SHORT COMMUNICATION

Anatomical variants of the cystic artery: An Australian perspective

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Aims and Objective: This cadaver-based study aims to identify variants of the cystic artery within the Australian population. At the time of writing, original research in this area toward the Australian population has been limited.

Methods: 200 cadavers were donated over 5 years to The University of Melbourne for surgical anatomy teaching. Each cadaver was meticulously dissected by experienced anatomists with particular attention to anatomical variants. The variants described where the origin of the cystic artery, number of vessels and relationship to Calot's triangle. These were compared to global studies designed in a similar fashion.

Results: 186 specimens demonstrated normal anatomy, and 14 demonstrated variant anatomy of the cystic artery. 96.0% originated from the right hepatic artery, 98.5% were single vessel, and 95.5% of specimens originated within Calot's triangle. An extremely rare variation was encountered.

Conclusion: The Australian population in this study demonstrates a constant albeit unique proportion of variation, dissimilar to some populations around the world. This is an important anatomical consideration for the Australian trained general surgeon attending to the international patient.

Key Words: *Cystic artery; Anatomical variation; Australia; General surgery*

Abbreviations: *ARHA: Aberrant Right Hepatic Artery; CHA: Common Hepatic Artery; GDA: Gastroduodenal Artery; HAP: Hepatic Artery Proper; LHA: Left Hepatic Artery; RHA: Right Hepatic Artery*

INTRODUCTION

Laparoscopic cholecystectomy is a very common general surgical procedure. It was performed on: 216 per 100,000 members of the Australian population; 202 per 100,000 in Canada; and, 125 per 100,000 in the United Kingdom [1].

Anatomical variants of the hepato-biliary vasculature are commonly encountered during such upper abdominal procedures and, without prior identification and knowledge, inability to recognize such variations may predict significant complications, morbidity and even occasional mortality. The particular risks are haemorrhage and bile duct injury, requiring a conversion from laparoscopic to open surgery. In one study, a conversion rate to open of 9% was quoted, the culprit being poor delineation of anatomy [2]. Publicly, this is associated with longer hospital stays and additional health costs.

The cystic artery is thus an important structure in cholecystectomy and its clear delineation in "The Critical View of Safety" is paramount prior to its dissection and related structures [3].

On review of the global literature, the incidence of atypical variations of the Cystic Artery vary widely across populations however yet to be described in the Australian population. Given the high incidence of cholecystitis and the broad ethnic demographic of Australia, local studies are needed to describe the variations amongst this significant population which is the aim of this article.

Normal anatomy

The cystic artery is the primary blood supply to the gall bladder, although it also receives an adequate supply of blood from the vessels that lay within in the gall bladder bed [4].

Origin and course: The cystic artery classically arises as a singular artery originating within Calot's triangle from the right hepatic artery. In the anatomical specimen it passes behind the cystic duct to reach the neck of the gall bladder and then branches out as superficial and deep branches over the surface of the gall bladder [4].

Calot's triangle: The hepatobiliary triangle (Calot's triangle) is a surgical landmark during laparoscopic cholecystectomy. Regarded as "The Critical View of Safety", the delineation of this landmark is the first step of this procedure to clearly identify all possible structures that need to be ligated and dissected prior to safe removal of the gall bladder [3]. Anatomically, it is bound by the common hepatic duct medially, the cystic duct laterally and the liver margin superiorly [4].

The primary structure within this triangle is of course the cystic artery. However, variations of the hepatic artery and accessory structures are commonly found within this triangle, hence dissection within this triangle is advised against without prior dissection and identification of the structures outside this triangle.

Academically, a lymph node may arise within this triangle and may act as an added structure to help identify this triangle (eponymously known as Lund's or Mascagni's Lymph node). It is commonly enlarged with cholecystitis and diseases of the biliary tree [4]. Furthermore, and outside the scope of this review, the cystic artery was the original superior boundary of this triangle as classically described by Calot, rather than the liver margin. Hence the descriptor of the triangle as "cystohepatic" is regarded a misnomer [5]. It has been suggested to rename this structure the "hepatobiliary" triangle after observed variations in this region were better described when bordered by the liver edge rather than the cystic artery [6].

