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Anatomical variations of the lateral collateral ligament of the ankle: Implications of sex and laterality on morphology and morphometry

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ABSTRACT

Introduction: A detailed understanding of the anatomical dimensions of the lateral collateral ligament (LCL) is essential in the surgical treatment of ankle joint injuries and ligament rehabilitation. While previous studies have explored the general morphology and morphometry of the LCL, there remains a gap in understanding how these characteristics vary based on sex and laterality. This study aimed to investigate the morphological and morphometric variations of the LCL, focusing on differences between sexes and between right and left ankles.
Method: Thirty-one ankles from sixteen human cadavers were dissected to investigate the LCL of the ankle. The LCL consists of the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL). Each ligament of the LCL was classified into three types according to the number of bands, i.e., Type I– single band, Type II– double bands (IIa-partially separated & IIb-completely separated), and Type III– triple bands for morphological observation. The length, width, and thickness of these ligaments were measured using a calliper for morphometric analysis and compared among sex and laterality.
Result: Type I was the most observed in all three ligaments (ATFL-61.3 %; CFL-87.1 %; PTFL-96.8 %). Significant sex differences were observed, with males having more Type I, while females had more Type II and III ($p < 0.05$). PTFL was significantly longer (25.31 ± 3.87 mm) and wider (7.05 ± 2.07 mm) in females ($p < 0.05$). CFL was significantly longer on the right (37.09 ± 4.57 mm; $p < 0.05$).
Conclusion: Morphological and morphometric variations significantly exist in the ligaments that make up the LCL in relation to sex and laterality. These identified variations could improve diagnostic accuracy, enhance surgical planning, and inform sex-specific rehabilitation strategies.

1. Introduction

The ankle joint is a complex hinge synovial type formed by the articulation of three bones, viz. fibula, tibia, and talus [1]. The complexity of the ankle joint supports a wide range of movements, such as dorsiflexion, plantarflexion, inversion, and eversion of the foot [2]. The proper function and stability of the ankle joint are achieved by the extrinsic function of the collateral ligaments around the ankle region that resist abnormal movements and prevent joint injuries [2]. The collateral ligaments are divided into two groups based on their location on the human lower limb: the lateral and medial (deltoid) ligaments. The ligaments ensure stability and normal function of the ankle joint [3, 4].

The ongoing study of the ligaments of the ankle can be traced back to the early investigations of the human body [5]. These explorations were conducted to understand the anatomy and function of the ankle for the treatment of injuries in athletes and military personnel [6]. A detailed description of the collateral ligaments of the ankle has been published from the last decades of the 19th century onwards. The use of biomechanical analyses, imaging techniques, and cadaveric studies throughout the 20th century further advances the understanding of the collateral ligaments of the ankle [7].

The lateral collateral ligament (LCL) consists of the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL) [2]. The ATFL is the shortest of the LCL, visualized as a single band originating from the anterolateral process of

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the talus attaching to the antero-inferior border proximally to the lateral malleolus [8]. The calcaneofibular ligament, located on the inferior tip of the lateral malleolus, originates on the inferior margin of the lateral malleolus and courses inferiorly to attach to the lateral tubercle of the calcaneus [1]. The PTFL ligament is the third ligament of the LCL. The PTFL is orientated horizontally and courses from the medial margin of the malleolar fossa to the posterior process of the talus [8]. The literature documented shows that there are morphological and morphometric variations of these ligaments in terms of sex and laterality [9,10].

A study by Inchai et al. [9] and Schoonover and Wright [10] conducted on cadavers and lower limb specimens reported morphological variations of the LCL. The LCLs were presented with varying numbers of bands, which can be classified into three groups/types: Type I, Type II, and Type III. Type I: LCL presented as a single band, while Type II: LCL presented as double bands. Furthermore, Schoonover and Wright [10] observed and reported Type II-a and Type II-b as subtypes of Type II. Type II-a: LCL presented as partially separated double bands, and Type II-b: LCL presented as completely separated double bands. Lastly, Type III: LCL presented as triple bands [10].

Various studies conducted to investigate the LCL reported measurements of the length, width, and thickness of the ligaments and compared the results between sexes and laterality [9–14]. These morphological and morphometric variations could result in sex-specific variations in how the ankle functions and the susceptibility of the ankle to injuries [9]. Recognizing these differences is crucial for creating prevention and treatment procedures for ankle sprains that are specific to each sex [4]. Furthermore, accurate diagnosis and therapy around the ankle joint can be optimized by comprehending the detailed anatomy and morphology of the ankle ligaments, as they are essential for the proper functioning and health of the ankle joint complex [15,16].

The existing literature on lateral ankle ligaments has primarily concentrated on the anatomy of the LCL for clinical diagnosis and management of the ligaments [4,17,18]. Recent literature stated that there is a lack of research that shows the relationship between the structure of ankle ligaments and their role in movement and joint stability [19,20]. This is due to limited knowledge of the size, thickness, fiber direction, and other key parameters of the ligaments of the ankle [20]. Furthermore, there is a lack of studies examining how these morphological and morphometric variations differ with respect to sex and laterality despite evidence suggesting that these factors may influence ligament function and susceptibility to injuries. Recognizing these differences is crucial for improving the understanding of ankle joint biomechanics, as sex-specific variations may impact ligament strength and flexibility, while laterality differences may be associated with mechanical loading and limb dominance. Exploring these parameters will contribute to providing a better understanding of how ankle ligament morphology and structure influence joint stability and the ability to withstand stress or trauma, thus improving injury treatment and prevention strategies related to ankle ligaments [19,14,21]. Hence, this study aimed to explore the anatomical variations of the LCL of the ankle joint in terms of morphology and morphometry, investigating the number of bands (types), connections between these bands, length, width, and thickness of the LCL. In addition, the study also considered sex and laterality.

