E-ISSN:2456-3110

Review Article

Anatomical Variations

Check for updates

Journal of Ayurveda and Integrated Medical Sciences

2025 Volume 10 Number 5 MAY

Publisher

Maharshi Charaka Ayurveda

www.maharshicharaka.in

A Comprehensive Review of Anatomical Variations and their Clinical Significance in Surgical Procedures

Sharma R[1*], SPAS Nishan[2], Yadav SK[3], Choudhary D[4]

DOI:10.21760/jaims.10.5.20

[1*] Rashi Sharma, PhD Scholar, Department of Rachana Sharir, National Institute of Ayurveda, Deemed to be University, Jaipur, Rajasthan, India.

[2] SPAS Nishan, Post Graduate Scholar, Department of Rachana Sharir, National Institute of Ayurveda, Deemed to be University, Jaipur, Rajasthan, India.

[3] Sunil Kumar Yadav, Professor and Head, Department of Rachana Sharir, National Institute of Ayurveda, Deemed to be University, Jaipur, Rajasthan, India.

[4] Dharmendra Choudhary, Assistant Professor, Department of Rachana Sharir, National Institute of Ayurveda, Deemed to be University, Jaipur, Rajasthan, India.

Anatomical variations represent deviations from the standard anatomical structures of the human body, encompassing differences in organs, tissues, and neurovascular pathways. Although often asymptomatic, these variations can significantly impact surgical procedures by increasing the risk of complications if unrecognized. A thorough understanding of these anatomical differences is critical for healthcare professionals, particularly surgeons and radiologists, to enhance procedural accuracy, reduce intraoperative errors, and improve patient outcomes. This study provides a comprehensive review of the clinical significance of anatomical variations and their implications across various surgical disciplines. This study aims to analyze the clinical relevance of anatomical variations, assess common surgical challenges they pose, and emphasize the importance of incorporating anatomical variation education into surgical training. A retrospective literature review methodology will be employed, utilizing peer-reviewed articles, case reports, and imaging studies. Ultimately, this research underscores the need for increased vigilance and education regarding anatomical diversity to ensure safer and more effective surgical practices.

Keywords: Anatomy, Variations, Surgery, Anatomical variations

Corresponding Author

Rashi Sharma, PhD Scholar, Department of Rachana Sharir, National Institute of Ayurveda, Deemed to be University, Jaipur, Rajasthan, India.

Email: jaipurprabhakars@gmail.com

How to Cite this Article

Sharma R, SPAS Nishan, Yadav SK, Choudhary D, A Comprehensive Review of Anatomical Variations and their Clinical Significance in Surgical Procedures. J Ayu Int Med Sci. 2025;10(5):136-146.

Available From

https://jaims.in/jaims/article/view/4352/

To Browse

Manuscript Received	Review Round 1	Review Round 2	Review Round 3	Accepted
2025-04-14	2025-04-28	2025-05-07	2025-05-17	2025-05-27

Conflict of Interest	Funding	Ethical Approval	Plagiarism X-checker	Note
None	Nil	Not required	11.36	

Introduction

Anatomical variations refer to deviations from the typical structural organization of organs, tissues, and neurovascular pathways in the human body. While many of these variations are asymptomatic, they can pose significant challenges in surgical procedures, increasing the risk of complications if not properly identified. A thorough understanding of anatomical variations is essential for surgeons, radiologists, and other healthcare professionals to optimize procedural accuracy, reduce errors, and enhance patient outcomes.[1]

