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Original Research Article

Anatomical Variations of the Thoracic Duct and Its Termination: A Comparative Cadaveric Study in Adult and Fetal Specimens Using Sequential Latex Perfusion

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Abstract

Background: The thoracic duct is the principal collecting vessel of the lymphatic system. Injury during oesophageal, thoracic, cervical or spinal surgery is a recognised cause of chylothorax and chylous fistula. Although classical descriptions portray a single continuous conduit terminating at the left venous angle, the frequency and topography of morphological variants—and whether these are congenital or acquired—remain incompletely defined.

Methods: Twenty-four human cadavers (12 adults aged 50–80 years; 12 fetuses at 35–40 weeks' gestation) were studied. Specimens were sequentially perfused with pigmented acrylic latex—first through the internal marginal vein, then through the thoracic duct via the interazygous–aortic recess, and finally through the posterior tibial artery—with intermediate hardening of latex at the left venous angle to prevent mixing of media. Specimens were fixed in 5% formalin, cleared in hydrogen peroxide, dissected and photographed. Frequencies of plexiform segments, cisterna chyli, duplication and terminal pattern were recorded. Proportions are reported with 95% Wilson score confidence intervals.

Results: Plexiform (plexus-shaped) segments and derivative pathways of the thoracic duct were present in 80% of adult specimens (approximately 9–10/12; 95% CI 46.8–95.3% across bracketing counts) and in none of the fetal specimens (0/12; 95% CI 0–24.3%). A cisterna chyli, presenting as an ampullary dilatation at the origin of the duct, was present in 100% of fetuses (12/12; 95% CI 75.7–100%) but in only one adult (1/12, 8.3%; 95% CI 1.5–35.4%), in whom the dilatation lay at the level of the left lumbar lymphatic trunk rather than at the classical confluence. No complete duplication of the duct was observed in either group; partial duplication was confined to the cervical segment in a minority of adults. Termination at the left venous angle (angle of Pirogoff), either directly or through interposed lymph nodes, occurred in 100% of specimens in both groups (24/24; 95% CI 86.2–100%).

Conclusions: The site of termination of the thoracic duct is anatomically stable; the morphology of the pre-terminal duct is not. The near-complete dissociation between adult and fetal patterns—plexuses in adults only, a cisterna chyli in fetuses almost exclusively—is most consistent with postnatal remodelling of the duct rather than with congenital variation alone. The resulting collateral capacity provides a plausible anatomical explanation for the clinical observation that some patients tolerate thoracic duct ligation without developing chylous effusion. Larger series with quantitative morphometry and correlation with in-vivo imaging are warranted.

Keywords: Thoracic Duct; Anatomical Variation; Cisterna Chyli; Left Venous Angle; Angle Of Pirogoff; Chylothorax; Lymphatic Anatomy; Cadaveric Latex Perfusion; Fetal Anatomy.

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Introduction

The thoracic duct is the largest lymphatic channel in the human body and conveys lymph from the entire body below the diaphragm and from the left half of the body above it [1,2]. In the classical description it begins at the cisterna chyli, an ampullary dilatation formed at the confluence of the right and left lumbar lymphatic trunks with the intestinal trunk at the level of the first to second lumbar vertebrae; it enters the thorax through the aortic hiatus, ascends in the posterior mediastinum between the descending thoracic aorta and the azygos vein, crosses the midline to the left between the fourth and sixth thoracic vertebrae, and terminates at the junction of the left internal jugular and left subclavian veins—the left venous angle, or angle of Pirogoff [1–3]. Reported dimensions place the duct at approximately 35–45 cm in length and 2–5 mm in diameter [1,4].

This classical account describes a single, continuous conduit. Operative and radiological experience is less tidy. Anatomical variation of the thoracic duct is common and may involve its origin, course, number of trunks and pattern of venous termination [2,5,6]. Historical cadaveric series documented multiple morphological types of the duct and emphasised that textbook anatomy is present in only about half of individuals [5,7]. More recent reviews and meta-analyses have confirmed substantial heterogeneity in termination site and branching pattern: although a single terminal channel is most frequent, division into two or more terminating branches occurs in approximately one quarter of cases, and the pooled prevalence of a recognisable cisterna chyli is only about 55% [6,8,9].