Variations

Variations surround the origin of the cystic artery, the number of cystic arteries and its location within or outside the hepatobiliary triangle.

Origin: The cystic artery usually arises from the right hepatic artery, but may also arise from the main trunk of the hepatic artery, from the left hepatic artery or from the gastroduodenal artery [6].

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Multiple arteries: Michels' described specimens where the superficial and deep branches of the cystic artery would arise from two separate origins and described this as a "double cystic artery" [7]. Two specimens in this study demonstrated this variant. Incredibly, a triple Cystic Artery with three separate origins was discovered in this collection of cadavers.

Location in relation to Calot's triangle: A classification proposed by Suzuki et al. described variants to occur within or outside of Calot's triangle. The current literature proposes this as the most consistent classification when required. New classifications have arisen, however still relate to the relationship of the cystic artery within or outside of this surgical triangle [8].

Variants of the cystic artery are typically classified based on their course within or outside of Calot's triangle. This originated from Suzuki et al.:

• **Group 1:** All vessels appearing within Calot's triangle with no other vascular supply.

o **1a:** Single vessel, including atypical origin

o **1b:** Two vessels

• **Group 2:** One vessel within and one vessel outside of Calot's triangle.

• **Group 3:** All vessels appearing outside Calot's triangle with no other vascular supply.

o **3a:** Single vessel

o **3b:** Two vessels

With this broad classification, this leaves much variation within each group, most notably regarding the origin of the cystic artery. A group 1a variation with the cystic artery originating from the right hepatic artery is considered typical. New classifications have been developed, however the description of the cystic artery inside or outside the triangle is constant [9].

For simplicity and global comparison, we present our data as arteries appearing within, outside or a compound relation to Calot's triangle.

Other anatomical considerations

The course of the cystic artery anterior or posterior to the hepatic ducts are also described in the literature [6]. With upward retraction during laparoscopy, the underside of the cystic duct is viewed hence bringing the cystic artery into anterior view. Importantly, the cystic artery may also pass in front of the cystic and bile ducts, and thus this variant may prove difficult access during laparoscopy. The length of the cystic artery is also commonly measured in the literature [6].

METHODS

This was a cadaver-based study conducted over five years from 2007 to 2012, with forty cadavers donated each year to the University of Melbourne for the teaching of surgical anatomy. Thus, a total of 200 cadavers were examined. Ethics approval was given by The University of Melbourne Ethics Committee and this study is consistent with the declaration of Helsinki [10-14].

Dissection was performed by experienced anatomists with direct and meticulous examination of anatomical variants. The dissection of the hepatobiliary tree in each specimen was performed by subspecialist anatomists with a particular interest in abdominal anatomy for the specific teaching of this region.

A description of the anatomical variants throughout each specimen including other systems was compiled. Specimens with variants in the cystic artery were selected and the de-identified findings were then described in detail. Details described were:

1. The origin of the cystic artery

2. The number of vessels, and

3. The location within or outside of Calot's triangle (as described by Suzuki et al.)

The data was then collated as a percentage and discussed in comparison to the rates observed in the global literature. Unfortunately, the length of the cystic artery was not measured in this study for completeness, nor the relationship of the cystic artery to the hepatic duct explicitly mentioned.

RESULTS

Of the 200 specimens, 76 demonstrated variations of the hepatobiliary architecture. Fourteen of these involved the Cystic Artery, with the remaining variants relating to venous, bilious or viscous anatomy. A unique specimen was found with three arteries arising from three separate origins both inside and outside of Calot's triangle, will be described independently in each section (Table 1).

