Research Article

Anatomical variations of the hepatic artery in patients who undergo Contrast Enhanced Computed Tomography (CECT) abdomen at a tertiary care hospital in Sri Lanka

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Abstract

Background and objective- Research on hepatic arterial anatomy is pivotal due to its clinical relevance for hepato-biliary interventions. Evidence on variant anatomy of hepatic vasculature is scarce in Sri Lanka. We aimed to assess the anatomical variations of the hepatic artery using Michel's classification and determine their association with gender and ethnicity.

Methods- Patients above the age of five years who underwent CECT abdomen in arterial phase from August to December 2023 were consecutively recruited. CECT images were analysed, and recorded with socio-demographic information of the patients. Chi-square tests were used to compare proportions.

Results- Among 139 participants, the majority were males (51.8%), middle-aged (54.7%) and Sinhalese (81.3%). 24.5% showed an anatomical variation of the hepatic artery. The most common variant patterns were replaced left hepatic artery (7.2%), replaced right hepatic artery (5%) and common hepatic artery arising from superior mesenteric artery (3.6%). Females had a 13% increased chance for hepatic artery variations compared to males, but this association was not statistically significant (p=0.73). Tamil participants recorded the highest proportion of variant anatomy (33%) but the differences between ethnicities were not significant (p=0.66). Only one participant showed an atypical distribution that did not match Michel's categories.

Conclusions- Variant hepatic arterial anatomy in this Sri Lankan clinical population largely tallied the global prevalence but with different patterns. Further research is needed into the gender- and ethnic- differences and atypical variations identified by this study.

Key words: liver, vascular, classification, diagnostic imaging, Asia

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Introduction

The anatomy of the hepatic artery has been recognized as an important area of research due to the vast range of variations observed and their clinical relevance in performing surgeries and other interventions. Studies on hepatic arterial anatomy are commonly carried out through cadaveric dissections, during surgeries and more importantly via imaging studies.

The 'normal anatomy' of the hepatic artery refers to the classic branching of the common hepatic artery from the coeliac artery in addition to the left gastric artery and splenic artery. Common hepatic artery gives rise to the hepatic artery proper which subsequently divides into right and left hepatic arteries to supply the entire liver. The presence of this normal hepatic arterial anatomy has been observed among 50% to 80% of the participants in different studies.[1] An international review which included nearly 19,000 patients from twenty studies identified normal hepatic arterial anatomy among 81% of the participants.[2]

Understanding the development of the hepatic artery is crucial for identifying its variants' origins. During embryonic development, four ventral segmental arteries interconnected by longitudinal anastomosis arise from the dorsal aorta. Typically, the coeliac artery is formed from the junction of the first three roots. The second and third roots become rudimentary during the growth of the fetus. The fourth trunk develops into the superior mesenteric artery. With fetal development the interconnections between the coeliac artery and superior mesenteric artery roots diminish, resulting in their anatomical separation. Individual differences in this process result in variations in the coeliac artery, superior mesenteric artery and common hepatic artery depending on the extent of degeneration of primitive splanchnic vessels.[3]

Variant anatomy of the hepatic artery could either be related to the alternative origin of the common hepatic artery or related to the anomalous origin of all or parts of the right and left hepatic arteries called 'aberrant hepatic arteries'. The common hepatic artery can arise directly from the abdominal aorta or the superior mesenteric artery. Aberrant hepatic arteries can be of two types. An 'accessory hepatic artery' arises from an anomalous origin and supplies a portion of the liver along with another artery. A 'replaced hepatic artery' arises from an anomalous origin and supplies a portion of the liver solely.[4]

Across the world, country- and region-specific variations in the hepatic arterial anatomy have been recorded in the literature.[5-9] However, the current Sri Lankan evidence regarding coeliac and hepatic arterial anatomy comes only from a few cadaveric studies and case series of surgical patients.[10-12] Hence there is a serious dearth of radiological evidence regarding anatomical variants of the hepatic artery in Sri Lanka. Our study was aimed at addressing this main gap in knowledge.