These morphological uncertainties have direct clinical consequences. Chylothorax after oesophagectomy occurs in up to approximately 3–9% of cases and remains an important source of morbidity through malnutrition, immunosuppression and respiratory compromise [10,11]. Chylous fistula may likewise complicate left-sided neck dissection, and the variable success of thoracic duct embolisation reflects dependence on a predictable cisterna chyli or single main channel for access [12,13]. Mass ligation of tissue between the aorta and azygos vein is often preferred to isolation of a single vessel precisely because collateral and plexiform pathways are anticipated [10,14].

What remains incompletely resolved is whether the plexiform and derivative pathways so often encountered in adults are congenital or acquired, and how consistently the cisterna chyli is present across developmental stages. Comparative data from fetal and adult material prepared with the same visualisation technique are scarce. The present original cadaveric study was therefore undertaken to (i) define the frequency and topography of thoracic duct variations in matched adult and late-fetal specimens using sequential colour-coded latex perfusion; (ii) compare the presence of plexiform segments, cisterna chyli, duplication and terminal pattern between groups; and (iii) interpret the findings in relation to surgical risk at the origin, mediastinal course and cervical termination of the duct.

Materials and Methods

Study Design and Ethical Considerations: This was a prospective comparative cadaveric anatomical study conducted at Department of Anatomy, Bhaskar medical college, Yenkapally, Hyderabad. All specimens were obtained and processed in accordance with institutional anatomical donation regulations and applicable national legislation governing the use of human cadaveric material for teaching and research. Identifiable clinical data were not linked to morphological observations. The study is reported in keeping with recommendations for anatomical research describing specimen source, preparation technique and observational endpoints [2,15].

Specimen Material: Twenty-four human specimens were examined: 12 adult cadavers (8 male, 4 female; age range 50–80 years) and 12 late-fetal cadavers (35–40 weeks' gestation; sex distribution not recorded for the fetal group). Specimens with macroscopic trauma, prior thoracic or cervical surgery, or extensive putrefaction precluding reliable perfusion were excluded. Sample size was determined by consecutive availability of intact donated material suitable for sequential latex injection during the study period, consistent with the scale of previous detailed cadaveric thoracic duct series [5,7,16].

Table 1: Specimen demographics.

Group	N	Sex distribution	Age / developmental stage
Adults	12	8 male / 4 female	50–80 years
Fetuses	12	Not recorded	35–40 weeks' gestation
Total	24	—	—

Sequential Latex Perfusion Protocol: Cadaveric visualisation of lymphatic pathways is limited by the small calibre and thin walls of the vessels and by the ease with which injection media mix with venous blood. Colour-coded latex injection with controlled sequence and intermediate hardening has been shown to improve topographic separation of lymphatic, venous and arterial compartments [16,17]. We therefore used a three-stage sequential perfusion protocol. All cadavers were injected with natural acrylic pigmented latex diluted in distilled water. Perfusion was performed with an APEMA PC II peristaltic pump at 150 ml/h.

The injection sequence was: (1) internal marginal vein; (2) thoracic duct, accessed by lateral right thoracotomy to the interazygous–aortic recess; and (3) posterior tibial artery. Catheter calibre was Abbocath-T 16 G in adults and 24 G in fetuses. Critically, latex introduced through the thoracic duct was allowed to harden at the left venous angle (angle of Pirogoff) before arterial perfusion was begun, so that venous, lymphatic and arterial media remained chromatically distinct and the lymphatic cast was not flushed into the venous system. Pre-injection preparation included 10% hydrogen peroxide (v/v). After perfusion, specimens were immersed in 5% formalin (v/v) for 7–14 days and cleared in 100% hydrogen peroxide for 24 hours. Dissections were photographed with an Olympus Stylus 1 digital camera (12 megapixels). Colour convention across plates was green or yellow latex for lymphatic channels (thoracic duct and tributaries), blue for veins, and pink/red for arteries.

Table 2: Perfusion and preparation parameters.