1. Origin of the cystic artery

192 of the specimens in this study had cystic arteries originating from the right hepatic artery (RHA). Our rate of the normal variant of the origin is thus 96.0% (192 out of 200). Two of these specimens had double artery variant originating from the RHA described in the next section. Of the other eight specimens with variation:

• Two specimens originated from the Hepatic Artery Proper (HAP) and thus 1.0%

• Two specimens originated from the Common Hepatic Artery (CHA) and thus 1.0%

• Two specimens from an Aberrant Right Hepatic Artery (ARHA) also corresponding to a rate of 1.0%

• A single variation with the cystic artery originating from the Left Hepatic Artery (LHA) was also found corresponding to a rate of 0.5%.

• Lastly, the unique specimen described had three separate origins from the RHA, CHA and Gastroduodenal Artery (GDA).

These results and comparison to the global literature are summarized (Tables 2a & 2b).

2. Number of vessels

197 of the specimens in this study had a single cystic artery. Our rate of single artery specimens is thus 98.5% (197 out of 200). Eight of these specimens had a cystic artery originating and coursing outside of Calot's triangle as described in the next section. Three specimens had more than one cystic artery.

• Two of these specimens had a double cystic artery corresponding to a rate of 1.0% (198 out of 200).

• The single, unique specimen, of course, had three arteries.

These results and comparison to the global literature are summarized in (Tables 3a & 3b).

TABLE 1

Selection of literature and related demographic.

Studies by authors	Number of specimens	Location	Primary demographic
Present Study	200	Melbourne, Australia	Australian
Michels et al. [7]	200	Pennsylvania, USA	American
Saidi et al. [11]	102	Nairobi, Kenya	African
Tejaswi et al. [12]	100	Karnataka, India	South Indian
Daseler et al. [13]	500	Illinois, USA	American
Flint et al. [14]	200	Leeds,United Kingdom	British
Gawali et al. [15]	30	Nagpur, India	Central Indian
Denderker et al. [6]	82	Maharashtra, India	Central Indian

TABLE 2a

Global comparison for the rates of the origin of the cystic artery.

Origin	Present study	Global comparison
Right Hepatic Artery (RHA)	96.0% (192 out of 200)	85.8% (71.7% - 98.0%)
Aberrant Right Hepatic Artery (ARHA)	1.0% (2 out of 200)	6.8% (0.0% - 16.1%)
Hepatic Artery Proper (HAP)	1.0% (2 out of 200)	1.9% (0.0% - 7.8%)
Common Hepatic Artery (CHA)	1.0% (2 out of 200)	1.0% (0.0% - 2.8%)
Left Hepatic Artery (LHA)	0.5% (1 out of 100)	2.6% (0.0% - 6.3%)
Gastroduodenal Artery (GDA)	0.0% (0 out of 100)	1.6% (0.0% - 4.0%)
Multiple origins	0.5% (1 out of 200)	Undescribed

TABLE 2b

Literature Review comparison for the rates of the origin of the cystic artery.

Origin	Present Study	Michels et al.	Saidi et al.	Tejaswi et al.	Daseler et al.	Flint et al.	Gawali et al.	Denderker et al.	Average of seven
RHA	96.0%	77.5%	92.2%	92.0%	71.7%	98.0%	90.0%	79.3%	85.8%
ARHA	1.0%	12.0%	0.0%	4.0%	16.1%	0.0%	3.3%	12.1%	6.8%
HAP	1.0%	0.0%	7.8%	2.0%	0.0%	0.0%	0.0%	3.7%	1.9%
CHA	1.0%	1.5%	0.0%	0.0%	2.8%	0.0%	0.0%	2.5%	1.0%
LHA	0.5%	5.0%	0.0%	1.0%	6.3%	1.5%	3.3%	1.2%	2.6%
GDA	0.0%	4.0%	0.0%	1.0%	2.6%	0.5%	3.3%	0.0%	1.6%
Multiple	0.5%	-	-	-	-	-	-	-	-

TABLE 3a

Global comparison for the rates of single, double and triple cystic arteries.

Number of arteries	Present study	Global comparison
Single	98.5% (197 out of 200)	84.8% (72.0% - 97.0%)
Double	1.0% (2 out of 200)	15.2% (3.0% - 28.0%)
Triple	0.5% (1 out of 200)	Rare

TABLE 3b

Literature review comparison for the rates of single, and multiple cystic arteries.