2. Materials and methods

Study Sample. Thirty-one (31) ankle joints, both right and left, from sixteen (16) human cadavers preserved in formalin from the Department of Clinical Anatomy, University of KwaZulu-Natal (Medical School campus), were used to conduct this study. The average age of the study sample was 79.44 years (range: 52–99 years) and comprised of nine (9) males and seven (7) female human cadavers. This study was approved by the Biomedical Research Ethics Committee (BREC) of the University of KwaZulu-Natal with reference number BREC/00005996/2023.

Inclusion and exclusion criteria. Embalmed, freshly preserved human cadavers without any history of injury, fracture, surgical repair, surgical implants, or signs of decomposition to the ankle joint were selectively included in this study.

Dissection. Each ankle joint was dissected following the procedure from Grant's dissector 16th edition [22]. However, additional steps were incorporated to enhance the procedure. In the ankle region, skin with fascia, vessels, nerves, and tendons crossing anteriorly to the ankle joint were cut using a scalpel and reflected away from the ankle using forceps. The superior and inferior fibular retinaculum were removed to retract the tendons of the fibularis longus and fibularis brevis. The tendons were cut slightly distally to their attachment and reflected; the CFL appears inferolateral to the lateral malleolus where these tendons coursed. After cleaning up the fascia between the anterior border of the distal fibular and the superolateral surface of the talus, the ATFL was visualized. The calcaneal tendon posterior to the ankle joint was cut and reflected. After cleaning the underlying fascia, the PTFL was visible. This made up the three ligaments of the LCL, which are termed in relation to their skeletal attachments. After dissection, the morphological and morphometrical analyses were carried out.

Morphological and morphometric analysis. Upon visualization of the LCLs, the morphologies of ATFL, CFL, and PTFL were analysed in types and subtypes according to the classification by Inchai et al. [9] and Schoonover and Wright [10] by observing the number of bands, i.e., Type I- single band, Type II- double bands (IIa-partially separated bands & IIb-completely separated bands), Type III- triple bands. A measuring string and an electronic digital vernier caliper with measuring range and accuracy of 0–6 inches/0–150 mm and ±0.001 inches/±0.002 mm, respectively (Wilson Wolpert 110-15DAB, Netherlands) was used to measure the length, width, and thickness of LCL. All morphometrical parameters were taken utilising the following steps according to Apoorva et al. [12], Inchai et al. [9], and Schoonover and Wright [10].

- The length of the ligaments was measured from their origins to their insertions.
- The ATFL and CFL were examined with respect to their origin at the antero-inferior margin of the lateral malleolus to their insertions at the anterolateral surface of the talus bone and the lateral tubercle of the calcaneus bone, respectively.
- The length of the PTFL was measured from the inferior tip of the medial surface of the lateral malleolus to the posterior process of the talus bone.
- The electronic digital vernier caliper was used to measure the width and thickness of the LCL at the midpoint of the ligaments.

Intra and inter-observer error. All measurements (i.e., length, width, and thickness of the LCL) were taken three times and analysed to determine the intra-observe error. A second observer independently repeated these measurements on ten randomly selected cadavers from the same sample in order to determine the inter-observer error.

Statistical Analysis. Stata v17 was used in the statistical analysis. Morphological observations were presented in frequency tables and percentages. The numeric measurements of the morphometric analysis were assumed to be normally distributed; hence, measurement data were summarized in mean and standard deviation. Statistical comparison was done according to sex and laterality using two-sample t-tests and Fisher's exact tests. The significance level was set at 5 %.

3. Results

3.1. Morphology

Anterior talofibular ligament (ATFL). All types and subtypes of ATFL, i.e., Type I (Fig. 1), Type II-a (Fig. 2), Type II-b (Fig. 3), and Type II (Fig. 4), were observed on both sides. Overall, Type I was observed to have the highest frequency (Table 1). Type I was observed more in males, while Type II-a, Type II-b, and Type II were observed more in

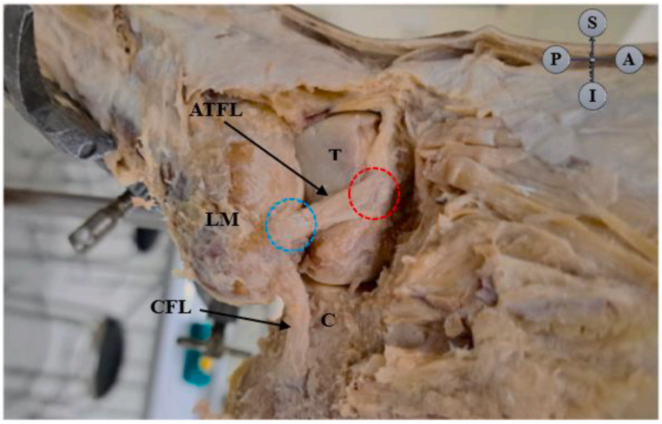

Fig. 1. Showing the origin and insertion of the ATFL (observed as Type I)
Key: ATFL – anterior talofibular ligament, CFL – calcaneofibular ligament, LM – lateral malleolus, T – talus, C – calcaneus, blue dotted circle – origin on the antero-inferior margin of the lateral surface of the lateral malleolus, red dotted circle – insertion on the anterolateral surface of talus.