Many classifications have been proposed to categorise the types of variations that occur. Michel's classification, Hiatt classification and Garg classification are some of the commonly used systems.[3] In 1966, Michel et al. identified ten types of anatomical variants of the hepatic artery. Over the last few decades, 'Michel's Classification' became the most widely applied method in describing hepatic vasculature and was thus used for the current study.[13] It is summarised in Table 1 and some of the common Michel's categories are schematically represented in Figure 1. Hiatt et al. were able to reduce the number of Michel's categories to six.[14] However, there is evidence of atypical and rare variations of the hepatic arterial system that are not captured by these classifications.[3,15] Another deficiency is that these classifications are based on the point of origin and do not necessarily describe the route taken by the hepatic arteries in relation to the surrounding anatomy.[16]

Table 1: Michel's classification of hepatic arterial anatomy

Michel's Type	Arterial Pattern
Type I	Normal anatomy
Type II	Replaced left hepatic artery (LHA) from left gastric artery (LGA)
Type III	Replaced right hepatic artery (RHA) from superior mesenteric artery (SMA)
Type IV	Replaced left and right hepatic artery
Type V	Accessory left hepatic artery
Type VI	Accessory right hepatic artery
Type VII	Accessory left hepatic artery and accessory right hepatic artery
Type VIII	Replaced left hepatic artery and accessory right hepatic artery or replaced right hepatic artery and accessory left hepatic artery
Type IX	Common hepatic artery (CHA) from superior mesenteric artery
Type X	Common hepatic artery from left gastric artery

