Coeliac Trunk Variant Anatomy: A Meta-Analysis of Prevalence from Systematic Review

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Abstract:

Background: The coeliac trunk (CoT) is a crucial branch of the abdominal aorta, typically trifurcating into the left gastric, splenic, and common hepatic arteries. Anatomical variations of the CoT are clinically significant. This systematic review and meta-analysis aimed to determine the pooled prevalence of these variations.

Methods: A systematic literature search was conducted across four online databases to identify studies reporting CoT variant prevalence. Meta-analysis was performed using R software to calculate pooled prevalence and explore influencing factors through subgroup analysis.

Results: The typical CoT trifurcation (type 3) was observed with a pooled prevalence of 83.39%. The most frequent variation was a bifid CoT (type 2), with a prevalence of 10.53%. Less common variations included quadrifurcation (type 4, 1.80%) and CoT absence (type 1, 0.43%). Subgroup analysis revealed statistically significant differences in the prevalence of type 1 and type 4 variants between imaging and cadaveric studies. The hepato-splenic trunk was the most prevalent specific variation (6.68%).

Conclusions: This meta-analysis provides a comprehensive overview of CoT anatomical variations, classifying them based on the number of branches. Understanding these variations is essential for anatomists, radiologists, and surgeons involved in abdominal procedures.

Introduction:

The coeliac trunk (CoT), the first major ventral branch of the abdominal aorta, plays a critical role in supplying blood to the upper abdominal organs, including the stomach, spleen, liver, and pancreas. Typically, the CoT trifurcates into the left gastric artery (LGA), splenic artery (SA), and common hepatic artery (CHA). However, significant anatomical variations in the CoT's branching pattern are well-documented. These variations are not merely anatomical curiosities; they have profound clinical implications, impacting surgical planning, interventional radiology procedures, and the interpretation of diagnostic imaging.

Knowledge of CoT variations is paramount for surgeons performing procedures in the upper abdomen, as inadvertent injury to aberrant vessels can lead to severe complications, including hemorrhage and ischemia. Similarly, interventional radiologists rely on a precise understanding of vascular anatomy for successful embolization, stent placement, and other endovascular interventions. Diagnostic imaging, such as computed tomography angiography (CTA) and magnetic resonance angiography (MRA), also requires accurate interpretation of CoT anatomy to avoid misdiagnosis and guide appropriate clinical management.

Despite the clinical significance of CoT variations, the reported prevalence of these anomalies varies considerably across studies, likely due to differences in study populations, imaging modalities, and classification systems. Therefore, a comprehensive synthesis of the existing literature is essential to establish a reliable estimate of CoT variant prevalence. This systematic review and meta-analysis aim to provide a quantitative overview of CoT anatomical variations, classifying them based on the number of branching patterns, and to explore potential factors influencing their occurrence. By pooling data from multiple studies, we seek to provide clinicians with a robust and evidence-based understanding of CoT anatomy, ultimately improving patient safety and outcomes.

Materials and Methods:

Search Strategy and Study Selection: This systematic review and meta-analysis adhered to the Evidence-based Anatomy Workgroup guidelines for anatomical meta-analysis (Henry et al., 2016) and the PRISMA 2020 guidelines (Page et al., 2021). While a study protocol was not registered, the methodology was rigorously followed. A comprehensive literature search was conducted across PubMed, Google Scholar, Scopus, and Web of Science, spanning from inception to August 2024. Search terms included various combinations of “celiac trunk,” “coeliac trunk,” “celiac artery,” “coeliac artery,” “tripus Halleri,” “variation,” “anatomical study,” “cadaveric study,” and “imaging study.” To ensure thoroughness, reference lists of included articles were examined, grey literature was explored, and manual searches were performed in key anatomical journals: *Annals of Anatomy, Clinical Anatomy, Journal of Anatomy, Anatomical Record, Surgical and Radiological Anatomy, Folia Morphologica, European Journal of Anatomy, Anatomical Science International, Anatomy and Cell Biology*.