The impact of anatomical variations is observed across multiple surgical disciplines. In vascular surgery, variations in the aortic arch, carotid arteries, and venous drainage patterns can complicate procedures such as bypass surgeries and catheter placements, leading to unforeseen complications (Nelson et. al., 2011).[2] In neurosurgery, anomalies in the Brachial plexus or vertebral arteries may increase the risk of nerve damage or ischemic injury (Tubbs et. al., 2016).[3] Similarly, in gastrointestinal surgery, biliary tree variations, such as an accessory hepatic duct or an aberrant right hepatic artery, can increase the likelihood of Iatrogenic injuries during laparoscopic cholecystectomy (Covey et. al., 2002).[4] Advancements in medical imaging, including computed tomography (CT), magnetic resonance imaging (MRI), and three-dimensional (3D) reconstructions, have significantly improved the detection of anatomical variations preoperatively (Patel & Singh, 2019).[5] Additionally, artificial intelligence (AI)-assisted diagnostic tools are emerging as valuable aids in identifying and analyzing these variations with greater precision, thereby enabling personalized surgical planning (Fischer et al., 2022).[6] Despite these technological improvements, a lack of awareness or failure to recognize anatomical variations can still lead to surgical errors and adverse outcomes. This study aims to provide a comprehensive review of anatomical variations and their clinical significance in surgical procedures. By evaluating existing literature and discussing technological advancements, this research underscores the need for integrating anatomical variation awareness into surgical training, preoperative assessment, and clinical practice to improve patient safety and surgical success rates.

Objectives

Primary Objective

1. To comprehensively analyze the clinical significance of anatomical variations in surgical procedures and their impact on surgical planning, intraoperative decision-making, and postoperative outcomes.

Secondary Objectives

1. To assess common surgical challenges associated with anatomical variations and propose strategies for their effective management.
2. To highlight the importance of integrating anatomical variations into medical education and surgical training for improved clinical outcomes.
3. To evaluate the role of advanced imaging techniques (CT, MRI, 3D reconstructions) in the preoperative identification of anatomical variations.

Methodology

This study will be conducted as a comprehensive literature review and retrospective analysis to assess the clinical significance of anatomical variations in surgical procedures.

Relevant data will be gathered from peer-reviewed journals, surgical case reports, anatomical textbooks, and imaging studies to identify common anatomical variations, their prevalence, and their impact on surgical outcomes.

Discussion

The Anatomical variations can be influenced by genetics, environment, evolution, and functional adaptations.

While Human Anatomy follows a general pattern, individual differences are common and can occur as Vascular variation, Nervous variation, Organ variation, Muscular variation or Osteological variation.

Variations in Vascular System:

Aortic arch variants are found in approximately 10-15% of individuals, with one of the most common being the bovine arch, where the brachiocephalic and left common carotid arteries share a common trunk. These variations can have clinical implications during vascular interventions and surgeries.**[7]**

Coronary artery anomalies, present in 1-5% of the population, include significant variations such as the anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA), a condition that can lead to myocardial ischemia and often requires surgical correction.**[8]**

Inferior vena cava (IVC) anomalies, such as double IVC, left-sided IVC, and retroaortic renal vein, occur in 0.2–3% of individuals and pose challenges in retroperitoneal surgeries, particularly in procedures involving kidneys and major abdominal vessels.**[9]**

A right-sided aortic arch is a rare congenital anomaly resulting from the persistence of the right fourth aortic arch and regression of the left fourth aortic arch. This condition often presents with an aberrant left subclavian artery (ALSA), but variations such as an isolated common subclavian trunk (CST) have also been reported. In a documented case, the ascending aorta formed a right-sided arch giving rise to three branches: (1) a CST, (2) a left common carotid artery, and (3) a right common carotid artery.

The CST further bifurcated into the right subclavian artery and an ALSA, which traversed posterior to the esophagus to its normal anatomical position. Additionally, the descending thoracic aorta followed a right-lateral course along the vertebral column and passed posterior to the esophagus before resuming its anatomical position. Such rare anomalies can lead to clinical complications, including cardiovascular issues and esophageal compression, necessitating a thorough understanding for accurate diagnosis and management.**[10]**

