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The evaluation of safe zones for the corona mortis using a cadaver simulation of the Modified Stoppa approach

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ABSTRACT

Background: The Modified Stoppa approach is a minimally invasive method of accessing the pelvis when treating pelvic ring and acetabular fractures. Although this approach is reported to be effective in exposing pelvic fractures, there are iatrogenic risks associated with the procedure. These risks arise from the inadvertent severing of vessels along the pelvic brim, resulting in bleeding, prolonged recovery, or even death. The specific vessels of concern include the corona mortis (CM) anastomosis and aberrant vasculature, which course over the superior pubic ramus.

Methods: The current study aimed to create and validate clinically significant safe zones to avoid injury to these anomalous vessels during the Modified Stoppa approach. Measurements were taken between the CM and crossing vessels (CV), as well as various bony landmarks encountered during the anterior approach, using 63 cadavers. Measurements were statistically analyzed for any significant differences between sides and sex using t-tests, and safe zones were formulated. The safe zones were then assessed for precision using a stepwise cadaver simulation of the Modified Stoppa approach.

Results: Safe zones from the pubic tubercle were calculated as 57.96 mm (SD ± 21.40) for the CM, while safe zones for the CV were reported as 48.07 mm (SD ± 25.52). These safe zones proved to be accurate when implemented during the cadaver simulation of the Modified Stoppa approach, as all cases of CM and aberrant vessels were positioned outside the prescribed zones.

Conclusion: The results reiterate the clinical significance of the CM and its impact on orthopedic surgery and patient care.

1. Introduction

The Modified Stoppa Approach to the pelvis is a minimally invasive technique first introduced by Stoppa et al. and later modified to treat abdominal wall hernias [1,2]. Today, the procedure is used to access the anterior column of the pelvis (iliopubic column) and acetabulum for the repair of fractures [3]. During this approach, the dissection is often intercepted by the CM, a vascular anomaly involving the anastomosis between the obturator vessels and the external iliac vessels or their branches [4]. The CM notably crosses the superior pubic ramus, making it particularly susceptible to injury as a result of fractures to the pubic ramus or during anterior approaches to the pelvis [5]. The high risk associated with injury to the CM vessels includes spontaneous vascular spasms and retraction into the pelvis, leading to excessive haemorrhaging [6].

The risk of CM injury is also imminent during procedures which involve pelvic dissection, including the repair of inguinal, obturator or femoral hernias, and tension-free vaginal tape (TVT) secures for the

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treatment of stress urinary incontinence [7,8]. However, orthopaedic procedures pose the greatest concern and warrant further investigated [3]. Therefore, awareness of the clinical significance of the CM during intraoperative procedures is necessary, though research in this area remains limited. While the iatrogenic implications are concerning, studies have shown little correlation between CM injury and mortality due to haemorrhage during pelvic surgery [3,9]. Jenson et al. and Rehder et al. concluded that the risk associated with the presence of the CM is minimal and of little concern to surgeons, as it is a controllable anomaly that can be readily amended if damaged [9,10]. Despite these conclusions, the number of cases of excessive bleeding potentially linked to CM injury may still be significant, due to discrepancies in its location and clinical significance.

The prevalence of the CM has been reported to range from 8 to 96 % in cadaver studies [11,12]. A pronounced presence of venous anastomoses has also been observed in previous studies [3,6,7,11–15]. Increased venous anastomoses may have further clinical implications due to decreased detectability following injury and the higher risk of inadvertent damage, especially when using imaging modalities [8,16]. This could explain the lack of venous communications reported in clinical studies despite its high incidence in cadaver research [17]. This underscores the need for further investigation of the CM and its associated clinical implications.

Variations in the CM anastomosis include aberrant obturator vessels originating from or draining into the external iliac system as well as the presence of additional vessels crossing the pelvic brim [14,18]. The risk of injury increases with the prevalence of these accessory vessels, which can lead to further bleeding or impaired blood supply to the lower limb. Therefore, investigation into the topography of these vessels is crucial in minimizing iatrogenic effects and mortality. Formulating safe zones for the CM and CV and validating their accuracy and clinical outcomes, will also assist clinicians in avoiding CM injury and inadvertent intraoperative bleeding.