Parameter	Specification
Injection medium	Natural acrylic pigmented latex diluted in distilled water
Sequence of perfusion	1. Internal marginal vein → 2. Thoracic duct (interazygous–aortic recess) → 3. Posterior tibial artery
Blocking step	Latex hardened at left venous angle before subsequent perfusion
Access to thoracic duct	Lateral right thoracotomy to interazygous–aortic recess
Catheter	Abbocath-T 16 G (adults) / 24 G (fetuses)
Perfusion pump	APEMA PC II peristaltic pump at 150 ml/h
Pre-injection preparation	10% hydrogen peroxide (v/v)
Fixation	5% formalin (v/v) for 7–14 days
Clearing	100% hydrogen peroxide for 24 hours
Documentation	Olympus Stylus 1 digital camera (12 Mp)

Anatomical Endpoints: For each specimen the following features were recorded by direct dissection under loupe magnification: (i) presence of plexiform (plexus-shaped) segments or derivative pathways of the thoracic duct, and their predominant vertebral or regional level; (ii) presence and topography of a cisterna chyli, defined as an ampullary dilatation at the origin of the duct formed by confluence of lumbar and intestinal trunks [1,8]; (iii) complete (total) duplication of the duct along its course; (iv) partial duplication, including preterminal cervical bifurcation; (v) site and pattern of venous termination (direct entry into the left venous angle, entry via interposed lymph nodes, or ectopic termination); and (vi) presence of transversely running paraesophageal lymphatic connections.

Definitions of variation followed classical and contemporary anatomical frameworks [2,5,6,9].

Statistical Analysis: Categorical findings are presented as absolute counts and percentages. Because both groups contained only twelve specimens and several proportions lay at 0% or 100%, 95% Wilson score confidence intervals were computed in preference to Wald intervals [18]. Where the observed percentage of approximately 80% of 12 specimens did not resolve uniquely to a whole number, bracketing integer values (9/12 and 10/12) are presented.

No formal hypothesis testing between adult and fetal groups was planned a priori, given the exploratory sample size; group comparisons are therefore descriptive. Analyses were performed manually and verified with standard binomial interval formulae.

Results

Frequency of Anatomical Variations: The principal morphological findings are summarised in Table 3. Plexiform segments and derivative pathways were the dominant adult pattern and were entirely absent in fetuses. Conversely, a true ampullary cisterna chyli was universal in fetuses and almost absent in adults. Termination at the left venous angle was invariant across both groups.

Table 3: Frequencies of anatomical features in adult and fetal specimens.

Anatomical feature	Adults (N=12)	Fetuses (N=12)	Topography and remarks
Plexus shapes / derivative pathways	80% (≈9–10/12)	0% (0/12)	Most frequent at origin (lumbar confluence and lower thoracic segment); absent in all fetuses
Cisterna chyli (ampullary dilatation)	8.3% (1/12)	100% (12/12)	In the single adult the dilatation lay at the left lumbar trunk
Complete (total) duplication	0% (0/12)	0% (0/12)	Not observed in either group
Partial duplication	Few cases (exact n not fully quantified)	0% (0/12)	Confined to cervical level in adults (Figure 2b)
Termination at left venous angle	100% (12/12)	100% (12/12)	Directly or through interposed lymph nodes; no ectopic termination
Paraesophageal lymphatic connections	Present	Present	Transverse vessels connecting paraesophageal plexus to the duct

Regional topography: Variability was greatest at the origin of the duct, intermediate in the lower and mid-thoracic segments, and least at the cervical termination (Table 4). In adults, plexiform networks most often replaced the classical single cisterna at the lumbar confluence and extended into the lower posterior mediastinum, where hepatic, jejuno-ileal and oesophageal tributaries joined the duct. In fetuses the duct was continuous and non-plexiform, with a constant ampullary cisterna. At the neck, a minority of adults showed partial bifurcation into two cervical limbs that reconverged on the same left venous angle; no fetus showed this pattern.

Table 4: Region-specific observations and clinical relevance.

Region	Adult findings	Fetal findings	Clinical relevance
Origin (L1–L2, lumbar confluence)	Plexus shapes most frequent; true cisterna in one specimen only	Ampullary cisterna chyli in every specimen	Potential obstruction and injury during retroperitoneal / upper abdominal surgery
Lower and mid-thoracic duct	Plexuses and derivative pathways common; paraesophageal connections	Continuous non-plexiform duct; paraesophageal vessels without plexus formation	Oesophagectomy and mediastinal lymphadenectomy; site of chyle leak
Cervical segment and termination	Partial bifurcation in a few specimens; termination always at left venous angle	Consistent termination at left venous angle; no plexus	Left neck dissection, subclavian access, embolisation planning

Absolute Frequencies and Confidence Intervals: Absolute frequencies with 95% Wilson score intervals are shown in Table 5. For plexiform morphology, the adult interval using the upper integer bracket of 10/12 (55.2–95.3%) and the fetal zero-event interval (0–24.3%) did not overlap; the lower adult bracket of 9/12 (46.8–91.1%) likewise remained clearly separated from the fetal estimate. For cisterna chyli, the fetal interval (75.7–100%) and the adult interval (1.5–35.4%) were disjoint. Complete duplication was not observed (0/24; 95% CI 0–13.8%). Termination at the left venous angle was universal (24/24; 95% CI 86.2–100%).