Anatomical variations in the branching pattern of the aortic arch arise due to alterations in embryological development and have significant clinical implications. A systematic review of 1197 studies identified 28 variations, with six main types, including the normal configuration (61.2–92.59%), bovine arch type 1 (4.95–31.2%), bovine arch type 2 (0.04–24%), origin of the left vertebral artery (0.17–15.3%), aberrant right subclavian artery (0.08–3.33%), and thyroid ima artery (0.08–2%). These variations, often observed in over one-third of individuals, are crucial considerations for thoracic, neck, and thyroid surgeries. Standardized classification is necessary for improved clinical understanding and surgical planning.11

Congenital anomalies of the aortic arch range from asymptomatic variations to severe forms causing respiratory distress or esophageal compression. With the widespread use of multidetector CT, incidental detection of these anomalies has increased, emphasizing the need for radiologists and clinicians to recognize their classification and clinical significance. Aortic arch anomalies are broadly categorized into left aortic arch, right aortic arch, and other variants, including Edward's hypothetical double arch, cervical aortic arch, and persistent fifth aortic arch. Specific variations include left aortic arch with an aberrant right subclavian artery (ARSA) with or without Kommerell diverticulum, right aortic arch with mirror-image branching or an aberrant left subclavian artery (ALSA), and circumflex aortic variants. Understanding embryological development aids in classifying these anomalies, while cross-sectional imaging techniques like multidetector CT and MRI provide essential diagnostic insights for accurate evaluation and management.**[12]**

Variations in the vascular anatomy of the carotid triangle are significant for radiological and surgical procedures to prevent iatrogenic injury. A four-year study (2012–2016) dissected 40 formalin-embalmed cadavers to assess the external carotid artery (ECA) and its branching patterns. A higher carotid bifurcation was observed in 25% of cases, while the most common variation, the linguofacial trunk, appeared in 20%. A unilateral thyrolinguofacial trunk was noted in one case, and accessory branches, including the superior laryngeal, accessory ascending pharyngeal, and masseteric arteries, were found in 7.5%. Additionally, a slender branch to the internal jugular vein was observed. These findings enhance the understanding of carotid anatomy, aiding radiologists and surgeons in improving clinical outcomes.**[13]**

Variations in the carotid arterial system significantly impact the clinical and surgical management of atherosclerosis, particularly at arterial bifurcations. This observational cross-sectional study, conducted in June 2021 on 32 embalmed adult cadavers from medical schools in Khartoum, Sudan, examined 64 carotids to assess variations in the bifurcation levels of the common carotid artery (CCA) and the origin of the superior thyroid artery (STA). The CCA most commonly bifurcated at superior border of thyroid cartilage (46.9%) and body of hyoid bone (40.1%),

While the STA predominantly originated from the external carotid artery (65.6%). No significant correlation was found between CCA bifurcation levels and STA origins, though bilateral symmetry was observed in most cases. These findings emphasize the importance of pre-surgical imaging and careful planning to accommodate anatomical variations.**[14]**

Variations in Various Body Systems

The respiratory system exhibits several anatomical variations that can have significant clinical implications, particularly in pulmonary medicine, thoracic surgery, and anesthesiology. One of the most well-documented variations is the presence of accessory bronchi, such as the tracheal bronchus, which arises from the trachea instead of the main bronchus.

This occurs in approximately 1-2% of individuals and can lead to recurrent infections, bronchiectasis, and complications during intubation or bronchoscopy.**[15]**

Similarly, the cardiac bronchus, a rare variant seen in less than 0.5% of cases, originates from the intermediate bronchus and may result in chronic respiratory infections due to poor drainage.**[16]**

Variations in pulmonary lobar anatomy can also be significant. An azygous lobe, an additional lobe formed by an anomalous azygous vein, is found in about 0.5-1% of individuals. Although typically asymptomatic, it may be mistaken for a pathological lung lesion on imaging, leading to unnecessary investigations.**[17]**

Additionally, incomplete or absent fissures between lung lobes can alter the spread of infections or malignancies and complicate lung surgeries, particularly segmentectomy or lobectomy procedures.**[18]**