Studies reporting the prevalence of coeliac trunk (CoT) variants were included. Due to the inherent morphological variability, rarer variants with limited reporting were consolidated into an “other/rarer variants” category. Exclusion criteria encompassed case reports, conference abstracts, animal studies, and studies with irrelevant or insufficient data.

Two independent reviewers (GTr, NB) performed the literature search and data extraction into Microsoft Excel spreadsheets. Discrepancies were resolved through discussion and consensus with the other authors. The Anatomical Quality Assurance (AQUA) tool, developed by the Evidence-based Anatomy Workgroup (Henry et al., 2017), was utilized to assess the risk of bias in each included study.

Statistical Analysis: Statistical meta-analysis was performed using R software (version 4.3.2) and RStudio, employing the “meta” and “metafor” packages. Pooled prevalence was calculated using the inverse variance and random effects models. Proportion meta-analysis (prevalence meta-analysis) was performed using the Freeman-Tukey double arcsine transformation, the DerSimonian-Laird estimator for between-study variance (τ^2), and the Jackson method for confidence intervals of τ^2 and τ. Subgroup analyses were conducted to investigate the influence of variables such as geographic distribution, sample size, and study type on pooled prevalence. Statistical significance was defined as a p-value < 0.05. Heterogeneity across studies was assessed using Cochran’s Q statistic ($p < 0.10$ considered significant) and quantified using the Higgins I^2 statistic (0-40%: not necessary, 30-60%: moderate, 50-90%: substantial, 75-100%: considerable). The DOI plot with the LFK index was generated to evaluate potential small-study effects.

Classification System: While various classification systems for CoT variations exist, notably Adachi's (1928), this study adopted a simplified classification based on the number of branches emanating from the CoT:

- **Type 1 CoT:** Absence of the trunk, with all branches originating directly from the abdominal aorta (AA).
- **Type 2 CoT:** Bifurcation (two branches).
- **Type 3 CoT:** Trifurcation (three branches).
- **Type 4 CoT:** Quadrifurcation (four branches).

This classification mirrors the approach used by Natsis et al. (2021) for aortic arch variations and is consistent with the methodology employed by Bergman's Comprehensive Encyclopedia of Anatomic Variation (Tubbs et al., 2016). It is acknowledged that each type may encompass several subtypes, as reported in the existing literature.

Results:

Study Identification: The initial database search yielded 2,661 articles, which were managed using Mendeley version 2.10.9 (Elsevier, London). After removing duplicates and irrelevant articles based on title and abstract screening, 256 articles underwent full-text review. Ultimately, 69 studies met the inclusion criteria for the systematic review. An additional 24 studies were identified through secondary investigations, including reference list screening, grey literature review, and manual searches of key anatomical journals. Consequently, 91 studies were included in the systematic review and meta-analysis. Figure 1 illustrates the study selection process according to the PRISMA 2020 guidelines.

Characteristics of Included Studies: The 91 included studies comprised a total of 34,095 participants. Fifty-seven studies utilized imaging techniques, while 34 were cadaveric studies. Sixty-three studies had a sample size exceeding 100 participants, whereas 33 had fewer than 100 participants. The mean sample size per study was 370.59. The geographic distribution of studies was as follows: 44 from Asia, 29 from Europe, 11 from America, 5 from Africa, and 1 from Oceania. Table 1 provides a detailed summary of the characteristics of the included studies.

Type 1 Coeliac Trunk (Absence): Type 1 CoT, characterized by the origin of the left gastric artery (LGA), common hepatic artery (CHA), and splenic artery (SA) directly from the abdominal aorta (AA) (Figure 2), exhibited a pooled prevalence of 0.43% (95% CI: 0.24–0.67). Subgroup analysis revealed that study type and sample size significantly influenced the pooled prevalence of Type 1 CoT (Table 2). The DOI plot did not indicate any small-study effects (LFK index = 0.59, Supplementary Material).