2. Materials and methods

2.1. Materials

A total of 63 cadavers, 34 males and 29 females, with intact pelves (123 hemi-pelves), aged between 22 and 95 years (mean age: 68, SD ± 16.66) were dissected. The mean height for cadavers was recorded as 1.67m (SD ± 0.12) and the mean weight was 60.5 kg (SD ± 18.58). Additionally, 2 cadavers, 1 male and 1 female, with intact pelves (4 hemi-pelves), aged 50 and 61 years respectively (mean age: 55.5, SD ± 7.78), were utilized for the cadaver simulation portion of the study. The mean height for these cadavers was 1.76 m (SD ± 0.06) with a mean weight of 61.9 kg (SD ± 4.95). All cadavers were obtained from the Department of Anatomy, Faculty of Health Sciences, University of Pretoria. Ethical clearance was obtained from the University of Pretoria, Faculty of Health Sciences Research Ethics Committee (clearance number: 259/2020). Research was conducted in accordance with the South African National Health Act, Act 61 of 2003. Cadavers aged above 20 years were utilized, and any cadaver which presented evidence of previous surgery, injury or pathology around the pelvis was excluded.

2.2. Methods

With the cadaver in the supine position, a midsagittal incision was made between the umbilicus and the pubic symphysis, and the anterior abdominal wall was reflected laterally towards the mid-axillary line to expose the abdomino-pelvic cavity. The intestines were resected at the rectosigmoid junction to expose the true pelvis. The peritoneal covering of the pelvis and the bladder was reflected to better visualize the branches of the internal iliac artery and vein as well as the quadrilateral plate of the pelvic bone.

The anterior division of the internal iliac artery and vein were identified, while the obturator vessels were traced to the obturator canal, accompanied by the obturator nerve. Any anastomosing vessels that communicated with the obturator artery or vein before passing through the obturator canal, were further investigated. These vessels were followed to their drainage (veins) or origin (arteries) from the external iliac vessels or their branches, in order to identify the CM.

Once observations were made, linear measurements were taken from the point of anastomosis to the following bony landmarks:

- The most prominent anterior aspect of the anterior inferior iliac spine (AIIS).
- Midpoints of the pubic symphysis (PS) at its superior (SPS) and posterior (PPS) aspects.
- The most prominent anterior point of the pubic tubercle (PT) (Fig. 1).

Due to the high frequency of vessels coursing over the superior pubic ramus, additional measurements were taken for each vessel from the point it intersected the superomedial aspect of the superior pubic ramus to the relative landmarks. These landmarks were the same bony structures used for the CM measurements, which included the SPS, PPS, PT and AIIS. An additional landmark was used for the CV which involved the medial aspect of the femoral vein (FV) as it crossed the superior aspect of the pubic ramus anteriorly (Fig. 2).

Once all measurements were taken, the diameter of the most proximal, most distal and midpoint of the anastomosing vessel was investigated to assess the average diameter of the vessels. All measurements were evaluated for statistically significant differences when comparing sides and sexes using *t*-tests. A p-value of less than 0.05 indicated significant statistical difference between left and right sides as well as male and female. Inter- and intra-observer reliability tests was conducted on 11 % of the study sample (14 hemi-pelves) in order to evaluate the repeatability and accuracy of results and methodology using interclass correlation. A correlation co-efficient of more than 0.90 indicated excellent reliability. Safe zones were formulated for the CM anastomosis and CV using the 95 % confidence interval of the measurements.

A cadaver simulation of the Modified Stoppa approach to the anterior pelvis was conducted to validate the precision of the determined safe zones by applying the findings to the two cadaveric simulations. The simulations were performed by a senior orthopaedic surgeon, following AO Foundation specifications for accurate and applicable results and to examine the clinical significance of the CM.

All equipment needed for the simulation was provided by Osso-tech™. The simulation was performed with the orthopaedic surgeon positioned on the contralateral side of the pelvis where the fracture would be replicated. A wooden block was placed posterior to the knee to relieve tension in the psoas muscle and femoral neurovascular bundle. A Pfannenstiel incision through the skin, fat and fascia of the anterior abdominal wall was made, and extended as far laterally as needed for optimal exposure. Caution was taken not to surpass the femoral vein. The subcutaneous tissue was reflected to expose the rectus sheath and a vertical incision was made through the rectus sheath and the rectus abdominis muscle along the linea alba. The two bellies of the rectus abdominus muscle were reflected from their origin at the pubic symphysis. A fracture to the anterior column of the pelvis was then created using an oscillating hand saw.