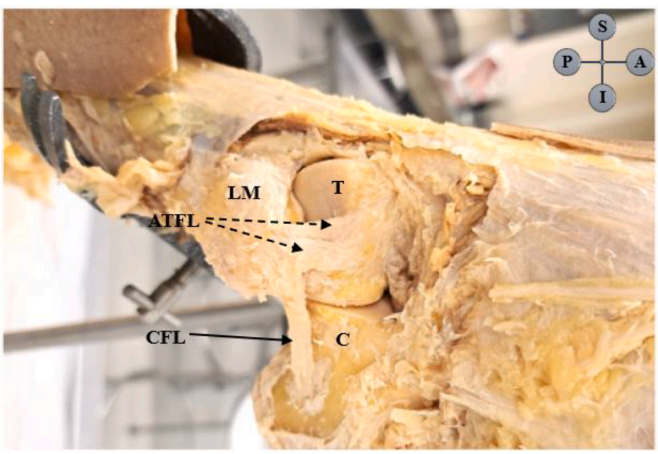

Fig. 2. The ATFL observed as Type II-a
Key: ATFL – anterior talofibular ligament, dotted black lines – showing two partially separated bands of the ATFL, CFL – calcaneofibular ligament, LM – lateral malleolus, T – talus, C – calcaneus.

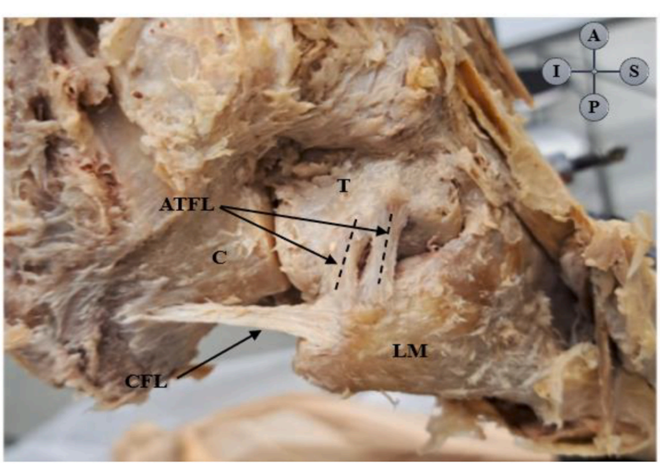

Fig. 3. ATFL observed as Type II-b
Key: ATFL – anterior talofibular ligament, dotted black lines – showing two completely separated bands of the ATFL, CFL – calcaneofibular ligament, LM – lateral malleolus, T – talus, C – calcaneus.

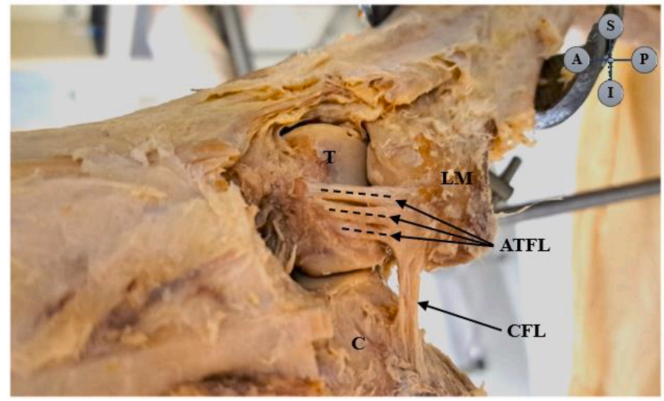

Fig. 4. showing ATFL observed as Type III
Key: ATFL – anterior talofibular ligament, dotted black lines – showing three separated bands of the ATFL, CFL – calcaneofibular ligament, LM – lateral malleolus, T – talus, C – calcaneus.

Table 1
Morphological observation of types and subtypes of ATFL, CFL, and PTFL according to laterality (n = 31).

LCL	Type	Left *f*	Right *f*	Total *f (%)*	p-value
ATFL	Type I	9	10	19 (61.3)	0.48
	Type II-a	2	2	4 (12.9)	
	Type II-b	2	2	4 (12.9)	
	Type III	3	1	4 (12.9)	
CFL	Type I	14	13	27 (87.1)	0.17
	Type II-a	1	1	2 (6.5)	
	Type II-b	1	0	1 (3.2)	
	Type III	0	1	1 (3.2)	
PTFL	Type I	15	15	30 (96.8)	0.24
	Type II-a	0	1	1 (3.2)	
	Type II-b	0	0	0 (0)	
	Type III	0	0	0 (0)	

females, with an overall significant difference of $p < 0.05$ (Table 2).

Calcaneofibular ligament (CFL). In all the cadavers dissected, the CFL was found to attach proximally on the inferior margin of the lateral surface of the lateral malleolus distally on the lateral tubercle of the calcaneus (Fig. 5). Type I was observed to have the highest frequency. Type I and Type II-a were found on both sides. However, Type II-b and Type III were only observed on the left and right sides, respectively (Table 1). Type I and Type II-b were observed more in males, while Type III was observed only in females, with an overall significant difference of $p < 0.05$ (Table 2).

Posterior talofibular ligament (PTFL). The PTFL was observed as the only ligament among the LCLs that attaches to the medial surface of

Table 2
Morphological observation of types and subtypes of ATFL, CFL, and PTFL according to sex (n = 31).

LCL	Type	Male(s)	Female(s)	p-value
ATFL	Type I	8	4	0.02[a]
	Type II-a	1	3	
	Type II-b	1	2	
	Type III	1	2	
CFL	Type I	9	6	0.02[a]
	Type II-a	1	1	
	Type II-b	1	0	
	Type III	0	1	
PTFL	Type I	9	6	0.02[a]
	Type II-a	0	1	
	Type II-b	0	0	
	Type III	0	0	

[a] Significant difference with $p < 0.05$.

