh frozen adult cadavers (6 males, 6 females), with a mean age of 81.6 years old (range 67–98 years), were obtained from Voluntary Donors Center of Poitiers University. We recorded the gender, age, weight, height, and body mass index (BMI). The pelvises with bone tumors or history of pelvic surgery were excluded from this study.

Bilateral dissections of the twelve pelvises (24 hemipelvises) were performed on 12 hemipelvises without perfusion (Model A), whereas the 12 other hemipelvises have been prepared with the SimLife® pulsatile perfusion (Model B). We evaluated the prevalence. And morphologic parameters, such as length, caliber (diameter), and the distance between the CMOR and the pubic symphysis were determined. Dissections have been performed by two operators, conducted by a senior surgeon.

Protocol of cadaver preparation using SimLife® (Simedys® technology for model B)

The model description and its assembly are composed of two phases: the fresh frozen cadaver preparation and the perfusion devices control (Fig. 1) [63]. A careful dissection exposed the common carotid artery and the internal jugular vein (Fig. 2). Both deep femoral artery and vein have been ligated after their exposure and cannulas (Fig. 3) were inserted into both femoral arteries and the left common carotid artery (input), and into both femoral veins and the left internal jugular vein (output). Four liters of a diluted solution of heparin (50.000 IU in 2 L) and warm water at 37 °C with a pressure of 0.4 Bar (300.02 mmHg) have been flushed to clear the vascular tree.

Liquid used

At 37 °C, water with a liquid composed of a red alimentary dye (gouache with cornstarch P4P, it means Pulse for Practice) or “red-like blood” has then been perfused in a pulsatile manner, with a pressure ranging from 90 to 120 mmHg (or 0.12 to 0.16 bar) during the anatomic dissection (Fig. 4).

Protocol of morphologic parameters measurements

We inventoried and measured all presence of supra-pubic and retro-pubic vessels between the internal or external iliac system, inferior epigastric system (Fig. 5), and obturator system for each hemipelvis, non-perfused (model A) and perfused (model B), for defining the prevalence.

We measured the morphologic parameters successively using a digital caliper DEXTER® to minimize errors in this order:

1. Length of vessels: from the internal or external iliac system, inferior epigastric system, and the obturator system for each hemipelvis, non-perfused (model A) and perfused (model B);

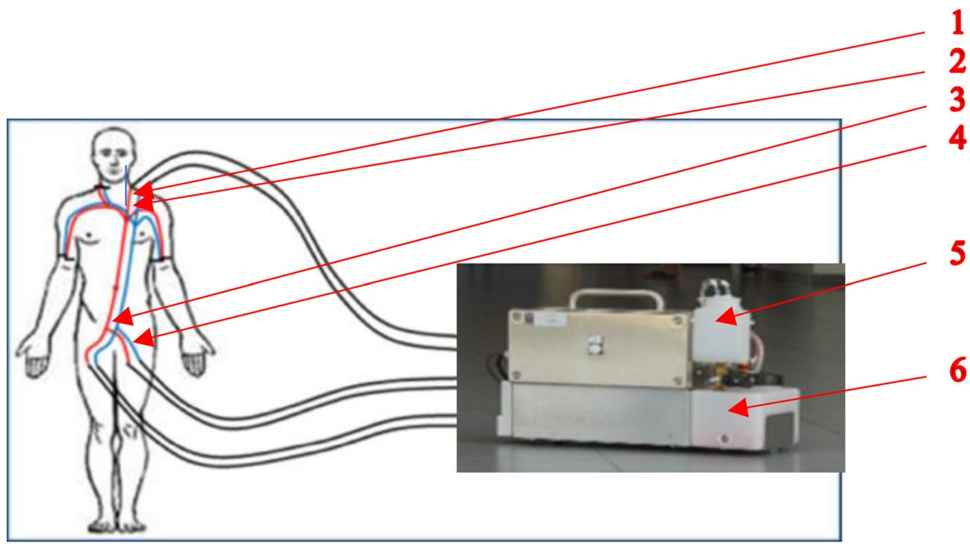

Fig. 1 SimLife® model connected to the specific device for pulsatile vascularization. 1 Common carotid arteria, 2 internal jugular vein, 3 femoral arteria and 4 femoral vein, 5 perfusion fluid "blood-like", 6 specific pulsatile devices