The pelvic brim was bluntly dissected with great caution to preserve all blood vessels on its medial surface. At this point, the surgeon applied the established pelvic brim safe zones using a ruler and evaluated their accuracy by recording the frequency of CV located lateral or medial to the safe zones. Once the pelvic brim was dissected, the CM safe zones were evaluated for each of the four bony landmarks by recording the frequency of anastomoses located lateral and medial to these safe zones. The Modified Stoppa approach was completed with appropriate fixation of screws and plates for an ideally simulated procedure (Fig. 3).

The simulation was used to not only assess the safe zones and the clinical relevance of the CM, but also to evaluate the effectiveness of

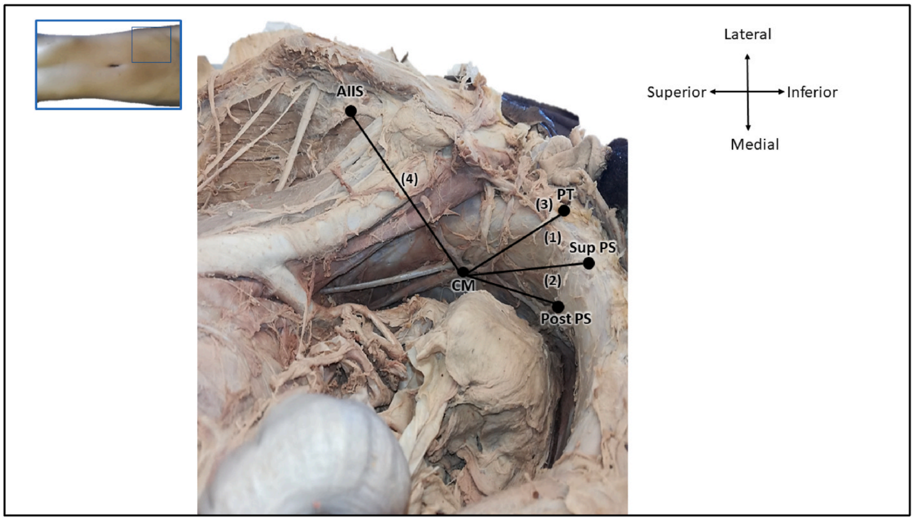

Fig. 1. Anterolateral view of the pelvis depicting the measurements taken between the corona mortis (CM) and the various bony landmarks. ***Key: (1)*** *Distance between the CM and the midpoint of the superior pubic symphysis (Sup PS),* ***(2)*** *Distance between the CM and the midpoint of the posterior pubic symphysis (Post PS),* ***(3)*** *Distance between the CM and the most anterior point of the pubic tubercle (PT).* ***(4)*** *Distance between the CM and the most anterior point of the anterior inferior iliac spine (AIIS).*