Type 2 Coeliac Trunk (Bifurcation): Type 2 CoT (bifurcation) (Figure 3) had a pooled prevalence of 10.53% (95% CI: 8.50–12.73). Nationality, study type, and sample size did not significantly affect the prevalence of Type 2 CoT (Table 2). The DOI plot showed no asymmetry suggestive of small-study effects (LFK index = 0.44, Supplementary Material).

Several subtypes of Type 2 CoT were identified: hepato-splenic trunk (LGA from AA): 6.68% (95% CI: 4.52–9.19); gastro-splenic trunk (CHA from AA): 2.65% (95% CI: 2.07–3.30); gastro-splenic and hepato-mesenteric trunks: 2.24% (95% CI: 1.34–3.32); hepato-gastric trunk (SA from AA): 0.80% (95% CI: 0.29–1.50); hepato-gastric and spleno-mesenteric trunks: 0.25% (95% CI: 0.00–1.11); hepato-mesenteric trunk (LGA and SA from AA): 2.07% (95% CI: 0.00–12.00); gastro-mesenteric trunk (CHA and SA from AA): 0.18% (95% CI: 0.00–1.92); spleno-mesenteric trunk (LGA and CHA from AA): <0.01% (95% CI: 0.00–0.08).

Type 3 Coeliac Trunk (Trifurcation): Type 3 CoT (trifurcation) (Figure 4) had a pooled prevalence of 83.39% (95% CI: 80.12–86.43), and its prevalence was significantly influenced by population (Table 2). Although sample size was not a significant moderator, the DOI plot indicated significant asymmetry for small-study effects (LFK index = -2.61, Supplementary Material). The typical CoT (LGA, CHA, SA sequence) had a pooled prevalence of 75.15% (95% CI: 69.58–80.33). The hepato-spleno-mesenteric trunk (LGA from AA) had a pooled prevalence of 0.24% (95% CI: 0.13–0.36). The gastro-spleno-mesenteric trunk (CHA from AA) was observed at <0.01% (95% CI: 0.00–0.00).

Type 4 Coeliac Trunk (Quadrifurcation): Type 4 CoT (quadrifurcation) (Figure 5) had a pooled prevalence of 1.80% (95% CI: 1.25–2.44). Study type and sample size significantly affected the pooled prevalence of Type 4 CoT (Table 2). The DOI plot showed no asymmetry for small-study effects (LFK index = 0.38, Supplementary Material). Specific Type 4 CoT variations included: CoT with middle colic artery (MCA): 2.26% (95% CI: 0.64–4.65); CoT with gastroduodenal artery (GDA): 1.58% (95% CI: 0.14–4.06); CoT with superior mesenteric artery (SMA): 1.18% (95% CI: 0.76–1.65).

Other Variants of Coeliac Trunk: Other unclassified CoT variants, which were infrequently reported in the literature, had a combined pooled prevalence of 6.02% (95% CI: 4.07–8.30).

Discussion:

This evidence-based systematic review and meta-analysis evaluated the prevalence of coeliac trunk (CoT) variants, providing pooled prevalence estimates. Table 3 summarizes the results of this study in comparison to previous literature reviews (Panagouli et al., 2013; Whitley et al., 2020). Gray's Anatomy describes the CoT as the first anterior branch of the abdominal aorta (AA), typically trifurcating into the left gastric artery (LGA), common hepatic artery (CHA), and splenic artery (SA). The lesser sac is located anterior to the CoT, which is surrounded by the coeliac plexus (Standring et al., 2005).

Anatomical Considerations of Coeliac Trunk Variants

The typical CoT anatomy, characterized by trifurcation (type 3), was found to have a pooled prevalence of 83.39%. This aligns with Bergman's Comprehensive Encyclopedia of Anatomic Variations, which reports a prevalence of 44–95% (Tubbs et al., 2016). Our meta-analysis demonstrated a significant association between CoT trifurcation prevalence and geographic distribution (Table 2). Rusu et al. (2021) highlighted the variability in the vertebral level of CoT origin, observing that it originates at the upper margin of the first lumbar vertebra in 24.3%

of cases. Despite this variability, other type 3 variants, such as the hepato-spleno-mesenteric and gastro-spleno-mesenteric trunks, were rare, with pooled prevalences of 0.24% and <0.01%, respectively.