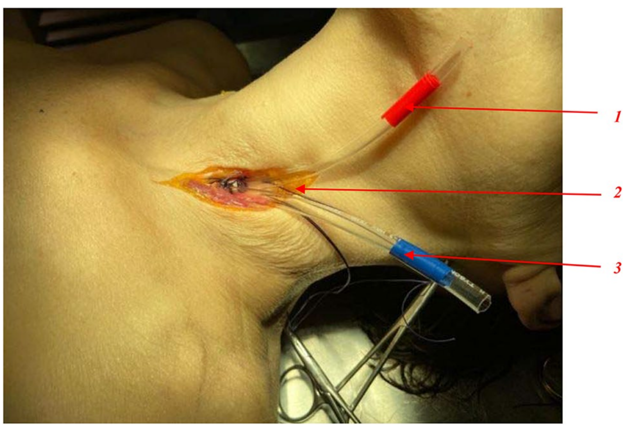

Fig. 2 Cervicotomy for common carotid artery and internal jugular vein cannulations. 1 Common carotid artery cannulation, 2 cervicotomy, 3 internal jugular vein cannulation

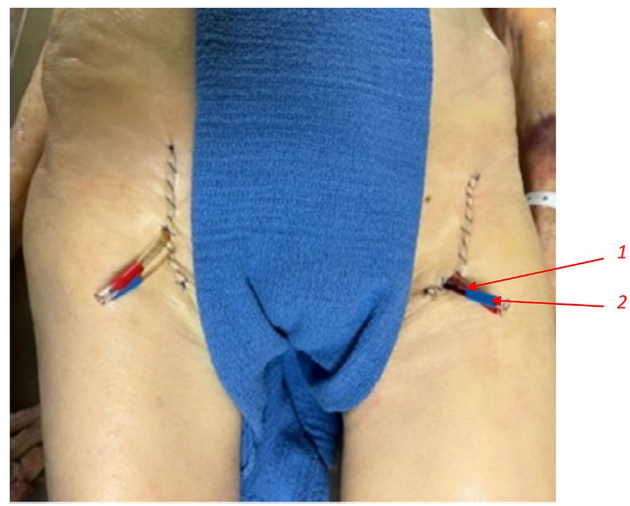

Fig. 3 Femoral vascular cannulations. 1 Femoral artery cannulation, 2 femoral vein cannulation

2. Caliber or diameter: the outer diameters of the vessels dimensions of the anastomotic vessels between the in ternal or external iliac system, inferior epigastric system, and the obturator system for each hemipelvis, non-perfused (model A) and perfused (model B);
3. Distance: between the symphysis pubis and the anastomotic vessels connecting internal or external iliac system, inferior epigastric system to obturator system for each hemipelvis, non-perfused (model A) and perfused (model B).

Protocol of anatomic dissections

In model A, the anatomic dissection began with a Pfannenstiel approach and extended laterally with the ilio-inguinal approach in a manner to show to the learners the three windows and their dangers. Measurements were done when identifying the vessels (Fig. 5).

An extra-peritoneal laparoscopic approach has been performed, to analyze the CMOR morphology in model B (Fig. 6).

Then, during the laparoscopic dissection, the CMOR has been identified, thanks to the SimLife® technology, and an iatrogenic injury of the CMOR has been simulated, leading to a hemorrhage-like event (Fig. 7).

In the second group, the ilio-inguinal dissection was performed for the model A.