Table 5: Absolute frequencies with 95% Wilson score confidence intervals.

Feature	Count / N	Proportion	95% Wilson CI	Note
Plexus shapes, adults (upper bracket)	10 / 12	83.3%	55.2–95.3%	Corresponds to reported ≈80%
Plexus shapes, adults (lower bracket)	9 / 12	75.0%	46.8–91.1%	Integer bracket for ≈80%
Plexus shapes, fetuses	0 / 12	0%	0–24.3%	Zero-event interval
True cisterna chyli, adults	1 / 12	8.3%	1.5–35.4%	At lumbar trunk level
Cisterna chyli, fetuses	12 / 12	100%	75.7–100%	Ceiling
Partial duplication, adults (upper bound)	≤3 / 12	≤25.0%	8.9–53.2%	Exact n not fully specified; ceiling estimate
Complete duplication, either group	0 / 24	0%	0–13.8%	Pooled zero-event
Termination at left venous angle	24 / 24	100%	86.2–100%	Pooled, both groups

Illustrated Morphology: Representative dissections are shown in Figures 1–3. Figure 1 demonstrates the adult pattern of a latex-filled thoracic duct with plexiform derivative pathways at the origin replacing a single cisterna. Figure 2 shows an ampullary cisterna chyli at the origin of the duct and a partial cervical bifurcation into two limbs converging on the left venous angle. Figure 3 illustrates the invariant terminal arch of the duct at the left venous angle (angle of Pirogoff), arching over the pleural dome between the arterial and venous planes, fed inferiorly by a plexiform mediastinal segment in the adult specimen.

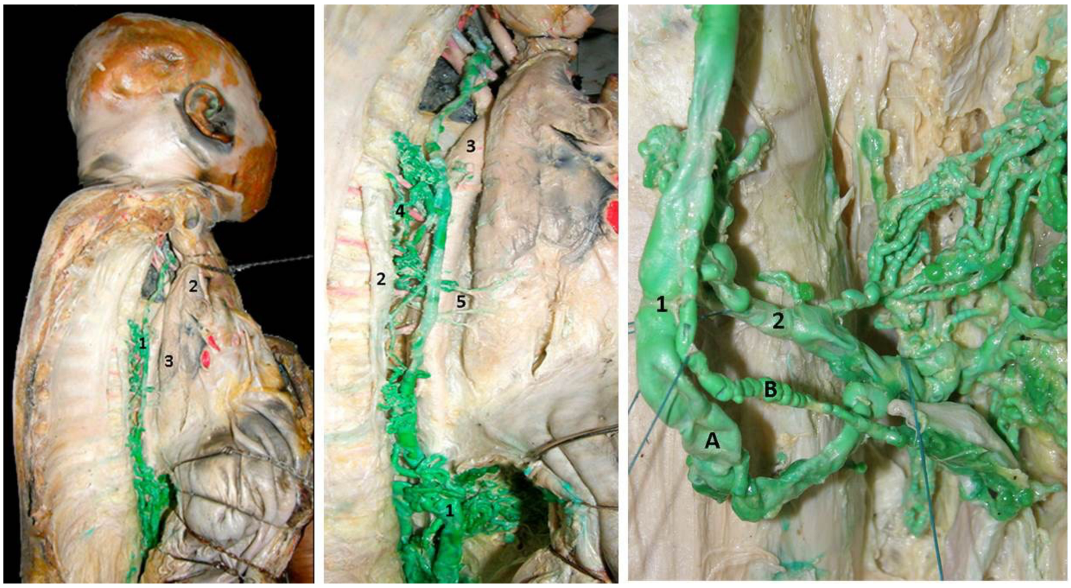

Figure 1: Adult specimen perfused with green pigmented latex through the thoracic duct. (a) Panoramic left posterolateral view of the head, neck and opened thorax showing the latex-filled duct ascending along the vertebral column. (b) Detail of the posterior mediastinum: the duct is continuous inferiorly but becomes plexiform in its mid-portion. (c) High magnification at the origin of the duct, showing the confluence of the lumbar trunks and the dense derivative network that replaces the classical single cisterna in this specimen.