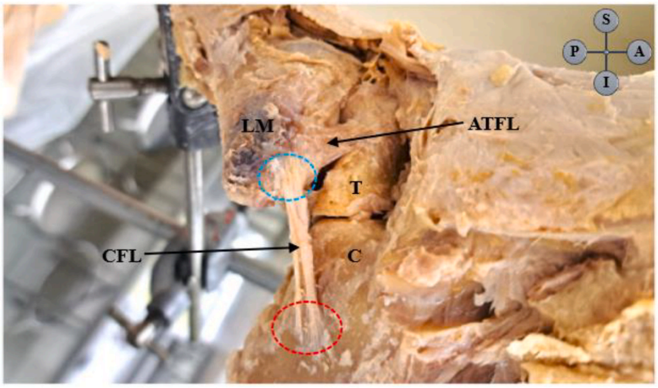

Fig. 5. Showing the origin and insertion of CFL (observed as Type II-a)
Key: ATFL – anterior talofibular ligament, CFL – calcaneofibular ligament, LM – lateral malleolus, T – talus, C – calcaneus, blue dotted circle – origin on the inferior margin of the lateral surface of the lateral malleolus, red dotted circle – insertion on the lateral tubercle of the calcaneus.

the lateral malleolus (Fig. 6). Type I and II were the only types present for the PTFL; however, for Type II, only Type II-a was observed (Table 1). Type I was evenly distributed on both sides, while Type II-a was only observed on the right. For sex, Type I was observed more in males, while Type II-a was only in females, with an overall significant difference of $p < 0.05$ (Table 2).

Connection between ATFL and CFL. Twelve cadavers showed connections between ATFL and CFL. In cases where the ATFL presented as a single band (Type I), the connection with the CFL was observed in ten ankle joints (6 left and 4 right) (Fig. 7). In Type II ATFL, where the ligament is observed as a double band, the connection was between the second or inferior band and the CFL in eight ankle joints (4 left; 4 right) (Fig. 8). Two limbs (1 left and 1 right) showed the connection between Type III ATFL and CFL (Fig. 9).

3.2. Morphometry

All morphometric measurements were presented in mean and standard deviation. The intraclass correlation coefficient (ICC) values for morphometric measurements yielded 0.92 for ATFL length, 0.91 for AFTL width, 0.85 for ATFL thickness, 0.90 for CFL length, 0.87 for CFL width, 0.89 for CFL thickness, 0.96 for PTFL length, 0.99 for PTFL width, and 0.94 PTFL thickness, indicating excellent reliability and repeatability.

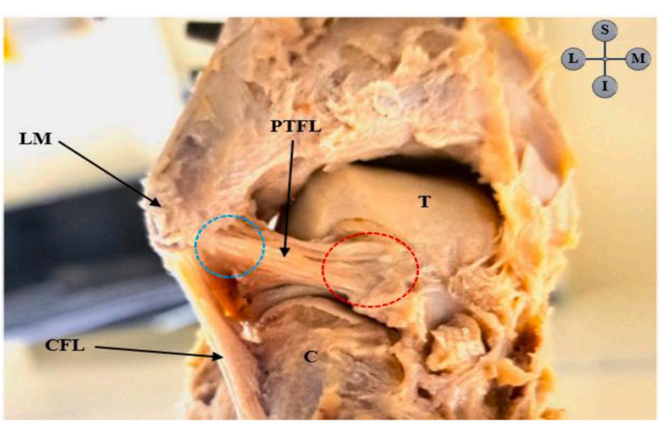

Fig. 6. The origin and insertion of the PTFL
Key: CFL – calcaneofibular ligament, LM – lateral malleolus, T – talus, C – calcaneus, PTFL – posterior talofibular ligament, blue dotted circle – origin of the posterior talofibular ligament at the medial margin of the malleolus at the malleolar fossa, red dotted circle – insertion of the posterior talofibular ligament at the posterior process of the talus.

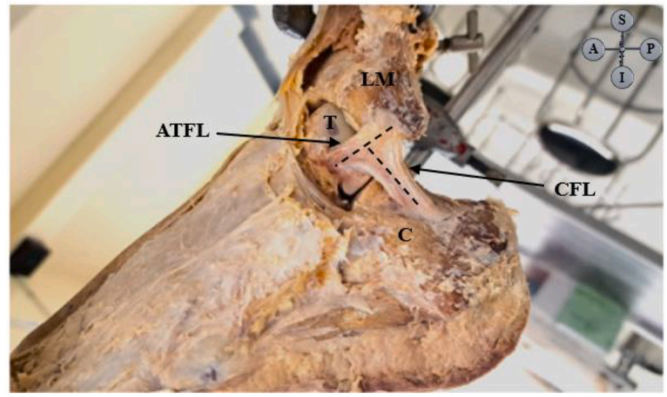

Fig. 7. Showing the connection between the ATFL and CFL (observed in Type I ATFL)
Key: ATFL – anterior talofibular ligament, dotted black lines – showing the connection between the anterior talofibular ligament and the calcaneofibular ligament, CFL – calcaneofibular ligament, LM – lateral malleolus, T – talus, C – calcaneus.