We began with the Pfannenstiel incision [12] which is prolonged with the ilioinguinal described by Letournel [36] and applied by most surgeons [66]. During these dissections,

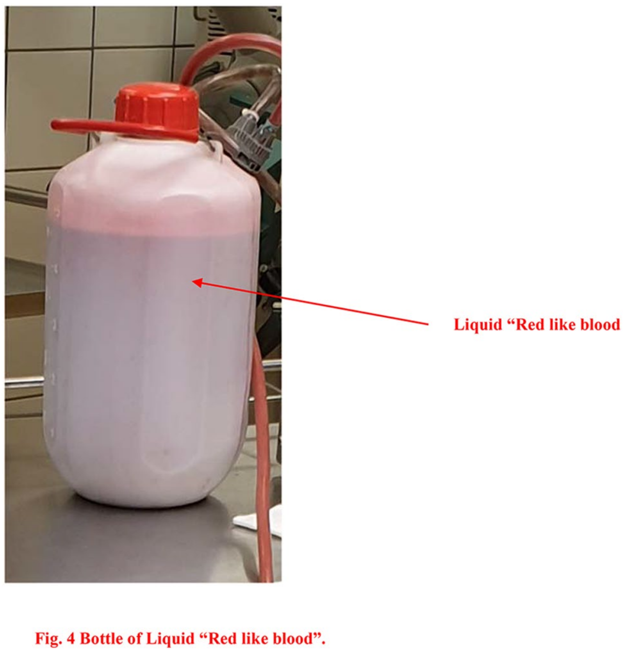

Fig. 4 Liquid “Red-like blood”

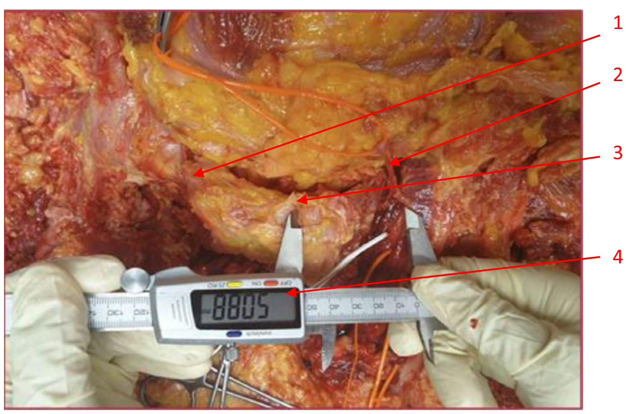

Fig. 5 Model A measurement during anatomical dissection with the digital caliper 1 ilio-pubic branch, 2 inferior epigastric artery, 3 pubic symphysis, 4 digital caliper DEXTER®

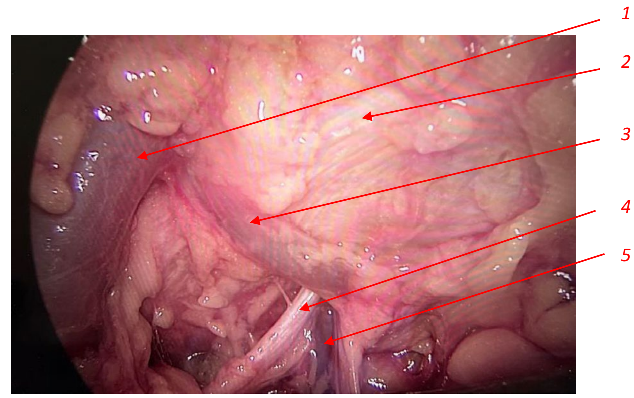

Fig. 6 Model B of corona mortis. 1 External iliac vein, 2 ilio-pubic branch, 3 CMOR vein, 4 obturator nerve, 5 obturator vein

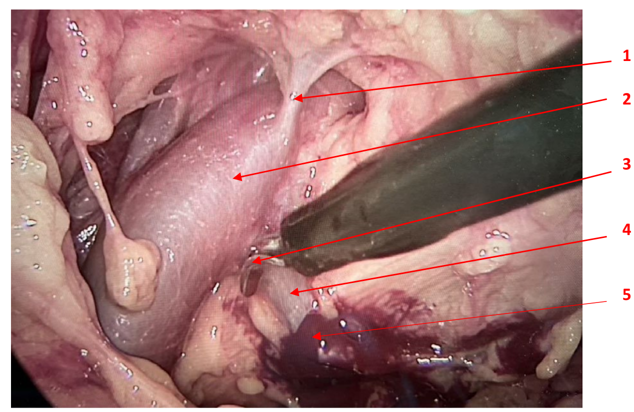

Fig. 7 Simulating of CMOR’s bleeding. 1 Inferior epigastric vein, 2 external iliac vein, 3 coelioscopic scissors, 4 CMOR vein, 5 bleeding “blood–like fluid”

we sought to analyze the vascular mapping of the supra-pubic and retro-pubic pelvic region.