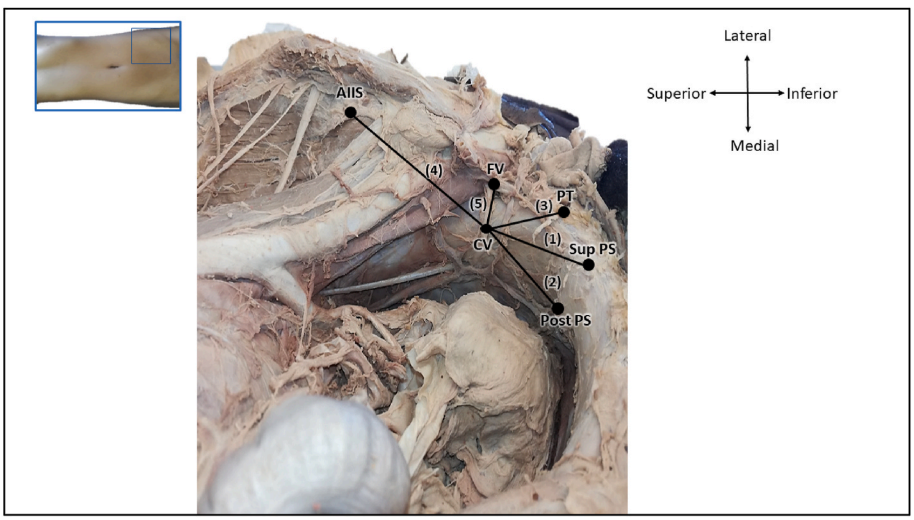

Fig. 2. Anterolateral view of the pelvis depicting the measurements taken between the CV (crossing vessel over the pelvic brim) to the various landmarks. ***Key: (1)*** *Distance between the CV and the midpoint of the superior pubic symphysis (Sup PS),* ***(2)*** *Distance between the CV and the midpoint of the posterior pubic symphysis (Post PS).* ***(3)*** *Distance between the CV and the most anterior point of the pubic tubercle (PT).* ***(4)*** *Distance between the CV and the most anterior point of the anterior inferior iliac spine (AIIS).* ***(5)*** *Distance between the CV and the medial aspect of the femoral vein (FV).*

clinical simulations in validating anatomical findings.

3. Results

The distances from the CM to the bony landmarks were compared between the left and right sides and produced p-values of 0.05 or more. Therefore, no statistically significant difference between sides was exhibited for safe zones of the CM. Comparisons between male and female samples resulted in a p-value of 0.01 or less for the distances between the CM and the SPS, PPS and AIIS. Thus, safe zones between these landmarks were altered, as shown in Table 1.

The number of documented vessels coursing over the superior pubic ramus was much greater than anticipated and included the accessory obturator vein and artery, second accessory obturator vein, aberrant obturator artery and vein, accessory obturator artery as well as pelvic branches. Each of these vessels was observed crossing the pelvic brim similarly to the vessels forming the CM anastomosis (Table 2).

No statistically significant differences were found when comparing the distances of the CV in relation to the landmarks on the left and right sides ($p \geq 0.26$). However, comparison of the distances between the CV and the landmarks in males and females resulted in a p-value of less than 0.01 for the SPS, PPS and AIIS. A p-value of 0.08 and more was found for distances between the CV and the PT and FV, between both sexes, suggesting that the safe zones between the sexes should be modified, as seen in Table 3.

A correlation co-efficient ranging between 0.86 and 0.99 was calculated for the correlation between inter and intra-observer and the original data, as well as between inter- and intra-observer. A p-value of 0.50 for the nil hypothesis (Mean = 0) was confirmed when comparing the difference of means between the inter-observer and original tests, demonstrating the repeatability of methods. A p-value of 0.26 for the null hypothesis (Mean = 0) was confirmed when comparing the difference of means between the intra-observer and original tests, indicating the accuracy of results.

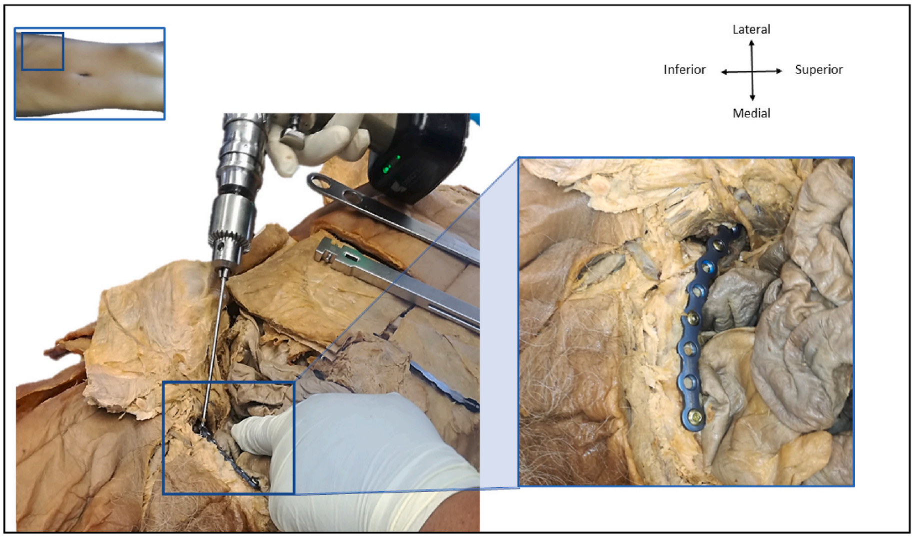

Fig. 3. Completion of the cadaver simulation of the Modified Stoppa Approach with customised plate fixation.