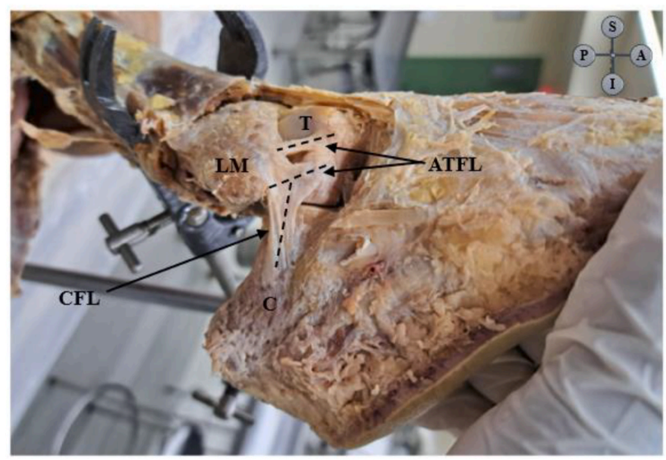

Fig. 8. Showing the connection between the ATFL and CFL (observed in Type II ATFL)
Key: ATFL – anterior talofibular ligament, dotted black lines – showing the connection between the inferior band of the anterior talofibular ligament and the calcaneofibular ligament, CFL – calcaneofibular ligament, LM – lateral malleolus, T – talus, C – calcaneus.

Anterior talofibular ligament (ATFL). The length, width, and thickness of ATFL were presented in Tables 3 and 4. The mean length, width, and thickness of the ATFL were more on the left (19.29 ± 4.22 mm, 7.11 ± 2.3 mm, & 1.56 ± 0.75 mm, respectively) than on the right, with no statistical significance in these differences (p-values = 0.17, 0.86, & 0.35). For sex, ATFL was longer and thicker in males, with mean length and thickness of 18.39 ± 4.07 mm and 1.68 ± 0.68 mm, respectively, but wider in females, with a mean width of 7.61 ± 3.25 mm. However, these sex differences were not statistically significant, with p-values of 0.77, 0.12, and 0.11.

Calcaneofibular ligament (CFL). In Table 3, the mean length of CFL was significantly longer on the right (37.09 ± 4.57 mm) than on the left (33.55 ± 3.74 mm), with $p < 0.05$. However, no significant differences were observed in the mean width and thickness of CFL regarding laterality ($p = 0.44$ & 0.25). For sex, CFL was longer and thicker in males than females but wider in females than males, with no significant differences ($p = 0.74$; 0.57; 0.05) (Table 4).

Posterior talofibular ligament (PTFL). The mean length, width,

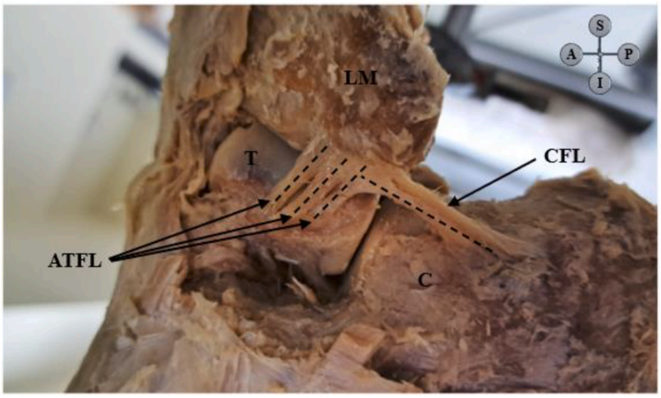

Fig. 9. Showing the connection between the ATFL and CFL (observed in Type III ATFL)
Key: ATFL – anterior talofibular ligament, dotted black lines – showing the connection between the inferior band of the anterior talofibular ligament and the calcaneofibular ligament, red marked area – point of connection, CFL – calcaneofibular ligament, LM – lateral malleolus, T – talus, C – calcaneus.

and thickness of the ATFL were more on the right (24.71 ± 3.77 mm, 6.29 ± 0.68 mm, & 3.24 ± 0.87 mm, respectively) than on the right, with no statistical significance in these differences (p-values = 0.17, 0.79, & 0.37) as shown in Table 3. For sex, the PTFL was significantly longer and wider in females ($p < 0.05$), having mean length and width of 25.31 ± 3.87 mm and 7.05 ± 2.07 mm. respectively. However, there was no significant difference in the thickness of PTFL between males and females (Table 4).

4. Discussion

As the LCLs play a crucial role in ankle joint motion and stability, as well as surgical planning, observing the morphological variations and understanding the anatomy of the LCL would aid in solving clinical problems related to the LCL [14,25]. The present study investigated the anatomical variations of the LCL of the thirty-one (31) ankle joints from a local Anatomy Department, with results showing implications of sex and laterality on morphology and morphometry of LCL of the ankles of a local population.

Table 3
Mean values of the length, width, and thickness of the ATFL, CFL, and PTFL according to laterality.

	Left mean	sd	Min	max	Right mean	sd	min	max	p-value	Average mean	sd
Length (mm)											
ATFL	19.29	4.22	12.87	25.69	17.11	4.42	10.06	28.97	0.17	18.2	4.21
CFL	33.55	3.74	28.37	39.73	37.09	4.57	28.44	47.69	0.03[a]	35.32	4.11
PTFL	22.57	4.7	11.19	31.98	24.71	3.77	14.52	30.91	0.17	23.64	4.02
Width (mm)											
ATFL	7.11	2.3	2.97	19.14	6.65	2.01	2.79	11.56	0.85	6.88	2.16
CFL	6.65	2.45	2.66	11.96	7.03	1.65	2.61	11.34	0.44	6.84	2.15
PTFL	6.48	2.58	3.02	10.94	6.29	0.68	0.81	11.99	0.79	6.59	1.6
Thickness (mm)											
ATFL	1.56	0.75	0.98	4.68	1.55	0.51	0.52	4.81	0.35	1.56	0.61
CFL	1.88	0.57	0.46	5.43	1.92	0.76	0.44	6.66	0.25	1.91	0.67
PTFL	3.24	0.87	0.3	5	3.68	0.69	0.51	5.96	0.37	3.46	0.72

[a] Significant difference with $p < 0.05$. sd−standard deviation.