Statistical methods

Demographic statistical analysis has been done using Excel (Microsoft Office Professional Plus 2016) with a Student’s T test for comparisons, with an alpha-risk $\alpha = 0.05$ and confidence interval of 95%. Quantitative data have been expressed by mean and standard deviation (SD). Qualitative data have been presented using absolute numbers and percentages.

Results

In total, 6 males and 6 females have been dissected in each model. Mean ages, weight, height, and body mass index (BMI) were comparable between the two groups. The SimLife® perfusion has been successful in the 12 hemi-pelvis of Model B. Demographic data are shown in Table 1.

Regarding the prevalence of the CMOR, 16 of 24 hemi-pelves showed a CMOR (66.67%), 50.00% ($n = 12$) of the bodies presented a unilateral CMOR, 16.70% ($n = 4$) bodies showed a bilateral presentation of the CMOR. In 4 bodies (8 hemipelvis), (2 males and 2 females), no supra- and retro-pubic vascular connection has been found (Table 2).

The mean distance between the CMOR and the pubic symphysis was 58.02 ± 6.27 mm for model A, and

Table 1 Demographic data for models A and B

Variables	Model A ($n = 12$ hemipelvises) (mean ± SD)	Model B ($n = 12$hemipelvises) (mean ± SD)	p value
Gender	3 males, 3 females	3 males, 3 females	
Age (years)	81.16 ± 11.3 (67–98)	82.16 ± 8.1 (68–88)	0.566
Weight (kg)	67.83 ± 9.89 (50–80)	67.5 ± 11.81 (45–80)	0.323
Height (cm)	169.67 ± 7.849 (160–175)	166.3 ± 7.89 (150–175)	0.223
BMI (kg/m^2)	23.5 ± 2.4 (16–28)	24.17 ± 2.48 (20–28)	0.624

$n = 24$ hemipelves, body mass index (*BMI*), standard deviation (*SD*)

Table 2 Prevalence of the CMOR and nature of the anastomosis for A and B according to the gender. $n = 24$ hemipelves

Variables	Arterial anastomosis (n%)	Venous anastomosis (n%)	None (n%)
Male	3 (12.5%)	5 (20.83%)	4 (16.67%)
Female	2 (8.33%)	6 (25.00%)	4 (16.67%)
Total	5 (20.83%)	11 (45.83%)	8 (33.34%)

Table 3 CMOR Morphologic parameters' data: length, caliber (diameter) and distance to the pubic symphysis for A and B models

Variables	Model A (mean ± SD)	Model B (mean ± SD)	p value
Length (mm)	51.19 ± 6.37	54.09 ± 9.02	0.029
Caliber (mm)	2.75 ± 0.13	3.08 ± 0.40	0.01
Distance (mm)	58.02 ± 6.27	60.97 ± 9.94	0.022

60.97 ± 9.94 mm for model B with a p value = 0.022 (Table 3).

When it is present, 20.83% of them were arterial, 45.83% of them were venous, with no difference between the genders [21] (Table 2). In model A, 16.66% ($n = 2$) of the anastomosis were arterial, 41.65% ($n = 5$) were venous and the CMOR was absent in 41.67% ($n = 5$) cases. In model B, 25.00% ($n = 3$) of the anastomosis were arterial, 50.00% ($n = 6$) were venous, and 25.00% ($n = 3$) of the cases did not show any retro-pubic vascular connection (Table 2). The CMOR mean length in Model A was 51.19 ± 6.37 mm, which is significantly lower than in Model B (54.09 ± 9.02) (p value = 0.029), the mean caliber was also lower in model A (2.75 ± 0.13 mm vs 3.08 ± 0.40 mm) (p value = 0.01) (Table 3).