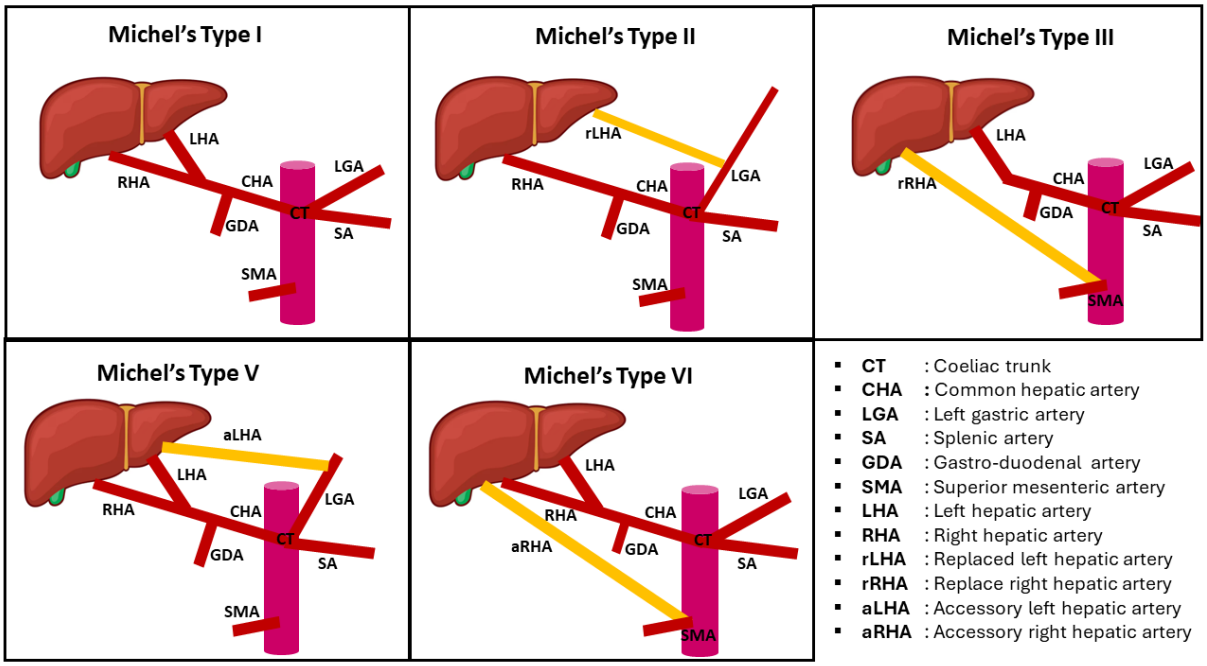

Figure 1: Schematic representation of common Michael's categories

Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are the most commonly used imaging methods to accurately detect the hepatic arterial system and its variants. Digital subtraction angiography (DSA) is considered the gold standard imaging modality for the demonstration of arterial anatomy. But, due to its invasiveness, it is rarely done solely for diagnostic purposes. Axial CT imaging has shown 96.3% sensitivity, 87% specificity and 88% accuracy for the detection of aberrant RHAs.[17] Therefore, hepatobiliary imaging by CT scans is being used in surgical practice for pre-operative identification of variant arteries. Newer CT developments - for example, multi-detector row CT angiography (MDCTA) - have been identified to improve the imaging of anatomical variants in the hepatic artery.[18]

Anatomical knowledge of the hepatic vasculature generated by this study becomes significant in fields of hepato-biliary surgery (both open and laparoscopic), pancreatic surgery and interventional radiology.[19] For example, aberrant right hepatic arteries have been observed among one in five patients undergoing pancreatic or biliary surgery.[16] Our findings can inform surgeons on safe surgical access during pancreatoduodenectomies and in minimizing intra-operative vascular complications in live donor liver transplants.[9,20] Knowledge of the most prevalent hepatic arterial patterns in Sri Lanka will have practical benefits in situations where CT imaging might not be readily available or in emergency trauma situations.

Associations have also been drawn between the presence of these variants and post-surgical complications.[19,21] There is also evidence to suggest that the presence of variant hepatic anatomy - for example, aberrant right hepatic arteries - can contribute to the process of hepatic metastasis.[19] Knowledge of variant hepatic arterial anatomy is also important for trans-arterial angioembolization in the non-operative management of traumatic liver injuries and chemo-embolization procedures in cancers of the liver.

So, the main aim of this study was to assess the anatomical variations in the hepatic artery according to Michel's classification and determine their associated factors among patients who undergo CECT abdomen (in arterial phase) at the Teaching Hospital Peradeniya. We also aimed to investigate any variant anatomies that are not defined by Michel's categories.

Methods

This descriptive, cross-sectional study was carried out from August 2022 to May 2024. Data collection was done at the Teaching Hospital Peradeniya from August 2023 to December 2023. All patients who were above the age of five years and underwent CECT abdomen in arterial phase at the Department of Radiology, Teaching Hospital Peradeniya during the study duration were included in the study. Patients who were not able to complete the CECT abdomen procedure, patients who have undergone hepatic vascular surgery and

those who have a history of hepatic trauma were excluded.

The minimum sample size was computed using the formula to estimate a population proportion with specified absolute precision.[22] The proportion with anatomical variations of the hepatic artery was considered to be 20% based on previous literature.[2] The sample size was calculated for a 95% confidence level and an absolute precision of 7%. 125 participants were required at the level of data analysis. This number was inflated by 10% to account for possible missing data and a final sample size of 138 patients was calculated. A consecutive sampling method was used to recruit participants. Each patient who was subjected to CECT abdomen in the arterial phase from August 2023 was recruited till the final sample size was achieved. In situations where patients did not meet the inclusion criteria, the next adjacent patient to undergo the procedure was selected.

CECT abdomen images in the arterial phase with 3D reconstruction were the main data source used in this study and a structured data collection sheet was used as the main study instrument. The data collection sheet was used to record the socio-demographic information of the study participants and the image findings. The user-friendliness and comprehensiveness of the data collection sheet were assessed via a pretest that was carried out using a few sample records.

Following the imaging procedures of patients, CECT images were examined by the primary investigator via the console to evaluate the visceral arterial anatomy for variations in the coeliac axis and hepatic arteries. Relevant findings of hepatic arterial anatomy according to Michel's classification and remarks on any other variations were then recorded in the data collection sheet. Expertise from the supervising consultant radiologist was taken in reporting all findings that were not clearly defined.