Table 1
The mean distances between the CM anastomosis and the bony landmarks (SPS, PPS, PT and AIIS) for males and females. ***(Key: CM:** Corona Mortis, **SPS:** Superior pubic symphysis, **PPS:** Posterior pubic symphysis, **PT:** Pubic tubercle, **AIIS:** Anterior inferior iliac spine, **M**: Male, **F**: Female).*

Variables	Sex	Mean (mm)	Range (mm)	Two standard-deviation	Safe zone (mm)
CM-SPS	M	68.12	48.04–89.93	17.08	65.62–70.63
	F	73.34	53.62–103.32	20.32	69.85–76.82
CM-PPS	M	54.11	33.88–89.17	20.54	51.12–57.09
	F	61.51	43.99–87.63	18.9	58.26–64.75
CM-PT	M & F	60.32	40.13–91.22	21.40	57.96–62.67
CM-AIIS	M	78.87	50.15–98.66	20.02	75.96–81.78
	F	72.52	51.12–94.11	18.92	69.27–75.77

Table 2
The average distance of vessels crossing the superior pubic ramus to the landmarks (SPS, PPS, PT, AIIS, and FV). ***(Key: CV:** Crossing vessels, **SPS:** Superior pubic symphysis, **PPS:** Posterior pubic symphysis, **PT:** Pubic tubercle, **AIIS:** Anterior inferior iliac spine, **FV:** Femoral vein.)*

CV	N	CV-SPS (mm)	CV-PPS (mm)	CV-PT (mm)	CV-AIIS (mm)	CV-FV (mm)
Aberrant obturator artery	32	58.34	51.22	47.20	63.62	14.94
Accessory obturator artery	8	59.71	52.74	46.33	66.23	21.51
Aberrant obturator vein	5	67.33	63.01	55.99	58.49	21.83
Accessory obturator vein	88	64.10	57.65	53.54	62.06	18.57
Second accessory obturator vein	15	61.47	55.77	50.75	68.24	13.81
Venous pelvic branches	18	50.74	46.42	38.13	67.37	12.19
Arterial pelvic branches	1	35.72	30.74	32.46	64.00	13.48

The average and two-standard deviations of the diameter for the venous anastomotic vessels were recorded as 1.97 ± 2.12 mm (Range: 0.32–4.4 7 mm), while 4 cases presented a diameter of more than 4 mm. The average diameter and two-standard deviation of the arterial anastomotic vessels resulted in 1.45 ± 1.24 mm (Range: 0.70–2.44 mm).

Table 3
The mean distances between all vessels coursing over the superior pubic ramus collectively and the various landmarks (SPS, PPS, PT, AIIS and FV) for males and females. ***(Key: CV:** Crossing vessel, **SPS:** Superior pubic symphysis, **PPS:** Posterior pubic symphysis, **PT:** Pubic tubercle, **AIIS:** Anterior inferior iliac spine, **FV:** Femoral vein, **M:** Male, **F:** Female.)*

Variables	Sex	Mean (mm)	Range (mm)	Two-standard deviation	Safe zone (mm)
CV-SPS	M	58.18	34.97–105.34	26.66	55.45–60.91
	F	64.81	31.94–96.94	20.00	62.46–67.16
CV-PPS	M	51.87	29.94–89.17	23.84	49.44–54.30
	F	58.67	30.51–87.04	18.26	56.53–60.82
CV-PT	M & F	50.01	26.77–92.71	25.52	48.07–51.96
CV-AIIS	M	66.57	36.71–90.80	18.90	64.66–68.49
	F	59.66	42.14–90.45	17.78	57.57–61.74
CV-FV	M & F	16.23	4.00–27.4	11.56	15.35–17.12

A 75 % (n = 3/4) incidence of accessory obturator veins was observed during the cadaver simulation with vessels averaging at 1.93 ± 2.08 mm (Range: 0.32–4.47 mm) in diameter. In 50 % (n = 2/4) of cases, pelvic branches occurred with one extending medially on the posterior aspect of the superior pubic ramus, before draining into the accessory obturator vein.