Number	Present Study	Michels et al.	Saidi et al.	Tejaswi et al.	Daseler et al.	Flint et al.	Gawali et al.	Denderker et al.	Average of seven
Single	98.5%	75.0%	92.2%	97.0%	86.0%	84.5%	86.7%	72.0%	84.8%
Double	1.0%	25.0%	7.8%	3.0%	14.0%	15.5%	13.3%	28.0%	15.2%
Triple	0.5%	1 case	-	-	1 case	-	-	-	-

3. Location in relation to Calot's triangle

191 of the specimens in the study had a cystic artery that originated within and coursed through the hepatobiliary triangle. Our rate of this normal variant is thus 95.5% (191 out of 200).

- Two of these specimens had double arteries both originated from the RHA within Calot's triangle corresponding to a Suzuki type 1b.
- Another two specimens coursed through Calot's triangle however originated from accessory branches of the right hepatic artery and thus considered atypical in origin.

Eight specimens originated and coursed outside of Calot's triangle as a single artery corresponding to a rate of 4.0% (8 out of 200). This would fall under Suzuki type 3a.

Finally, the unique specimen described had arteries coursing within and outside and this compound arrangement and is regarded as a Suzuki type 2. The rate of this rare entity in our study is 0.5% (1 out of 200). These results and comparison to the global literature are summarized in (Tables 4a & 4b).

TABLE 4a

Global comparison for the rates of the cystic artery in relation to Calot's triangle.

Location	Rates in study	Global comparison
Inside	95.5% (191 out of 200)	64.9% (2.0% - 90%)
Outside	4.0% (8 out of 200)	35.1% (10.0% - 98%)
Compound	0.5% (1 out of 200)	Rare

DISCUSSION

Our cohort had far less variation amongst variants than the international studies. There are many possible explanations for this, the most salient being that this study describes the true anatomical variation in prevalence amongst general cadaver specimens. The results of this study are presented and compared to the global literature in (Tables 2a, 2b, 3a, 3b, 4a and 4b).

1. Selection for literature review

After a comprehensive literature review, seven studies were selected that described a similar design to our study. Each study also represented a separate demographic as described in (Table 1). Each study yielded a range of thirty to 500 specimens with an average of 173 specimens across all studies compared to the 200 cadavers examined in the present study.

A comprehensive morphological study of the cystic artery was performed by Dandekar et al. and figures from that study are quoted in this discussion [6,15].

2. Discussion of the origin of the cystic artery

The cadavers in this Australian study yield a similar distribution to the average of the seven studies under review with regard to the origin of the cystic artery (Table 2b). The origin of the cystic artery from the right hepatic artery is the most common across all populations (96.0% compared to 85.8%). The American populations described by Daseler et al. and Michels et al., and the Indian population described by Denderker et al. have a more varied distribution regarding the origins of the cystic artery.

In contrast, the distribution of the origin of the cystic artery in the Indian populations described by Tejaswi et al. and Gawali et al. are quite dissimilar to the North Indian counterpart described by Denderker et al. and more similar to the Australian population. A separate review on South Indian cadavers by Pushpalatha et al. quotes a figure as low as 54% [16].

The Australian distribution is interestingly, albeit not unexpectedly, most similar to the British population described by Flint et al. suggesting a common lineage. Multiple origins are rare and were not described in any of the reviewed articles.

3. Discussion of the single and multiple cystic arteries

The distribution of single and double arteries across the reviews is much more scattered and therefore less conclusive to interpret without further data. However, this does exemplify that a triple cystic artery is a rare and exotic finding in the anatomical literature.

As observed in one of our specimens, only one other case was described by Michels et al. and another by Daseler et al.

Regarding the worldwide commonality of the double artery, we discover that up to 28.0% of specimens (over one in four) yield this variation. This

TABLE 4b

Literature review comparison of the cystic artery in relation to Calot's triangle.