Data were initially entered into Microsoft Excel and were exported into SPSS 25 (Statistical Package for Social Sciences 25.0) software for data coding and analyses. The main outcome variable was the anatomy of the hepatic artery as operationalised by the Michel's classification (Table 1). Michel's Type 1 was recoded as normal anatomy and Michel's Type II to X was recoded as variant anatomy. The main exposure variables were gender and ethnicity. Both numerical and graphical methods were used to present the findings. Normally distributed continuous data related to exposure variables were summarized using mean and standard deviation. Categorical data related to exposure and outcome measures were presented numerically using percentages in tables and graphically via pie charts and bar charts. Differences in proportions between categorical variables were assessed using the chi square test. A *p*-value less than 0.05 was considered to be statistically significant.

All the participants underwent CECT imaging as a part of their diagnostic workup and no participants were subjected to radiation for the purpose of the study.

Following the entry of data, all the spreadsheets and datasets were kept in a password-protected computer. All the identifiable information of the participants was removed or coded for anonymity prior to data analyses. Ethical clearance was obtained from the Ethical Review Committee of the Teaching Hospital Peradeniya (ERC Number: TP/PLANNING/ERC/19/2023). Necessary administrative permissions were obtained from the administrators of the Teaching Hospital Peradeniya and the consultants attached to the Department of Radiology.

Results

Study participants

The total sample comprised 139 participants. The majority were males (51.8%). The mean age of the sample was 53.4 years (SD: 16.3). Most of the participants (54.7%) were middle-aged (25 to 59 years of age). There were 38.8% of older persons (60 years and above) and 5.8% young persons (16 to 24 years). The sample mostly included Sinhalese participants (81.3%), followed by 10.8% Muslim and 7.9% Tamil participants.

Hepatic arterial anatomy

Michel's Type 1 or normal anatomy of hepatic vasculature was observed in 75.5% (n=105) of the patients. Among the variant anatomy, replaced left hepatic artery was the most common pattern which was present among 7.2% (n=10). This was followed by the replaced right hepatic artery seen among 5% (n=7) and the common hepatic artery arising superior mesenteric artery observed among 3.6% (n=5).

The least common variant anatomy was the combined presence of accessory right hepatic and left hepatic arteries and the common hepatic artery arising from left gastric artery which were seen in only one participant each. These findings are summarised in Figure 2.

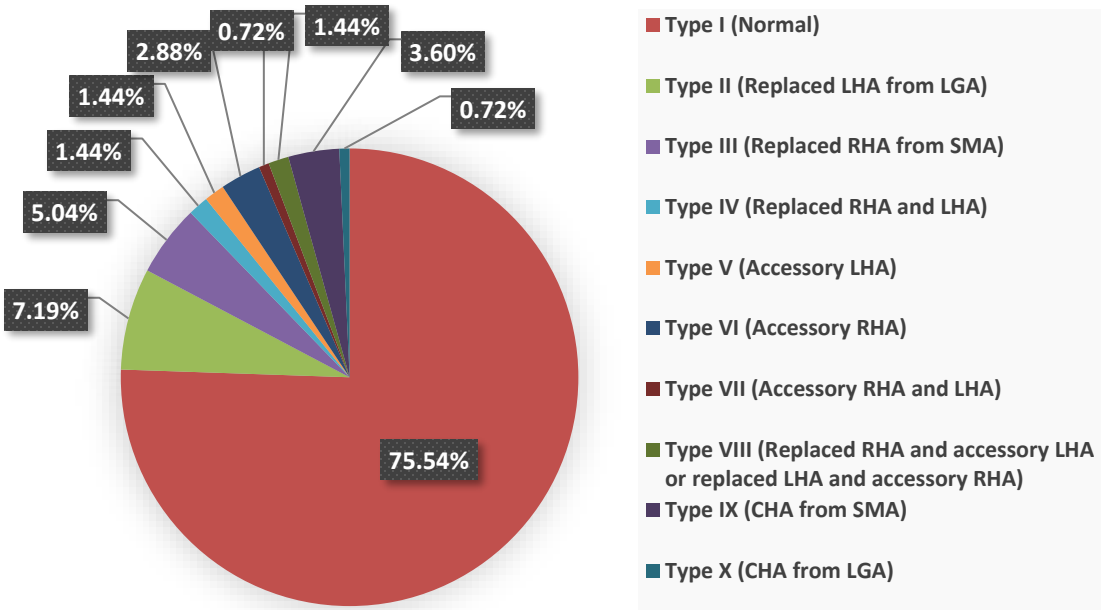

Figure 2: Hepatic arterial anatomy variations in the sample based on Michel's classification