Pelvic brim safe zones were applied for all 4 sides, as each side exhibited one or more CV coursing over the pelvic brim. All pelvic brim safe zones were found to be accurate, with all three accessory obturator veins and two pelvic branches existing lateral to the formulated safe zones. The CM safe zones applied to the single case of anastomosis were also accurate, with the point of anastomosis lying lateral to the determined safe zones.

4. Discussion

Understanding the parameters of the CM and CV vessels within the pelvis is crucial in formulating safe zones and enhancing the clinical significance of these anomalies. Clinical validation of safe zones, as demonstrated in the current study, is essential for improving patient safety during orthopaedic procedures. The positioning and morphology of the anastomosis and accessory aberrant vessels along the superior pubic ramus are closely related to the area of exposure during the Modified Stoppa approach which makes the CM susceptible to injury, as proven in the current study. These findings, along with the documented adverse effects of severing the CM highlight the clinical impact of the anomaly in reducing the risks associated with anterior approaches to the pelvis and creating more effective procedures.

The average distance between the CM and the SPS was documented as 70.35 mm and 57.23 mm between the CM and the PPS. These results correlate closely with the average distance of venous anastomotic vessels to the PS, as reported by Okcu et al. [6]. A study by Darmanis et al. also reported comparable results, with an average of 71 mm from the PS for arterial anastomotic vessels (Table 4) [3]. The current study reported the average distance between the CV and the SPS as 61.06 mm, and the average distance between the CV and the PPS was 54.80 mm. These findings are consistent with the average distance between the CM and PS reported by Tornetta et al. and the venous anastomoses documented by Darmanis et al. [3,13]. Bargoria et al. also reported an average distance from the PS of 53.20 mm in arterial communications and 54.30 mm concerning venous connections, which correlates with the current study (Table 4) [19].

The PS was the most prominent landmark used to relate the distance from the CM and various CV with little representation of other bony landmarks. The average distance between the CM vessels and the PS as reported by previous studies are presented in Table 4.

The average distance of the CM in relation to the PT was concluded as 60.32 mm (range: 40.13–91.22 mm), while the average distance between the CV and the PT was 50.01 mm (range: 26.77–92.71 mm). Although this landmark is underutilised in research, a previous study by Du et al. produced similar findings, with an average distance of 59 mm between the CM and PT [27]. The current study demonstrated that parameters between the PT do not exhibit a significant difference between males and females, making it a reliable intraoperative landmark. Differences between the remaining landmarks may be attributed to morphometric differences between the male and female pelves, which alters the proportions between bony landmarks [28]. Significant differences in distances between the sexes have also been documented in studies by Okcu et al., Bargoria et al. and Ruangwannasak et al. [6,19,29].

The positioning and diameter of the CM vessels, and the neighbouring CV over the superior pubic ramus make it susceptible to accidental severing which may lead to vascular spasm [11]. This reaction involves the abrupt contraction of the muscular component of vessels and is assisted by endothelin within the vascular layers [30]. This results in the retraction of these vessels into the surrounding tissue, making them difficult to locate and clamp, increasing the risk of haemorrhage [3]. Therefore, these safe zones are of clinical importance as the threat of vascular injury along the pelvic brim during the Modified Stoppa approach is significant [3,4,6,11].

The diameter of the anastomotic vessels which included either the accessory and or the second accessory obturator vessels averaged at 1.93 mm, with the average diameter of venous and arterial anastomotic vessels being 1.97 mm and 1.45 mm, respectively. Similar to the current study, Berberoğlu et al. also noted a smaller arterial diameter [12]. However, Stavropoulou-Deli and Anagnostopoulou reported a larger average diameter of 3 mm [7]. The broad range in diameter in the current study (0.32–4.47 mm) should be considered, with four cases exhibiting a diameter greater than 4 mm. Darmanis et al. also noted two cases with a diameter greater than 4 mm in their sample which could exacerbate injury to the vessel [3].

The Modified Stoppa approach can be applied for the treatment of certain fracture patterns that predict intra-pelvic injuries [31]. Lateral compression pelvic fractures result in increased vascular injury with a 7 % mortality rate due to damage involving the obturator artery [32]. These fractures commonly involve the pubic rami and exhibit a horizontal or coronal pattern [33]. Therefore, this particular type of fracture may be a causative factor for injury to the CM vessels.