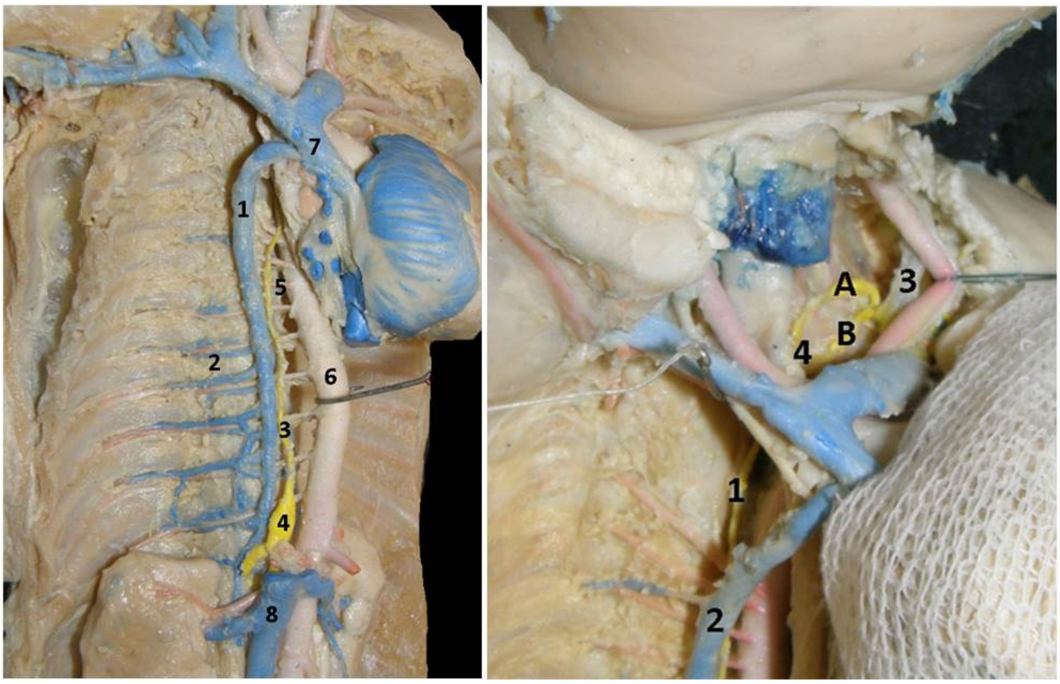

Figure 2: Specimen with venous system perfused blue, arteries pink and the thoracic duct yellow. (a) Posterior mediastinum: the yellow duct ascends alongside the blue azygos system, with an ampullary dilatation (cisterna chyli) at its inferior end. (b) Left cervical and supraclavicular region: the duct divides into two limbs before converging on the left venous angle — partial (cervical) duplication.

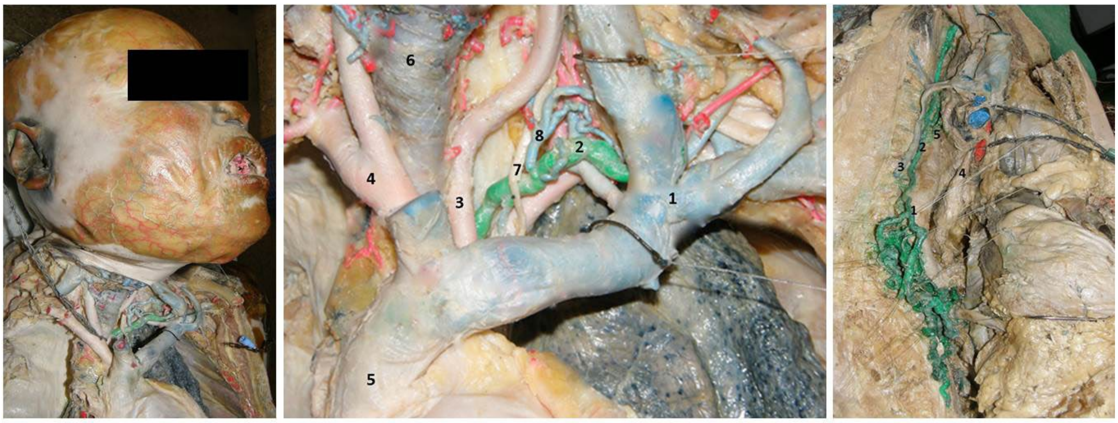

Figure 3: Whole-specimen orientation and the terminal segment of the duct. (a) Orientation view of the head, neck and upper thorax. (b) Magnified left supraclavicular dissection: the green latex-filled thoracic duct arches over the pleural dome and opens at the left venous angle. (c) Thoracic view showing the plexiform mediastinal segment feeding the single terminal channel.