Discussion

During this preliminary dissection work, we thought about the difficulties of neuro-vascular management. Indeed, the surgeon is usually confronted with this challenge during medial and middle windows of the ilio-inguinal approach, especially during the dissection of the ilio-pectineal fascia, regarding its insertion on the pectineal eminence [36]. Aiming to acquire surgical skills away from the operating theater [65], we suggested helping the surgeon to characterize the CMOR dynamic morphology with the SimLife® Technology. This pulsatile perfusion model could facilitate the dissection as the small size or flatness of the non-perfused pelvic vessels are frequently an issue. Our study is the first assessment of a new perfusion pulsatile SimLife® model for the morphologic description of the CMOR in pelvic surgery.

Fresh, human cadavers allow for high fidelity tissue handling making them superior to synthetic models [67].

We noticed a prevalence of 66.67% of vascular anastomosis between the obturator and external iliac vessels, with a predominance of venous anastomosis. This data is in line with Cardoso et al.'s systematic review over 3.107 hemi-pelvises, which reported a CMOR prevalence of 63% with most veins [68]. The venous pattern seems to be more frequent than the arterial one [41, 68, 69]. In the literature, this ratio ranges from 14.3% to 83% [20, 21] varying by the method of exploration (Table 4).

Nevertheless, Heichinger R et al. studied the size of CMOR in relation to the regular obturator artery, and used two methods for determining the diameter: "unfolded" and "Hillen" [21]. They reported that an average diameter of the CMOR was 2.5 ± 0.5 mm ("unfolded"), and 2.1 ± 0.4 mm ("Hillen"), no difference between the diameters of the regular obturator artery and the CMOR, neither for the method "unfolded" (p value = 0.947) nor for the method "Hillen" (p value = 0.880), no correlation between the occurrence of CMOR with gender (p value = 0.771) or with body side (p value = 0.444). Between the two methods, the diameters of the regular obturator artery and the CMOR measured with the method "Hillen" were significantly smaller than those measured with the method "unfolded" (p value < 0.001) [21].

Although, Rusu et al. reported by detailed anatomical dissections and systematize the morphological possibilities of the vascular connections that are termed CMOR [42].

Clinically, through an ilioinguinal approach, the CMOR prevalence ranges from 61 to 83% [20, 37, 41, 70]. The presence of CMOR constitutes a risk factor for complications.

Table 4 Incidence of a CMOR according to the method of exploration in relation to hemipelvises, comparison with the results to the current study and the method of exploration

Authors	Hemipelvises (*n*)	Incidence (%)	Method
Cloquet 1817 [23]	500	30.4	Dissection
Hesslebach 1819 [24]	64	42.2	Dissection
Schlobig 1844 [25]	112	30.4	Dissection
Quain 1844 [26]	361	31.6	Dissection
Hoffman 1878 [27]	400	32.5	Dissection
Hartmann 1881 [28]	180	18.9	Dissection
Pfitzner 1889 [29]	242	35.1	Dissection
Jastschinski 1891 [30]	1034	30.0	Dissection
Dwight 1894 [31]	500	25.8	Dissection
Lipshutz 1918 [32]	181	19.3	Dissection
Adachi 1928 [33]	692	13.2	Dissection
Pick et al. 1942 [34]	640	29.0	Dissection
Braithwaite 1952 [35]	169	20.6	Dissection
Letournel et al. 1993 [49]	150	10.15	Surgical
Teague et al. 1996 [37]	79	43.0	Dissection
Tornetta et al. 1996 [38]	50	34.0	Dissection
Gilroy et al. 1997 [39]	45	38.0	Dissection
	60	33.0	
Berberôglu et al. 2001 [48]	14	14.3	Dissection surgical
	26	8.3	
Karakurt et al. 2002 [53]	98	28.5	Angiography
Sarikcioglu et al. 2003 [40]	54	14.8	Dissection
Okçu et al. 2004 [41]	150	19.0	Dissection
	72	50	Dissection
Pungpapong et al. 2005 [51]	66	77.27	Laparoscopy
Darmanis et al. 2007 [20]	80	37.5	Dissection
Kawai et al. 2008 [75]	709	13.5	Dissection
Pai et al. 2009 [76]	98	21.0	Dissection
Rusu et al. 2010 [42]	80	40	Dissection
Rusu et al. 2012	65	40	Dissection
Lee et al. 2013 [44]	36	8.3	Laparoscopy
Stavropoulou-Dei and Anagnostopoulou 2013 [43]	70	11.4	Dissection
Rajive and Pillay et al. 2015 [44]	50	26.0	Dissection
Bargoria et al. 2015 [45]	40	38	Dissection
Al-Talalwah 2016 [46]	208	9.8	Dissection
Ates et al. 2016 [50]	398	28.4	Surgical
Wada et al. 2017 [54]	196	14.3	Radiological
Duenas-Garcia et al. 2017 [55]	174	27.9	Radiological
Steinberg et al. 2017 [56]	200	33.0	Radiological
Perandini et al. 2018 [57]	300	30.0	Radiological
Cavalié et al. 2019 [47]	36	61.1	Dissection
Heichinger et al. 2022 [21]	150	24.0	Dissection
Mean	210.21	28.45	
Maximum	1034	77	
Minimum	14	8	
Mean ± SD	210.21 ± 226.25 (range 14–1034)	28.45 ± 14.43% (range 8–77)	
our study	24 (hemipelvises)	66.67% (prevalence)	Dissection