A greater understanding of the clinical implications of the CM is essential. Clinical investigations using CT or angiogram imaging and cadaveric simulations of standardized parameters where clinical relevance can be successfully determined, will aid this endeavour. This is necessary due to the many discrepancies found when comparing cadaveric and patient studies as reported in a review article by Papagrigorakis et al. [34]. This was confirmed by a nominal prevalence of anastomoses and bleeding due to the CM severing in clinical studies [16,22,35]. These results contradict the findings of most cadaveric studies which report a higher incidence of CM cases and clinical threat. A comparative study between patient and cadaver studies reported an incidence of 37 % (n = 14/38) CM amongst patients, while a 73 % (n = 38/79) incidence was presented in the cadaver study, further validating the inconsistencies [11].

As seen in Table 5, a significantly higher incidence of venous anastomoses is observed in various cadaver studies [3,6,11,13,36] with a study by Berberoğlu et al. noting an especially high incidence of 100 % [12]. These findings are inconsistent with many CM investigations involving a patient sample, as confirmed by Jian et al. [37]. This study revealed a total of 46.2 % (n = 24/52) arterial constituents amongst the 61.5 % (n = 32/52) incidence of CM found in patients, which was significantly higher than the venous constituents. Karakurt et al.

Table 4
Average distance between the CM vessels and the pubic symphysis. (***Key: Avg.:*** *Average,* ***R:*** *Range,* ***CM:*** *Corona Mortis,* ***PS:*** *Pubic symphysis,* ***SPS:*** *Superior pubic symphysis,* ***PPS:*** *Posterior pubic symphysis.)*

Author	Avg. distance between arterial CM vessels and PS (mm)	Avg distance between venous CM and PS (mm)	Avg. distance between all CM and PS (mm)
Tornetta et al. (1996) [13]			62 (R: 30–90)
Berberoğlu et al. (2001) [12]		40.4 (R: 33.2–52.7)	
Hong et al. (2004) [20]			52
Okcu et al. (2004) [6]	64 (R: 45–90)	56 (R: 37–80) mm	
Pungapong and Thumumnauysak (2005) [21]			52.8
Darmanis et al. (2007) [3]	71 (R: 42–88)	65 (R: 39–82)	
Stavropoulou-Deli and Anagnostopoulou (2013) [7]	52.4	46.7	
Bargoria et al. (2015) [19]	53.2	54.3	
Han et al. (2017) [22]	59.6 (R: 43–82)	66.9 (R: 41–119)	
Leite et al. (2017) [23]			49.6
Güzel et al. (2018) [24]			35.9 (R: 21.6–48.7)
Kashyap et al. (2019) [25]	51	41 (R: 35–70)	
Konarska-Włosińska et al. (2024) [26]	62.2 (R: 50.5–70.7)		
Current study (2021)	**SPS: 69.9 (R: 63.2–76.6)** **PPS: 55.7 (R: 50.5–69)**	**SPS: 70.9 (R: 48–105.3)** **PPS: 57.4 (R: 33.9–89.2)**	**SPS: 70.4 (R: 48–105.3)** **PPS: 57.2 (R: 33.9–89.2)**

Table 5
Incidences of venous and arterial corona mortis in cadaver studies. *(**Key: CM:** Corona Mortis.)*

Author	% venous CM (n)	% arterial CM (n)
Teague et al. (1996) [11]	59 (47)	43 (34)
Tornetta et al. (1996) [13]	70 (29)	34 (13)
Berberoğlu et al. (2001) [12]	100 (14)	85.7 (12)
Okcu et al. (2004) [6]	52 (78)	19 (29)
Darmanis et al. (2007) [3]	60 (48)	36 (29)
Pillay et al. (2017) [36]	60.7 (34)	12.5 (7)
Naicker et al. (2024) [38]	94.6 (76)	8.4 (7)

reported a 28.5 % incidence of purely arterial anastomoses in their clinical study which mirrored the reports of Ates et al. [16,17]. During a clinical study of the ilioinguinal approach to the pelvis, Ates et al. reported a 28.4 % incidence (n = 113/398) of arterial CM cases [17]. However, venous cases were rarely identified, and in the few cases venous anastomoses were observed, the calibre of the vessel was too small which is highly contradictory to cadaveric studies.