Table 4
Mean values of the length, width, and thickness of the ATFL, CFL, and PTFL according to sex.

	Male mean	sd	min	max	Female mean	sd	min	max	p-value
Length (mm)									
ATFL	18.39	4.07	10.06	25.02	17.93	4.84	12.87	28.97	0.77
CFL	35.65	4.77	28.44	47.69	35.09	4.33	28.37	40.98	0.74
PTFL	22.14	4.24	11.19	27.78	25.31	3.87	17.56	31.98	0.04[a]
Width (mm)									
ATFL	6.23	1.89	2.97	11.05	7.61	3.25	2.79	19.14	0.11
CFL	6.14	1.45	2.67	10.38	7.71	2.41	2.61	11.96	0.05
PTFL	5.95	1.13	0.81	10.94	7.05	2.07	3.74	11.99	0.04[a]
Thickness (mm)									
ATFL	1.68	0.68	0.52	4.81	1.39	0.55	0.98	4.64	0.12
CFL	1.98	0.74	0.44	4.62	1.73	0.56	0.46	6.66	0.57
PTFL	3.7	1.4	0.79	5.96	3.17	0.75	0.3	5.69	0.15

[a] Significant difference with $p < 0.05$. sd−standard deviation.

4.1. Morphology

In previous studies, the LCLs were recognized as three separate ligaments on the lateral side of the ankle joint, namely the ATFL, CFL and PTFL, and their variations were observed with respect to the number of bands by classifying them into three types, namely, Type I, Type II and Type II [4,9,10,26,27]. Similarly, these three ligaments and their types were observed in this study. Schoonover and Wright [10] further classified Type II into subtypes: Type II-a (partially separated double bands) and Type II-b (completely separated double bands) for the ATFL. However, these subtypes were adapted into this study not only for the ATFL but also for CFL and PTFL in order to investigate possible anatomical variations.

General anatomy identifies Type I ATFL as a single-band ligament [2]; however, Type II ATFL has been reported as the most common type in existing literature [9,10,26,27] (Tables 5 and 6). This differs from the present study, where Type I was observed as the most common with high significant incident rates. This difference may be due to the population group used for this study. However, this corresponds with the findings of Taser et al. [11,23]. Type II and Type III ATFL were also observed in this study but at low incidence rates. For all types of ATFL observed, no significant difference was observed in the case of laterality. However, sex differences were significantly observed ($p < 0.05$), with males having Type I ATFL and females having Type II (a & b) and III ATFL. In the studies of Kobayashi et al. [26] and Schoonover and Wright [10], Type II ATFL was observed more in females than males. Also, during inversion of the foot, Type I ATFL is stronger than Type II ATFL [14]; hence, males are likely to have more inversion than females, an indication of functional variability of the ATFL [4,28].

In addition, the ATFL has been reported to be more clinically significant among the LCLs as the ligament is susceptible to injuries, especially during inversion of the foot [9,11,29]. This explains the lack of studies investigating the CFL and PTFL [18]. Although higher deforming forces with consistency could propagate to the CFL and even damage the PTFL, there is not much report on the CFL and PTFL (Vega et al., 2020). The present study made provision for this lack and observed the CFL and PTFL to be mostly of single-band ligament (i.e., Type I) rather than other types. Type I, mostly observed in CFL, corresponds to the study of Szaro et al. [27]. On the contrary, Type I mostly observed in PTFL differs from the findings of Inchai et al. [9], who reported the PTFL as two bands (Type II) in all 54 dissected cadaveric ankles. Other types of CFL were observed in the present study, with Type II-a, Type II-b, and Type III having a single incident. However, only Type II-a was the other type of PTFL observed as a single incident on the right. These possible variations can be due to the onset of embryological development of the LCL, as fibers may change direction during their development (Ruzik et al., 2023). Concerning sex, ATFL Type I and Type II-b were observed more in males, while ATFL Type III was observed only in females, with an overall significant difference of p-value less than 0.05. For PTFL, Type I was observed more in males, while Type II-a was only in females, with an overall significant difference of p-value less than 0.05. No significant difference was observed in relation to laterality for both CFL and PTFL.

Furthermore, various studies have reported connections between ATFL and CFL [12,14,27]. This study also observed these connections occurring between all types of ATFL and CFL. These connections highlight a mutual relationship between the ATFL and CFL of LCLs, subjecting CFL to be prone to injury as ATFL has been reported to be the most injured ligament of the LCLs [27].

4.2. Morphometry

A clear understanding of the morphometric analysis of the LCL can be useful when estimating the degradation of ligaments during surgical practice, which will aid in the selection of accurate reconstruction procedures ([4]; Yildiz et al., 2013).

4.2.1. Thickness

Reporting the thickness of the ligaments that make up the LCL, the present study measured the thickness of ATFL, CFL, and PTFL at the midpoint, according to Schoonover and Wright [10] and Stella et al. [20]. The ATFL, CFL, and PTFL were thicker in males, while PTFL and

Table 5
Comparisons of the morphology of LCL among previous studies.