About anatomical and clinical implications of corona mortis in the anterior approaches of pelvis, Abbas et al. advised that surgeons who carry out an anterior approach to pelvis and acetabulum have to be cautious about corona mortis vessels at around 58 ± 16 mm (range 44–80 mm) lateral to the symphysis pubis [71]. And Du et al. found a distance of 12.6 ± 3.0 mm (range 18.3–8.8 mm) [72]. Karakurt et al. have noted the distance from the symphysis pubis to the anastomotic artery averaged 33.4 mm (range 21.4–41 mm) with a difference between men: 31.8 mm (21.8 mm (range 21.4–39.3 mm) and for women: 36.2 mm (range 25–41 mm), difference estimated significant with a p value < 0.05 [53].

Therefore, Darmanis et al. conducted an anatomical study with clinical implications of the CMOR in approaches to the pelvis and acetabulum; and they suggested orthopedic surgeons planning for an anterior approach to the acetabulum [20]. Hong HX, et al. concluded in their study that the vascular connections between the obturator system and external iliac or inferior epigastric system are prone to be damaged during the ilioinguinal approach as an anterior approach to the acetabulum and pelvis [70, 71]. Thus, corona mortis located over the superior pubic ramus deserves great attention during the ilioinguinal approach [71]. Du et al. studied the morphology of the CMOR and the position relation between the corona mortis and the placement of sub-periosteal tunnel for plate insertion through the minimally invasive ilioinguinal approach [72].

In a superior pubic ramus fracture, which led to a severe picture of hemodynamic instability, the emergent angiography demonstrated a CMOR's injury [73]. Xu et al. performed a super-selective embolization of the CMOR artery with a balloon-assisted coiling technique and the patient progressed satisfactory [73].

During the pelvic osteotomies, pubic medial approach appears technically easy, there are several anatomical structures at risk, such as the femoral vein and the CMOR [74].

In our study, the impact of comparing SimLife® to conventional dissection was to teach learners both surgical techniques. As Aboud described and reported by Gabro, the fresh, human cadavers with vascular perfusion were useful in allowing for simulation of the critical challenges faced during operative trauma as well as allowing for training in the skills necessary to manage vascular injuries [67].

We performed these different measurements to know the pelvic vascular mapping and to compare our results with those of other authors.

We did not find any difference of CMOR prevalence between genders, in line with Rusu [42] and Okcu's outcomes [41]. In the same way, in their angiographic study, Karakurt et al. reported a non-significant difference regarding the incidence of the arterial CMOR between males 28.5% (range, 28 of 98) and females 25.6% (10 of 39) with $p > 0.05$ [53]. In our study, the CMOR was usually found at a mean distance of 58.02 ± 6.27 mm in model A and 60.97 ± 9.94 in model B from the pubic symphysis. In the literature, this distance ranges from 31.8 mm to 52 mm [53, 70].