Atypical hepatic arterial anatomy

Among the 139 participants who underwent CECT abdomen imaging during the study duration, only one participant was observed to have hepatic arterial anatomy that deviated from the typical pattern of Michel's categories. This patient had a hepatic arterial anatomy that largely followed Michel's Type I distribution but where the coeliac axis was branched below the superior mesenteric artery in the aorta to give rise to hepatic vasculature.

Hepatic arterial anatomy by gender

As illustrated in Table 2, normal anatomy of the hepatic artery was reported among 73.6% (n=53) of males compared to 77.6% (n=52) of females. The most common variant anatomy (8.3%, n=6) among males was the replaced left hepatic artery. This was followed by the accessory right hepatic artery seen among 5.6% (n=4) of males and by the replaced right hepatic seen among 4.2% (n=3) of males.

The most common variant anatomy among females was the replaced left hepatic artery and the replaced right hepatic artery, accounting for 6.0% (n=4) each.

When comparing normal versus variant anatomy between genders, females showed 1.13 times increased chance of having variant anatomy of the hepatic vasculature compared to males. Figure 3 summarises these differences. However, this increased odds was not statistically significant (chi square value = 0.11, *p*-value = 0.73, confidence intervals (CI) = 0.53 – 2.46).

Table 2: Hepatic arterial anatomy of the patients by gender

Michel's Classification		Gender					
		Male		Female		Total	
		n	%	n	%	n	%
Type I	Normal	53	73.6%	52	77.6%	105	75.5%
Type II	Replaced LHA from LGA	6	8.3%	4	6.0%	10	7.2%
Type III	Replaced RHA from SMA	3	4.2%	4	6.0%	7	5.0%
Type IV	Replaced RHA and LHA	2	2.8%	0	0.0%	2	1.4%
Type V	Accessory LHA	1	1.4%	1	1.5%	2	1.4%
Type VI	Accessory RHA	4	5.6%	0	0.0%	4	2.9%
Type VII	Accessory RHA and LHA	0	0.0%	1	1.5%	1	0.7%
Type VIII	Replaced RHA and accessory LHA or replaced LHA and accessory RHA	0	0.0%	2	3.0%	2	1.4%
Type IX	CHA from SMA	3	4.2%	2	3.0%	5	3.6%
Type X	CHA from LGA	0	0.0%	1	1.5%	1	0.7%