Location	Present Study	Michels et al.	Saidi et al.	Tejaswi et al.	Daseler et al.	Flint et al.	Gawali et al.	Denderker et al.	Average
Inside	95.5%	81.0%	2.0%	65.0%	69.8%	84.0%	90.0%	62.2%	64.9%
Outside	4.0%	19.0%	98.0%	35.0%	30.2%	16.0%	10.0%	37.8%	35.1%
Compound	0.5%	-	-	-	-	-	-	-	-

would suggest that although it may be tempting to cease exploration once a single cystic artery is identified, it is important to actively search for a second cystic artery and even consider exclusion pre-operatively with angiographic imaging.

4. Discussion of cystic artery in relation to Calot's triangle

The most striking revelation from this review is the 2% group 1 normal variation within the Kenyan population described by Saidi et al. To further support this, a separate review by Bakheit amongst the Sudanese population, only 25% of the cystic arteries were within Calot's triangle, the majority outside the critical view of safety [17]. This indeed is an important variant amongst the African population, suggesting greater care is required in this subset of patients undergoing laparoscopy.

Again, the distribution of Australian cadavers in this instance is most similar to the British population described by Flint et al. further supporting a common lineage.

5. Unique aspects of this study and limitations

Our case series is the first Australian study to examine the prevalence of these anatomical variants using cadaver specimens. It further benefits from the dissection of the cadavers being assessed by experienced anatomists and having a relatively large cohort.

Prior to this, variations were commonly identified indirectly via imaging such as CT angiography, or directly during laparoscopy and open surgery [18]. Such patients present a biased cohort given that they were pre-selected for the indicated modalities as by the clinical suspicion of disease.

An example of this bias the preponderance of female patients in such studies given the established gender based established risk factor for cholecystitis. This discrepancy can be up to 75% female preponderance [18]. The presence of disease and may also distort the anatomy furthering confounding its interpretation. Of course, comparing laparoscopy to the appearance of the biliary tree in open procedure further complicates the discussion [18].

Despite this, laparoscopy can be argued to be a more applicable method of studying variants of the cystic artery, and the magnification and retraction of this modality particularly in the live patient falls in its favor. Of course, this is an entire of area of anatomical study in its own right under the heading of "laparoscopic anatomy" [18].

The limitation of this study is that it is a single centre study and ideally a multi-centre case series is needed for further evaluation. There indeed may be some selection bias as to which cadavers meets criteria for scientific donation and where thus available.

All in all, cadaver studies are essential and have an impact on doctors who train in the treatment of the associated pathology. Cadaver dissection inherently offers a broader and thorough view of the anatomy versus what is feasible through laparoscopy or open surgery. Ideally a combination of these modalities would be an interesting area of review not currently seen at the time of writing.

6. Surgical application and significance in laparoscopic cholecystectomy

The frontiers of study within the art of laparoscopic cholecystectomy surround avoiding bile duct injury, avoiding haemorrhage, exquisite knowledge of the cystic anatomy and its variants and surgical technique [9].

The classification of the cystic artery in relation to Calot's triangle in this study benefits each of these four frontiers. Intra-operative or even pre-operative knowledge of the cystic artery and its course through Calot's triangle would indeed limit the risks of bile duct injury and haemorrhage. Lastly, it provides a practical framework to organize the anatomy of the cystic artery in the Surgeon's mind, the knowledge of which adds to confident surgical technique.

CONCLUSION

This is the first study to assess the prevalence of cystic artery variants amongst the Australian population. It suggests that such variants appear to be far less common than is seen internationally. It shows the value of understanding anatomical variants and the value of appropriate pre-surgical planning.

This study also demonstrates the importance of international variation of surgical anatomy. Hence, this reinforces the importance of training and exposure via international fellowships with concomitant anatomical teaching, to increase exposure to significant variants not commonly encountered within a particular region. Even if the higher rates of normal variation in the literature are discarded, the atypical variants still do not follow the same trend in our cohort. This implies that there is indeed a local dissimilitude of prevalence.

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