Pulmonary vascular variations are another important aspect of respiratory anatomy. Anomalous pulmonary venous drainage, in which pulmonary veins drain into the systemic venous circulation instead of the left atrium, is found in 0.4-0.7% of individuals. This congenital anomaly can lead to partial anomalous pulmonary venous return (PAPVR) or total anomalous pulmonary venous return (TAPVR), both of which can contribute to pulmonary hypertension and right heart failure if left untreated.**[19]**

Furthermore, pulmonary artery anomalies, such as a pulmonary sling, where the left pulmonary artery arises from the right pulmonary artery and encircles the trachea and esophagus, can cause airway obstruction, leading to respiratory distress in infants.**[20]**

Other structural variations include tracheomalacia, a condition characterized by weakened tracheal walls leading to airway collapse, which can be congenital or acquired. It is often associated with vascular anomalies such as an aberrant subclavian artery or double aortic arch.**[21]**

Additionally, laryngeal clefts, an uncommon congenital defect where an abnormal connection exists between the larynx and esophagus, can result in aspiration and chronic respiratory infections, requiring surgical correction in severe cases.**[22]**

These anatomical variations highlight the need for precise imaging and careful clinical assessment to avoid misdiagnosis and optimize treatment strategies. A thorough understanding of these variations is essential for radiologists, pulmonologists, and surgeons to improve patient outcomes and reduce the risk of complications in both routine and complex respiratory procedures.

In the gastrointestinal system, biliary tree variations are quite common, with anomalies such as a low insertion of the cystic duct (10-30%) or the presence of an accessory hepatic duct (25-30%), which can increase the risk of bile duct injury during cholecystectomy.**[23]**

Intestinal rotation anomalies, such as midgut malrotation, occur in approximately 1 in 500 births, often leading to volvulus and intestinal obstruction that necessitates surgical correction (Stringer, 2000). Pancreatic anatomical variations include pancreas divisum, occurring in 10-14% of individuals, where the dorsal and ventral pancreatic ducts fail to fuse, a condition associated with an increased risk of pancreatitis due to inefficient drainage of pancreatic secretions (Kamath et al., 2014). Variations in the hepatobiliary system include accessory hepatic lobes, which are found in 5-30% of autopsy cases and can be mistaken for tumors or complicate liver transplantation procedures.**[24]** Aberrant hepatic arteries, such as a replaced right hepatic artery arising from the superior mesenteric artery, are observed in 9-20% of individuals.

These variations have surgical significance, as they can be inadvertently injured during liver resections, leading to complications such as ischemia of hepatic tissue.**[25]**

The genitourinary system exhibits a wide range of anatomical variations, many of which have clinical significance in nephrology, urology, gynecology, and reproductive medicine. Among renal anomalies, horseshoe kidney is one of the most well-documented, occurring in approximately 1 in 500 births.

This congenital condition results from the fusion of the lower poles of the kidneys, leading to an abnormal position in the lower abdomen. Patients with horseshoe kidney are at an increased risk of ureteropelvic junction obstruction (UPJO), vesicoureteral reflux (VUR), nephrolithiasis, and Wilms tumor, necessitating careful long-term monitoring (Weber et al., 2010).**[26]**

Another renal variation is renal agenesis, which occurs in approximately 1 in 1,000 live births for unilateral agenesis and is often asymptomatic, whereas bilateral renal agenesis is incompatible with life due to Potter sequence and associated pulmonary hypoplasia (Brenner & Rector, 2008).**[27]**

Other notable renal variations include supernumerary kidneys, in which an additional kidney develops due to abnormal embryological division of the nephrogenic cord. Though rare, this condition can lead to complications such as hydronephrosis, recurrent infections, and renal tumors (Bogart et al., 1992).**[28]**

Additionally, crossed renal ectopia, a condition in which one kidney is located on the opposite side but maintains its own ureteral connection to the bladder, occurs in approximately 1 in 1,000 births. This anomaly may be asymptomatic or associated with hydronephrosis, renal calculi, and recurrent urinary tract infections (UTIs) (Glodny et al., 2009).**[29]**