Discussion

Principal Findings: In this comparative cadaveric series the thoracic duct terminated at the left venous angle in every adult and fetal specimen, either directly or through interposed lymph nodes. No ectopic termination was observed. In contrast, the morphology of the duct proximal to that terminus differed sharply between groups: plexiform and derivative pathways were present in approximately 80% of adults and in no fetus, whereas a cisterna chyli was present in every fetus and in only one adult. These two group separations are too complete, and their confidence intervals too clearly non-overlapping, to be dismissed as small-sample noise, even though absolute numbers remain modest.

The Termination is Stable; The Course is Not: Stability of the terminal address is surgically reassuring but easily misread. It means that the site of the terminus can be predicted, not that the vessel arriving at it can be. Reviews of terminal anatomy have reported the internal jugular vein, jugulosubclavian angle and subclavian vein as the commonest receiving sites, with substantial series-to-series variation in relative frequencies [6,8,9,19]. Our 100% left venous angle rate sits at the high end of published estimates and may reflect both the definition used (angle of Pirogoff including immediately adjacent nodal entry) and the small sample. What matters clinically is that, in approximately 80% of adults in this series, the duct approaching that terminus was plexiform rather than singular, and in a minority it arrived as two cervical limbs. A surgeon who identifies “the” thoracic duct in the left supraclavicular fossa and ligates it therefore has a material chance of having controlled only one of several channels [6,9,19].

Adult–Fetal Dissociation and Developmental Interpretation: Two features separated the groups almost completely and in opposite directions. If plexuses were purely congenital they should be visible at 35–40 weeks’ gestation, and they were not. If the cisterna chyli were a permanent adult structure it should not have been absent in eleven of twelve adults. The pattern instead suggests that the fetal ampulla is progressively remodelled during postnatal life into the plexiform arrangement seen in the adult. Embryologically, the adult thoracic duct is derived from bilateral embryonic ducts with selective atrophy and anastomosis; disturbances of this process are long recognised as a source of structural variation [3,5,7]. Our data add a temporal dimension: even when the late-fetal duct is a continuous channel with a universal cisterna, adult morphology frequently shows secondary plexiform remodelling.

Two non-exclusive postnatal drivers are plausible. First, assumption of upright posture imposes sustained changes in hydrostatic and lymphatic pressures along a long vertical collector. Second, cumulative lymphatic insult or intermittent obstruction over decades may recruit collateral pathways, of which a plexus is the natural anatomical response [2,16]. Neither mechanism can be proved in a cross-sectional cadaveric design; both generate testable predictions for longitudinal imaging cohorts. The low adult prevalence of a discrete cisterna chyli in our material (8.3%) is lower than the pooled estimate of approximately 55% from mixed cadaveric and imaging meta-analysis [8], but it is directionally consistent with reports that a classical ampulla is far from constant in adults [1,8,20].

Duplication

No complete duplication was found in either group. Partial duplication occurred in a small number of adults and was confined to the cervical segment. Historical and modern series have reported complete duplication as uncommon (often in the low single-digit percentages) and partial or segmental doubling as considerably more frequent [5,7,16]. Our zero event for complete duplication among 24 specimens is compatible with a rare trait and does not refute literature rates near 1–2%. The derived upper bound of ≤25% for partial cervical duplication is a ceiling rather than a point estimate and overlaps the 10–20% range often cited for partial doubling [2,5].