Regarding the morphologic data, we noticed a CMOR mean length of 51.19 ± 6.37 in model A, and 54.09 ± 9.02 in model B. This is slightly smaller than Okçu et al. results, as they reported a mean length of 64 mm (45–90) for arterial anastomosis and 56 mm (37—80) for venous anastomosis [41].

Thanks to the Simlife® model, the CMOR caliber was slightly higher than non-perfused vessels with a mean of 3.08 ± 0.40 mm. In Cardoso et al. recently study, the mean caliber was about 2.8 mm among 1,608 hemipelvises [68], which is consistent with the 2.75 ± 0.13 mm diameter we reported in Model A. As expected, the CMOR diameter could vary a lot according to the method of exploration, as Berberoğlu et al. showed: in their anatomical study, the CMOR diameter was about 3.3.mm (ranging from 2.2 to 4.9 mm), whereas in laparoscopic findings the diameter was less than 1 mm) [48].

In Table 4, we collected in the literature 210.21 ± 226.25 hemipelvises (range 14–1034 hemipelvises) with an incidence of 28.45 ± 14.43% (range 8–77%).

The significant difference we found between models A and B regarding the length and the diameter of the CMOR underlines that the SimLife® technology could give more precision in the CMOR identification. Thus, the surgeon might push his dissection further, as the CMOR is easier to identify as its caliber increases with the quantity of liquid perfused. In their model, Redman and Ross used a saline solution with continuous infusion and confirmed that a perfused cadaver that bleeds provides more training value and allows for more procedures to be accurately simulated and performed [77]. The successful establishment of a venous perfused pulsatile cadaveric circulation was first described by Garrett et al. in 2001 [78]. In 2014, Carrey et al. improved this protocol using water and alimentary dye to include salt and carbohydrate. Their arterial solution consisted of a mix of tap water, red-pigmented concentrate corn syrup, and sodium chloride [79]. They combined it with a venous solution, made from an identical recipe with the replacement of the red pigment with blue-pigmented concentrate [79]. In our study, a blood–like red solution has been used, combined to a pulsatile perfusion to mimic bleeding in case of vessel iatrogenic injury during the dissection. But it seems expensive and difficult to obtain because it requires cadavers. But it is of great pedagogical interest through high-level simulation. So, it has major benefits for the learners, and it is a model for advanced training at the end of the cursus or for doctors who are already specialists. The SimLife® is cheaper than those techniques and it improves the learning curve for anatomy and surgery [63], Carden et al. have conducted a randomized controlled trial comparing dynamic simulation with static simulation in trauma and concluded that the addition of dynamic hemorrhage to simulators might inexpensively augment trauma skills training [80].

The integration of perfused fresh cadaver training in the program of teaching surgery has an impact in providing high fidelity and dynamic training and assessment method [67].

Limitations

However, our study might be limited by its specimen's number. These preliminary results could also be improved by the intelligent digital calipers that are now available, giving a measurement resolution of 0.01 mm and a low inaccuracy of 0.03 mm [81].

Future clinical perspectives

We recommend, as the other authors, the use of laparoscopy or arthroscopic control (optional) to dissect the pelvic region and then perform pelvic osteo-synthesis [18, 42, 64, 72]. "Laparoscopic internal fixation" delivered an in situ result as good as that of open surgery [64].

The great interest of SimLife® is for simulating the hemorrhage due to CMOR and training the surgeons to be aware and able to treat it.

Conclusion

As expected, the corona mortis presents several anatomic variations. The SimLife® model did not allow to find it at its anatomical reference point in every case, but this vascular loop might be absent. As the blood vessels diameter is larger in perfused models, it thus facilitates the evaluation of the corona mortis cartography.

The great interest of the SimLife® is to provide a dynamic aspect of the anatomy.

The SimLife® creates a surgical simulation model adapted to the training of surgeons of all specialties who operate on the retro-pubic area, especially trauma surgeons, to manage the open book lesions. It follows the current evolution of pedagogical principles: "Never the first time on the patient".

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Declarations

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