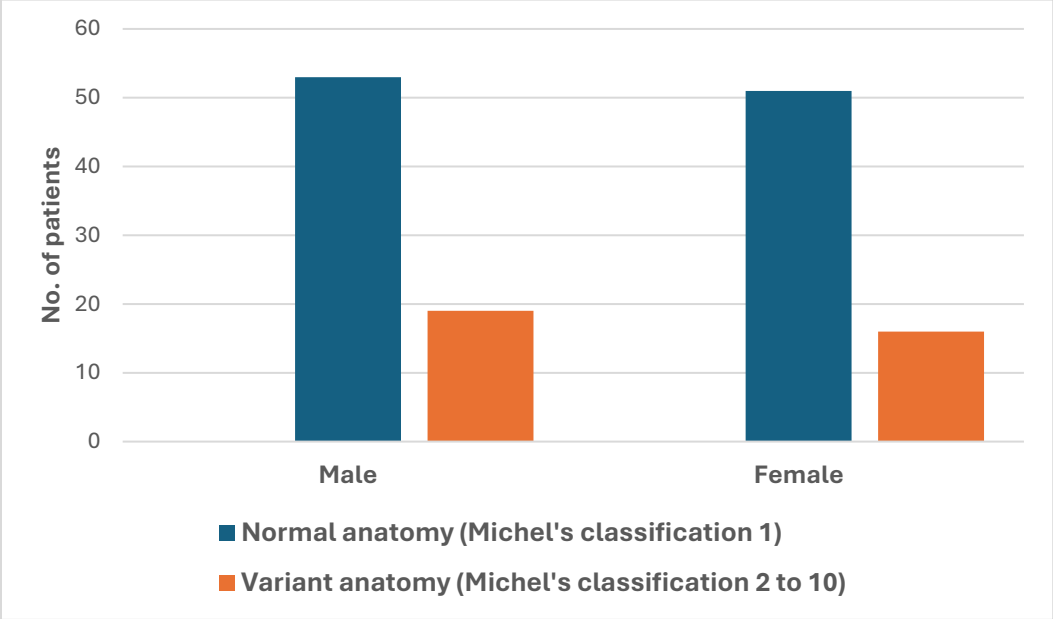

Figure 3: Distribution of normal versus variant anatomy by sex

Hepatic arterial anatomy by ethnicity

Normal anatomy of the hepatic vasculature was reported among 77% of the Sinhalese (n=87), 73.3% of the Muslim community (n=11) and 63.6% of the Tamils (n=7). As shown in Table 3, the most common type of variant anatomy noted among the Sinhalese was the replaced left hepatic artery (7.1%, n=8) which was followed by the replaced right hepatic artery (5.3%, n=6). 3.5% (n=4) of the Sinhalese participants had either an accessory right hepatic artery or were found with a common hepatic artery arising from superior mesenteric artery.

As evident by Table 3, among the Muslim participants, replaced left hepatic artery, accessory left hepatic artery, combined left and right accessory hepatic arteries, and common hepatic artery arising from superior mesenteric artery were the reported variant categories.

Replaced left hepatic artery, replaced right hepatic artery, combined left and right replaced hepatic arteries, and common hepatic artery arising from the left gastric artery were the observed categories among the Tamil participants.

Table 3: Hepatic arterial anatomy of the patients by ethnicity

Michel's Classification		Ethnicity					
		Sinhala		Muslim		Tamil	
		n	%	n	%	n	%
Type I	Normal	87	77.0%	11	73.3%	7	63.6%
Type II	Replaced LHA from LGA	8	7.1%	1	6.7%	1	9.1%
Type III	Replaced RHA from SMA	6	5.3%	0	0.0%	1	9.1%
Type IV	Replaced RHA and LHA	1	0.9%	0	0.0%	1	9.1%
Type V	Accessory LHA	1	0.9%	1	6.7%	0	0.0%
Type VI	Accessory RHA	4	3.5%	0	0.0%	0	0.0%
Type VII	Accessory RHA and LHA	0	0.0%	1	6.7%	0	0.0%
Type VIII	Replaced RHA and accessory LHA or replaced LHA and accessory RHA	2	1.8%	0	0.0%	0	0.0%
Type IX	CHA from SMA	4	3.5%	1	6.7%	0	0.0%
Type X	CHA from LGA	0	0.0%	0	0.0%	1	9.1%

Figure 4 summarises the prevalence of normal and variant anatomy between ethnicities. However, there was no statistically significant difference in the prevalence of normal and variant categories of hepatic arterial anatomy between ethnicities shown in Figure 3 (chi square value= 0.85, *p*-value = 0.65).