Authors	Population	Sample size	LCL	Incidence of Types (n)			
				Type I	Type II		Type III
					Type II-a	Type II-b	
[23]		42	ATFL	41	1	–	–
			CFL	–	–	–	–
			PTFL	–	–	–	–
[11]	European	20	ATFL	14	5	–	–
			CFL	–	–	–	–
			PTFL	–	–	–	–
[24]		47	ATFL	–	–	–	–
			CFL	21	–	–	–
			PTFL	–	–	–	–
Kobayashi et al., 2020	Japanese	152	ATFL	66	83	–	3
			CFL	–	–	–	–
			PTFL	–	–	–	–
Szaro et al., 2021		251	ATFL	58	193	–	–
			CFL	175	76	–	–
			PTFL	–	–	–	–
Inchai et al., 2023		54	ATFL	23	31	–	–
			CFL	54	–	–	–
			PTFL	–	54	–	–
Ruzik et al., 2023		60	ATFL	–	–	–	–
			CFL	32	–	–	–
			PTFL	–	–	–	–
[10]		40	ATFL	9	13	12	3
			CFL	–	–	–	–
			PTFL	–	–	–	–
Present study	**South African White**	**31**	**ATFL**	**19**	**4**	**4**	**4**
			CFL	**27**	**2**	**1**	**1**
			PTFL	**30**	**1**	**-**	**-**

Table 6
Comparison of the morphology of the LCL with respect to sex.

Authors	Population	Sample size	LCL	Sex (n)									
				Male					Female				
				Type I	Type II	Type II-a	Type II-b	Type III	Type I	Type II	Type II-a	Type II-b	Type III
Schoonover and Wright [10]		20	ATFL	3	–	6	5	–	6	–	7	7	3
			CFL	–	–	–	–	–	–	–	–	–	–
			PTFL	–	–	–	–	–	–	–	–	–	–
[26]	Japanese	152	ATFL	33	40	–	–	1	33	43	–	–	2
			CFL	–	–	–	–	–	–	–	–	–	–
			PTFL	–	–	–	–	–	–	–	–	–	–
Present study	**South African White**	**31**	**ATFL**	**8**	**-**	**1**	**1**	**-**	**4**	**-**	**3**	**2**	**2**
			CFL	**9**	**-**	**1**	**0**	**0**	**9**	**-**	**1**	**0**	**0**
			PTFL	**9**	**-**	**-**	**0**	**0**	**6**	**-**	**1**	**0**	**0**

CFL were thicker on the right and ATFL thicker on the left. These differences observed in sex and laterality were not statistically significant (Table 3).

4.2.2. *Length*

Anterior Talofibular Ligament (ATFL) – The ATFL, the shortest ligament among the LCL, had an average length comparable to previous studies [9–11,27,23] (Table 7), which reported a range of ~12–25 mm [30]. The left ATFL was longer than the right, though the difference was not statistically significant ($p = 0.17$) (Table 3). Males had a slightly longer ATFL than females, but this was not statistically significant (Table 8). Previous studies have not directly compared sex and laterality differences in ATFL length [9,11], making the present study a valuable contribution.

Calcaneofibular Ligament (CFL) – The CFL, the longest ligament among the LCL [12], showed significant laterality differences, with the right CFL being longer than the left ($p < 0.05$). This observation is consistent with Apoorva et al. [12] and may be attributed to mechanical loading and limb dominance, as many individuals are right-footed [9]. Previous studies [11] reported a shorter CFL length, likely due to embalming techniques affecting ligament dimensions. Although males had a slightly longer CFL than females, this difference was not statistically significant ($p = 0.74$).

Posterior Talofibular Ligament (PTFL) – The PTFL, one of the least investigated ligaments of the LCL [18], exhibited significant sex differences, with females having a longer PTFL than males ($p < 0.05$). However, no significant laterality differences were observed ($p = 0.17$). The findings correspond with those of Taser et al. [23] but differ from Inchai et al. [9], who reported greater PTFL lengths, possibly due to methodological differences, such as detachment of ligaments from their bony attachments and imaging-based assessments. The observed sex differences may be influenced by hormonal factors, such as oestrogen receptors affecting ligament structure in females [31].

4.2.3. *Width*

Anterior Talofibular Ligament (ATFL) – The ATFL width measured in this study corresponds to previous reports [9,11,27,23] (Table 7). Females had a greater average width than males (7.61 ± 3.25 mm vs. 6.23 ± 1.89 mm), differing from Schoonover and Wright [10] (Table 8), who observed a wider ATFL in males. The left ATFL was wider than the right, but this difference was not statistically significant ($p = 0.85$).

Calcaneofibular Ligament (CFL) – The width of the CFL was consistent with previous studies (Table 7). The right CFL was observed to be wider than the left, a trend also reported by Apoorva et al. [12]. Females had a greater average width than males, with a near-significant difference of $p = 0.05$. However, this may be due to the small sample size of the present study, as a possible statistical significance may occur in a larger sample size in regards to the female having a greater width than males.

Posterior Talofibular Ligament (PTFL) – The PTFL width recorded in this study corresponds to the findings of Taser et al. [23] but was lower than values reported by Inchai et al. [9], likely due to methodological variations. Significant sex differences were observed, with females having a wider PTFL than males ($p < 0.05$). However, laterality

Table 7
Comparison of the morphometric parameters of the LCL.