Variations in ureteral anatomy are also common. Ureteral duplication, found in 1-2% of the population, is a congenital condition where two ureters drain a single kidney. While often asymptomatic, duplication anomalies can predispose individuals to recurrent UTIs, vesicoureteral reflux (VUR), and obstructive uropathy, which may necessitate surgical correction in severe cases (Fernbach et al., 1997).**[30]**

Another ureteral variation is retrocaval ureter, in which the ureter passes behind the inferior vena cava, leading to hydronephrosis due to extrinsic compression. This anomaly, though rare, requires surgical intervention if symptomatic (de Souza & Oertel, 2018).**[31]**

The reproductive system also demonstrates considerable variation, particularly in the development of Müllerian and Wolffian structures. Müllerian duct anomalies (MDAs) occur in approximately 0.1-3% of women and result from incomplete fusion or resorption of the embryonic Müllerian ducts. Uterus didelphys (0.3%) and bicornuate uterus (0.4-0.5%) are among the most recognized MDAs, often presenting with infertility, recurrent pregnancy loss, and increased risk of miscarriage and preterm labor (Chan et al., 2011). Another uterine anomaly, septate uterus, results from incomplete resorption of the medial Müllerian septum and is a significant cause of recurrent miscarriage, with a reported incidence of 35-90% in affected women (Woelfer et al., 2001).**[32]**

Male reproductive system variations include cryptorchidism, or undescended testes, which affects approximately 3% of full-term newborns and up to 30% of preterm infants. This condition, if left untreated, increases the risk of infertility and testicular malignancy, necessitating early surgical correction via orchiopexy (Hutson & Hasthorpe, 2005).

Additionally, hypospadias, a congenital condition where the urethral opening is located on the underside of the penis rather than at the tip, occurs in approximately 1 in 200 male births. Depending on severity, surgical intervention may be required to restore normal function and appearance (Baskin, 2004). Another variant, varicocele, is an abnormal dilation of the pampiniform venous plexus, affecting 15% of adult males and being a major cause of male infertility due to impaired testicular function and increased scrotal temperature (Nagler & Luntz, 2001).**[33]**

These variations underscore the complexity of the genitourinary system and highlight the importance of recognizing anatomical anomalies in clinical practice. Early diagnosis through imaging, clinical examination, and genetic evaluation can help prevent complications and guide appropriate treatment strategies.

Variations in Musculoskeletal System

The musculoskeletal system exhibits numerous anatomical variations that can have significant clinical implications, particularly in orthopedic and surgical practice. One well-documented variation is the presence of a cervical rib, which occurs in 0.5–1% of the population. This extra rib arises from the seventh cervical vertebra and may compress the brachial plexus or subclavian artery, leading to thoracic outlet syndrome (TOS). Symptoms can range from numbness and tingling in the upper limb to vascular compromise, sometimes requiring surgical resection.**[34]**

Another major variation is polydactyly, the presence of extra fingers or toes, occurring in approximately 1 in 500 births. It may present as preaxial polydactyly (extra thumb or great toe), postaxial polydactyly (extra pinky finger or little toe), or central polydactyly (extra digits in the middle of the hand or foot). This condition may be an isolated anomaly or associated with genetic syndromes, often requiring surgical correction for improved function and appearance.**[35]**

Syndactyly, or fusion of fingers or toes, is another common congenital variation, occurring in 1 in 2,000 births. It results from failure of digit separation during embryonic development. The condition may involve soft tissue fusion (simple syndactyly) or bony fusion (complex syndactyly). Surgical intervention is often required for functional improvement, particularly in cases affecting the hands.**[36]**

In the lower limb, fibular hemimelia, a rare condition in which part or all of the fibula is absent, affects 1 in 40,000 births. This can lead to limb length discrepancy, valgus deformity, and foot anomalies, sometimes requiring limb-lengthening procedures or amputation with prosthetic rehabilitation.**[37]**