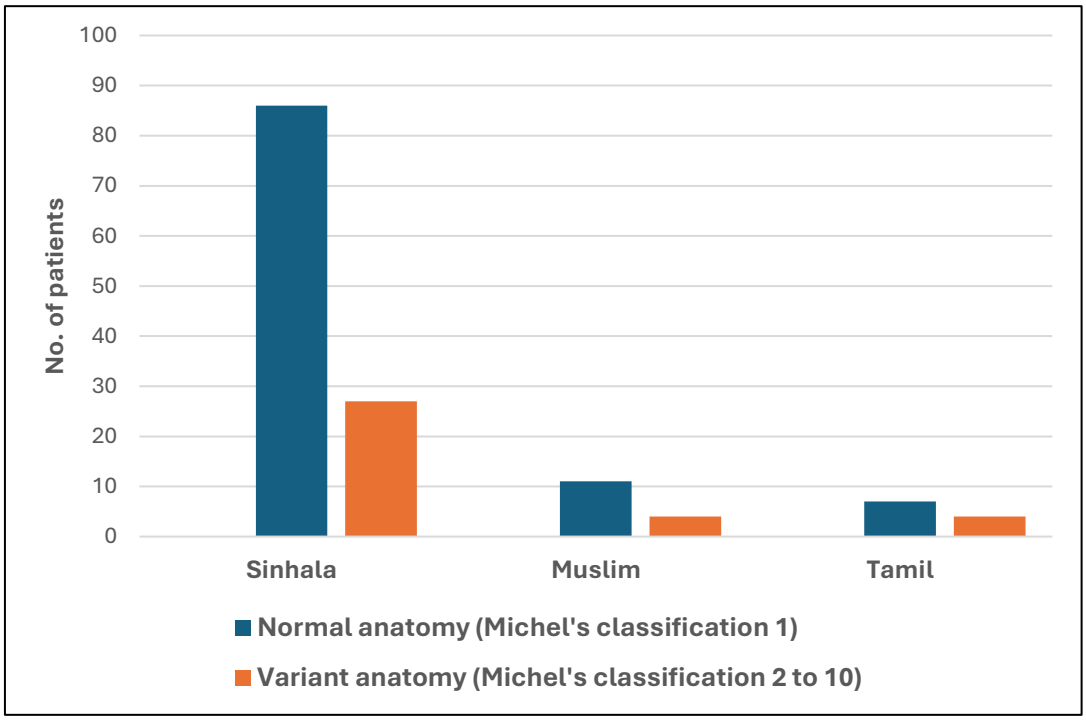

Figure 4: Distribution of the normal versus variant anatomy by ethnicity

Discussion

To the best of our knowledge, this is the first study that was conducted in Sri Lanka to determine the prevalence of normal and variant hepatic arterial anatomy among a clinical population using radiographic imaging methods. The study population had a near equal representation of males and females with the majority being middle-aged and Sinhalese. 24.46% of participants showed variations in hepatic arterial anatomy. However, there were no statistically significant associations of variant anatomy with either gender or ethnicity.

Noussios et al. (2017) and Malviya and Verma (2023) in their reviews of hepatic arterial variations identify variant anatomy to be present around 20% or 20% - 30% of the population respectively.[2,16] Our findings of the overall prevalence of anatomical variations largely tallied this evidence and were also similar to the prevalence rates seen in several countries. For example, the prevalence of variant anatomy in a study carried out in Greece in 2019 using CT images of 1520 patients was 22.2%.[15] Among studies in the Asian region, a study done in South Korea in 2021 with the participation of 5625 patients showed a prevalence of 27.1%.[23]

However, our findings also had discrepancies with the prevalence rates observed in many other countries. For example, a study done in Portugal in 2019 using CT images showed a markedly lower prevalence for variant anatomy of 13%.[24] Meanwhile, in South Asia, two studies conducted in India (between 2014-15) and in Pakistan (between 2016-18) using CT imaging showed the prevalence of hepatic arterial variations to be 43% and 35.6% respectively.[8,25] Considering other regions of the world, Turkey (between 2019-21), West Indies (2021) and France (between 2019-20) also showed a high prevalence for variant anatomy of 39.1%, 45.4% and 34.4% respectively.[5,7,26] These disparities in the presence of variant anatomy could be attributed to the heterogeneity of the sampled populations and methodological differences. However, they may have also been influenced by genetic and geographic factors which provide directions for future research.