Authors	Population	Sample size	LCL	Length (mm)	width (mm)	Thickness (mm)
[9]		54	ATFL	19.54 ± 2.96	8.04 ± 1.66	1.06 ± 0.32
			CFL	34.67 ± 7.27	5.08 ± 1.10	1.11 ± 0.37
			PTFL	27.23 ± 3.35	8.00 ± 1.27	1.84 ± 0.51
[10]		40	ATFL	21.14 ± 2.52	8.20 ± 2.17	
			CFL	–	–	–
			PTFL	–	–	–
[23]		42	ATFL	22.37 ± 2.50	6.75 ± 2.89	–
			CFL	31.94 ± 3.68	4.68 ± 1.34	–
			PTFL	21.66 ± 4.84	5.55 ± 1.25	–
[11]	European	20	ATFL	15.5 ± 7.7	10 ± 7	–
			CFL	18.5 ± 6.3	7.5 ± 3.5	–
			PTFL	–	–	–
Stella et al., 2021		15	ATFL	–	–	–
			CFL	–	–	–
			PTFL	–	–	3.3 ± 0.2
Apoorva et al., *2014*		60	ATFL			
			CFL	27 ± 3.89	5.5 ± 1.12	1.65 ± 0.43
			PTFL	–	–	–
[27]		251	ATFL	24.5 ± 3.3	5 ± 0.7	2.2 ± 0.3
			CFL	33.7 ± 4.1	6.6 ± 1.4	2.1 ± 0.2
			PTFL	–	–	–

Table 8
Comparisons of the morphometric parameters of LCL with respect to sex and laterality.

Authors	Population	Sample size	LCL	Morphometric Parameters (mm) ± SD for Laterality					
				Left			Right		
				Length	Width	Thickness	Length	Width	Thickness
Apoorva et al., *2014*		60	ATFL	–	–	–	–	–	–
			CFL	26.72 ± 3.52	5.33 ± 0.26	1.68 ± 0.07	27.22 ± 4.25	5.55 ± 0.17	1.62 ± 0.09
			PTFL	–	–	–	–	–	–
Present study	**South African White**	**31**	**ATFL**	**19.29 ± 4.22**	**7.11 ± 2.3**	**1.56 ± 0.75**	**17.11 ± 4.42**	**6.65 ± 2.01**	**1.55 ± 0.51**
			CFL	**33.55 ± 3.74**	**6.65 ± 2.45**	**1.88 ± 0.57**	**37.09 ± 4.57**	**7.03 ± 1.65**	**1.92 ± 0.76**
			PTFL	**22.57 ± 4.7**	**6.48 ± 2.58**	**3.24 ± 0.87**	**24.71 ± 3.77**	**6.29 ± 0.68**	**3.68 ± 0.69**

Authors	Population	Sample size	LCL	Morphometric Parameters (mm) ± SD for Sex					
				male			Female		
				Length	Width	Thickness	Length	Width	Thickness
[10]		40	ATFL	20.56 ± 2.62	9.93 ± 1.41	–	18.67 ± 3.39	9.15 ± 2.40	–
			CFL	–	–	–	–	–	–
			PTFL	–	–	–	–	–	–
Present study	**South African White**	**31**	**ATFL**	**18.39 ± 4.07**	**6.23 ± 1.89**	**1.68 ± 0.68**	**17.93 ± 4.84**	**7.61 ± 3.25**	**1.39 ± 0.55**
			CFL	**35.65 ± 4.77**	**6.14 ± 1.45**	**1.98 ± 0.74**	**35.09 ± 4.33**	**7.71 ± 2.41**	**1.73 ± 0.56**
			PTFL	**22.14 ± 4.24**	**5.95 ± 1.13**	**3.7 ± 1.4**	**25.31 ± 3.87**	**7.05 ± 2.07**	**3.17 ± 0.75**

differences were minimal, as the right and left PTFL had closely related widths (6.29 ± 0.68 mm and 6.48 ± 2.58 mm, respectively).

5. Conclusion

This study analysed the morphological and morphometric variation of the three ligaments (ATFL, CFL, and PTFL) that make up the LCL. Overall, Type I was the most observed type, while Type III was the least observed type for all ligaments of the LCL. Significant variation was observed for sex only. The lengths, widths, and thicknesses of the ligaments of LCL were observed to vary according to sex and laterality. However, significant variations were limited to the length of CFL in terms of laterality (right side longer than left) and the length and width of PTFL in terms of sex (females longer and wider than males). A more detailed understanding of the morphological and morphometric variations of the ligaments of the LCL with respect to sex and laterality can aid in the early detection of underlying conditions responsible for ankle joint trauma. The observed sex differences suggest that variations in ligament dimensions may influence joint stability and predisposition to injuries, while laterality differences, such as the significantly longer CFL on the right, may be associated with mechanical loading and limb dominance. These findings provide a basis for future research to develop sex-specific and laterality-informed strategies for ligament reconstruction, rehabilitation, and clinical management.

5.1. Limitations of the study

A small sample size of thirty-one (31) ankle joints as a result of the limited number of cadaver specimens available in the local Anatomy Department where this study was carried out, resulting in a small number in some comparisons.

CRediT authorship contribution statement

Ndumiso Siphelele Hlengwa: Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Okikioluwa Stephen Aladeyelu:** Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization. **Seke Nzau Mafuika:** Writing – review & editing, Methodology, Conceptualization. **Livashin Naidu:** Writing – review & editing, Methodology, Conceptualization. **Carmen Olivia Rennie:** Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization.

Ethical statement

The study was carried out in accordance with the University of KwaZulu-Natal standard-approved guidelines and regulations (Reference number: BREC/00005996/2023), as well as all experimental protocols in accordance with the declaration of Helsinki.

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Declaration of competing interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

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