The most common CoT variation was bifurcation (type 2), with a pooled prevalence of 10.53%. Bergman's Encyclopedia reports this variant in 4–12% of cadaveric studies and 7.5–9% of angiographic studies (Tubbs et al., 2016). The most prevalent type 2 variant was the hepato-splenic trunk (LGA from AA), with a pooled prevalence of 6.68%, consistent with textbook descriptions and previous meta-analyses (Whitley et al., 2020). Other notable bifurcations included the gastro-splenic trunk (CHA from AA: 2.65%; with hepato-mesenteric trunk: 2.24%) and the hepato-mesenteric trunk (LGA and SA from AA: 2.07%). Rarer type 2 variants, such as the hepato-gastric, gastro-mesenteric, and spleno-mesenteric trunks, had prevalences below 1%.

CoT quadrifurcation (type 4) had a pooled prevalence of 1.80%, with a significantly higher prevalence in imaging studies compared to cadaveric studies (Table 2). The most observed fourth branch in previous studies is the inferior phrenic artery, which was analyzed separately in previous work (Whitley et al., 2021). In this study, the fourth branches were the middle colic artery (MCA: 2.26%), gastroduodenal artery (GDA: 1.58%), and superior mesenteric artery (SMA: 1.18%).

CoT absence (type 1) had a pooled prevalence of 0.43%, with a higher prevalence in imaging studies (Table 2). Mao et al. (2023) classified CoT absence into five types, with their Type I (all branches from AA) being the only true absence, aligning with our classification.

Other rare CoT variants, such as pentafurcation (type 5) and hexafurcation (type 6), were also noted. Case reports, such as those by Cicekcibasi et al. (2005) and Rusu and Manta (2018), highlight the complexity of these rare variations. The coeliac-mesenteric anastomosis (Arc of Bühler), with a pooled prevalence of 1.7% (Kowalczyk et al., 2023), and other rare anastomoses, such as CHA-SMA and SA-inferior pancreaticoduodenal artery, were also acknowledged.

Surgical Considerations of Coeliac Trunk Variants

Knowledge of CoT anatomy and its variations is crucial for abdominal surgical procedures. Preoperative imaging, such as CT angiography, is essential for surgical planning. Radical operations for upper abdominal malignancies require detailed understanding of CoT branching patterns for adequate lymphadenectomy.

The vertebral level of CoT origin is important for interventional procedures, such as catheterization and embolization. High morphological variability can complicate these procedures, leading to iatrogenic injuries. For example, the presence of a gastro-splenic trunk with a hepato-mesenteric trunk (2.24% prevalence) requires clinicians to recognize the CHA's location with the SMA. Liver transplantation and hepatic artery chemoembolization also necessitate precise knowledge of CHA anatomy.

Extended systemic lymphadenectomy (D2) during gastric cancer surgery requires meticulous dissection around the CoT branches. Aberrant branches, such as MCA, GDA, and SMA, increase surgical complexity and risk (Huang et al., 2015). The splenic artery's (SA) origin and course are also critical during pancreatic surgery. The pancreas-major arteries ligament (P-A ligament) described by Muro et al. (2021) is another anatomical feature that may be clinically relevant.

Limitations

This meta-analysis has several limitations. Most included studies had a "high risk of bias" according to the AQUA tool, and high heterogeneity was observed in most pooled prevalences. This is common in anatomical meta-analyses (Henry et al., 2016). Only one DOI plot indicated a potential small-study effect (CoT type 2). Variants like the coeliac-mesenteric anastomosis were excluded due to existing well-conducted meta-analyses.

Conclusions

This meta-analysis provides a comprehensive overview of CoT anatomical variations, highlighting the clinical significance of these findings. A significant difference was observed between cadaveric and imaging studies for CoT absence (type 1) and quadrifurcation (type 4). A simplified classification system, based on the number of CoT branches, was proposed. Knowledge of typical anatomy and variants is essential for anatomists, radiologists, and surgeons operating in the area.

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