The replaced right hepatic artery is the most common hepatic arterial variation recorded in the global literature.[2,16] However, the replaced left hepatic artery arising from the left gastric artery was the most common variant observed in the current study. This variation has been reported in the Sri Lankan population before.[27] Malviya and Verma (2023) in their literature review identified the prevalence of the replaced left hepatic artery to range from 5% - 10% which tallied with our findings.[16] The regional evidence however gives a mixed picture about the commonest variation. Hanif et al. (2020) identified the replaced left hepatic artery (13.5%) to be more common in Pakistan than the replaced right hepatic artery (12.1%).[8] Choi et al. (2019) reported that in South Korea aberrant left hepatic artery (16.3) was more common than the aberrant right hepatic artery (15.6).[23] Meanwhile, in neighbouring India, the replaced right hepatic artery was

the most common variant (8%) compared to other categories.[25] The presence of the common hepatic artery originating from the superior mesenteric artery - the third most common variant anatomy - appeared to be more prevalent in the study population (3.6%) than in the regional statistics (1.8%).[6]

The least common categories observed in this study, accessory left hepatic and right hepatic arteries being together and common hepatic artery originating from left gastric artery, were rarely seen in the world literature as well.[19] Nevertheless, the combined presence of left and right accessory hepatic arteries has been previously reported in cadaveric studies in Sri Lanka.[28]

Replaced left hepatic artery was more commonly seen in men than women in this study although it has a female predominance regionally.[6] Replaced left and right hepatic arteries showed equal prevalence among females in the study population and might indicate the need to consider both variations during interventions of female patients. The study also showed that although females show an increased occurrence of hepatic arterial variations, the association between gender and variant anatomy was not statistically significant. However, this loss of significance could have been due to a Type II error caused by a limited sample size.

The majority of participants in the study were Sinhalese as the Teaching Hospital Peradeniya is based in a Sinhalese predominant community. Nevertheless, the study revealed that the Tamil population shows the highest proportion of anatomical variations followed by Muslims and Sinhalese. The smaller number of participants from Tamil and Muslim populations may have affected the validity of the results. This limited representation could have also been a reason for observing no statistically significant differences in the prevalence of variant categories among ethnicities.

Research and clinical implications

This study highlights several important hypotheses to be tested by future research and points toward other relevant studies that could be built on this evidence. The hypotheses that were generated about the association of the variant anatomy with gender and ethnicity among Sri Lankans must be evaluated by larger studies with increased sample diversity. The sample sizes of such studies must be calculated based on statistical tests aimed at assessing those differences to ensure sufficient statistical power.

Coeliac axis branching below the superior mesenteric artery in the aorta to give rise to hepatic vasculature was observed in the study which cannot be classified under Michel's classification or any other classification systems currently available. This emphasizes the importance of further studying hepatic arterial variations in view of building broader classification systems.

Cohort (longitudinal) studies can be planned to investigate the effect of these anatomical variations on surgical and clinical outcomes of patients. Such studies could be able to

quantify the incidence and relative risk associated with common variations of the hepatic artery. Moreover, there are also possibilities for novel research that examines the association of genetic factors with the common variations of the hepatic arterial anatomy.

Our findings have a direct influence on the clinical practices in Sri Lanka, in the areas of pancreatico-biliary surgery, liver transplantations and endovascular radiological interventions, as outlined before. This study informs hepato-biliary surgeons and interventional radiologists in Sri Lanka to be equipped with in-depth knowledge of the anatomy of Michel's Type II category since it is the variation that has the highest probability of encountering during their surgeries or interventions. This is particularly important for clinical encounters where prior imaging is not available. However, it is also recommended to direct attention to the course of Michel's Type III category since it is not uncommon among Sri Lankan clinical populations. Our findings also inform the surgical community of the level of anticipation that is required for variations such as the combined presence of aberrant hepatic arteries or variations at the level of the common hepatic artery when preparing for surgery.

Conclusions

Every one in four participants who underwent CECT abdomen imaging at Teaching Hospital Peradeniya had an anatomical variation of the hepatic artery. This study also demonstrated that the overall prevalence of variant anatomy in a Sri Lankan clinical population was similar to global estimates but differed in its patterns. As practice recommendations, this study has highlighted the most common variants of the hepatic artery to be considered during hepatobiliary interventions in Sri Lanka. Furthermore, this study recommends future research into gender and ethnic differences and atypical variations of the hepatic vasculature identified by this study.

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