Clinical Implications: Thoracic duct ligation and chyle leak. If the adult duct is commonly a plexus rather than a single conduit, collateral capacity is already present at the moment of ligation. This offers an anatomical explanation for the long-standing observation that some patients tolerate ligation or clipping of the duct without developing chylothorax or chylous ascites, and conversely that mass ligation of tissue between aorta and azygos is more reliable than attempting to isolate a single vessel [10,11,14]. Oesophagectomy and mediastinal surgery. Plexiform segments and transverse paraesophageal connections lie precisely in the plane of mediastinal lymphadenectomy. Variability was greatest in the lower and mid-thoracic duct—the region of surgical dissection—consistent with the known risk of postoperative chyle leak after oesophageal resection [10,11]. Left neck dissection and central venous access. The terminal arch crosses the pleural dome before entering the venous angle. Its position is predictable; its calibre and the number of limbs are not. Partial cervical duplication means that a chylous leak may persist after apparently successful ligation of a single identified duct [6,9,19]. High-resolution ultrasound can visualise the cervical duct in a high proportion of living subjects and may help identify branching before intervention [19].

Thoracic duct embolisation and lymphangiography. The near-absence of a true cisterna chyli in adults is directly relevant to techniques that depend on cannulating it. Where the classical ampulla has been replaced by a plexus, the target for access is a network rather than a sac, and a dilatation seen on imaging at the lumbar trunk level should not be assumed to be a cisterna [12,13,20]. Success of percutaneous embolisation depends on recognising such variants and, when needed, using alternative access strategies [12,13]. Abdominal and retroperitoneal procedures. The origin of the duct at L1–L2 was the region of greatest anatomical variability in the entire series and is a plausible site of both obstruction and inadvertent injury during upper abdominal and spinal approaches [1,14,15].

Methodological Considerations: Sequential colour-coded latex perfusion with venous-angle blocking produced consistent full-length casts in both adult and fetal specimens and allowed simultaneous display of lymphatic, venous and arterial relations. Similar injection strategies have been advocated to overcome the technical difficulty of filling delicate lymphatic trunks without venous contamination [16,17]. Nevertheless, latex distribution depends on the patency of channels at the time of injection; a channel that fails to fill is indistinguishable from a channel that is absent. Classification of "plexus shape" is a qualitative judgement, and inter-observer reliability was not formally assessed. Quantitative morphometry of duct diameter, length and plexus vessel calibre was not performed; dimensional values cited in the introduction are literature reference ranges rather than measurements from this series [1,4].

Limitations: Sample size was small (N = 12 per group), so confidence intervals are wide for all but the two principal group differences, and rare events such as complete duplication cannot be estimated with useful precision. Fetal sex distribution was not recorded, and the adult group was sex-imbalanced (8 male : 4 female), precluding examination of sex-related differences. Partial duplications were noted qualitatively rather than as an exact count. The study is cadaveric and cross-sectional; developmental inferences are therefore hypothesis-generating. Correlation with in-vivo magnetic resonance or conventional lymphangiography was not available [13,20].

Hypotheses Generated: Four testable hypotheses emerge. First, plexiform and derivative pathways of the thoracic duct are acquired postnatally rather than congenital. Second, the classical cisterna chyli is predominantly a fetal and perinatal structure that regresses or is remodelled into a plexiform network during growth and with upright posture. Third, the collateral capacity of adult plexuses explains why some patients tolerate thoracic duct ligation without clinical chylothorax. Fourth, sequential colour-coded latex perfusion with venous-angle blocking is a high-yield technique for complete visualisation of the duct and its tributaries in cadaveric material. None of these is established by the present data alone; each is a proposition for larger anatomical series and imaging cohorts [8,12,16].

Conclusion

Across twenty-four latex-perfused specimens the thoracic duct terminated at the left venous angle without exception. Everything upstream of that point behaved differently in adults and in fetuses: adults showed plexiform, derivative pathways in approximately four fifths of specimens and almost never a true cisterna chyli, while fetuses showed a continuous duct with a universal ampullary cisterna and no plexus formation. The dissociation is most consistent with postnatal remodelling of the duct rather than with congenital variation alone.

For the clinician the practical translation is narrow but useful: the address of the thoracic duct is reliable; the vessel arriving at it is not. Procedures that depend on finding the terminus—left supraclavicular exploration, ligation at the venous angle—rest on relatively stable anatomy. Procedures that depend on the duct being a single conduit, or on the cisterna chyli existing as a discrete sac, do not. Confirmation requires larger series and correlation with in-vivo lymphatic imaging.

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Data Availability: All morphological data supporting the findings are contained within the article and figures. Additional photographic material is available from the corresponding author on reasonable request.

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