Such discrepancies can be linked to varying demographic and ancestry groups within a sample as incidences between population groups may differ [39]. An older age group is more prominent in a cadaver sample than in a patient sample. Therefore, more cases of pathology and cardiovascular disease are expected in the cadaver samples [39]. The development of alternate circulation is significant in these cases and less so among trauma patients which is the preferred sample in clinical studies [39]. Trauma patients are also prone to haemorrhage and hematoma formation after arterial laceration, which decreases the detectability of anomalies after injury. Inconsistencies among both cadaveric and clinical studies are often due to the misinterpretation of the definition of CM as well as the exclusion criteria used in categorising CM cases [39]. This includes cases of anastomoses involving vessels of a small diameter where the clinical impact is interpreted as non-lethal, and therefore not considered a CM case [17,39].

In a clinical study conducted by Jensen et al. complications resulting from CM injury were evaluated during surgical treatment of acetabular fractures or pelvic ring instability using the anterior approach to the pelvis [9]. The incidence of CM resulted in 41.5 % (n = 54/130), with bleeding complications occurring in 6.2 % of patients with the anastomosis, while mortality occurred in only 9.2 % (n = 12/130) of the patients. Therefore, a lack of a statistically significant difference ($p = 0.06$) proved there was no association between the presence of the CM and cases of haemorrhage [9]. These results contradict the clinical implication of the CM previously presented in literature. The clinical component of a study by Darmanis et al. observed only five cases of CM among patients [3]. One of these anastomoses was unintentionally severed and complications were treated via a blood transfusion, while no other patient experienced significant blood loss [3]. Divisive conclusions like these, diminish the established clinical impact of the CM and the necessity for clinical studies surrounding this anomaly. However, many clinical cases prove otherwise with results depicting the detrimental effects of CM injury [40,41].

Key examples include case reports of trauma patients who exhibit evidence of CM injury resulting in haemodynamic instability [40,41]. In both cases, complications were successfully treated with embolization, although a lack of immediate treatment could have resulted in detrimental consequences [40,41]. The current study observed a large variety of vessels coursing over the posterior aspect of the superior pubic ramus (n = 167). Similarly, Teague et al. reported an incidence of 16 % (n = 6/38) of cases that presented with multiple vessels on the landmark in addition to the CM vessels [11]. These anomalous vessels are susceptible to injury and reinforce the dangers associated with CM severing as well as these accessory branches [3,6,8].

5. Conclusion

The threatening physiological complications of CM injury underscore the importance of the clinical study of the CM. Therefore, studies which address these adverse effects by providing preventative measures such as the formulation and validation of safe zones of the CM and CV are necessary to minimise patient mortality. Results from the current study show that the formulated safe zones are clinically accurate and precise making them a valuable guide for orthopaedic surgeons during anterior approaches to the pelvis. These safe zones are needed to prevent unintentional severing of the CM or aberrant CV which could lead to haemorrhage and probable mortality. The adverse effects on the well-being of patients and the success of the procedure further emphasize the importance of the accuracy and effectiveness of the safe zones.

6. Limitations

To simulate the Modified Stoppa approach as realistically as possible, the blood supply of the pelves was not previously observed, which made it difficult to detect any observations of the CM or aberrant vessel prior to the simulations. A small number of anastomotic vessels were too minute to dissect and therefore a diameter could not be measured. Anastomoses which occurred distal to the obturator canal could not be followed as this would disturb the intrapelvic blood supply and affect additional observations occurring in the area. Additionally, some vessels were compromised due to previous dissections performed in the same area. However, many of these limitations were mitigated due to the large sample size of the study.

CRediT authorship contribution statement

Jade Naicker: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Zithulele Nkosinathi Tshabalala:** Writing – review & editing, Supervision. **Andries Masenge:** Formal analysis. **Obakeng Modisane:** Writing – review & editing. **Steven Matshidza:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Nkhensani Mogale:** Writing – review & editing, Supervision, Methodology, Investigation.

Ethical statement

Approval was obtained from the Faculty of Health Sciences Research Ethics Committee, University of Pretoria (259/2020). Research was conducted in accordance with the National Health Act 61 of 2003.

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Declaration of competing interest

The 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.

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