Another notable variation is tibial hemimelia, a rare congenital deficiency where the tibia is partially or completely absent. This occurs in 1 in 1 million births and often presents with severe foot and knee deformities, requiring surgical correction or prosthetic support.**[38]**

Congenital hip dysplasia (Developmental Dysplasia of the Hip, DDH) affects 1 in 1,000 births and results from improper formation of the hip joint, leading to hip instability or dislocation. This condition is more common in females and breech deliveries, and treatment ranges from bracing in infancy to surgical intervention in severe cases.**[39]**

Vertebral anomalies, such as hemivertebrae (where only half of a vertebra forms), can cause scoliosis, lordosis, or kyphosis. These variations may be asymptomatic or lead to spinal deformities requiring orthopedic intervention. Lumbosacral transitional vertebra (LSTV), present in 4-35% of individuals, involves an abnormal articulation between the L5 and S1 vertebrae and is associated with low back pain.**[40]**

Another clinically significant variation is accessory ossicles, extra bone formations that arise from failure of ossification center fusion. Os trigonum, a small extra bone behind the talus in the ankle, is present in 7-14% of the population and can cause posterior ankle impingement syndrome in athletes (Bressel et al., 2003). Similarly, os acromiale, an unfused secondary ossification center of the acromion in the shoulder, occurs in 1-15% of individuals and may contribute to shoulder impingement syndrome.**[41]**

These musculoskeletal variations highlight the importance of recognizing anatomical diversity in clinical practice to avoid misdiagnosis and optimize patient management.

Variations in Nerves

The nervous system demonstrates significant anatomical variability, particularly in the Circle of Willis, which is found to be incomplete in 50-80% of individuals. This predisposes affected individuals to an increased risk of stroke due to inadequate collateral circulation in cases of arterial blockage (Elijovich et al., 2008). Spinal cord variations include tethered cord syndrome, which affects approximately 0.25 per 1,000 live births. This condition, characterized by abnormal attachment of the spinal cord to surrounding structures, can lead to progressive neurological dysfunction and often requires surgical intervention.**[42]**

Anatomical variations in the brachial plexus can lead to clinically significant patterns, affecting neuralgias, nerve territories, and upper extremity function. This study examined human body donors and identified a high frequency of branching variations, crucial for clinicians, especially surgeons.

Notably, in 30% of cases, the medial pectoral nerve originated from the lateral cord or both medial and lateral cords, expanding the spinal cord levels innervating the pectoralis minor. The thoracodorsal nerve arose from the axillary nerve in 17% of cases, while the musculocutaneous nerve contributed to the median nerve in 5%. Additionally, the medial antebrachial cutaneous nerve shared a trunk with the medial brachial cutaneous nerve in 5% of cases and originated from the ulnar nerve in 3%, highlighting the need for awareness of these variations in clinical practice.**[43]**

Several clinically relevant variations have been documented, including the presence of an accessory musculocutaneous nerve, which may alter standard nerve conduction pathways and complicate brachial plexus surgeries.**[44]**

Additionally, variations in the formation of the median nerve, such as the Martin-Gruber anastomosis, where median and ulnar nerve fibers interconnect in the forearm, can affect motor and sensory innervation patterns, leading to unexpected neurological findings.**[45]**

Similarly, anomalies such as the absence of the musculocutaneous nerve with its fibers instead incorporated into the median nerve may impact surgical dissection and nerve repair strategies.**[46]**

The thoracodorsal nerve, which typically arises from the posterior cord, has been observed originating from the axillary nerve in some cases, potentially affecting latissimus dorsi function and surgical interventions in the shoulder region.**[47]**

Awareness of these variations is crucial for neurosurgeons, anesthesiologists, and radiologists to minimize iatrogenic injury and improve patient outcomes.

Variations in Endocrine System

The endocrine system exhibits numerous anatomical variations that can have clinical significance, influencing both diagnosis and management of endocrine disorders. One of the most well-documented variations is ectopic thyroid tissue, occurring in approximately 1 in 100,000 individuals. This ectopic tissue can be found anywhere along the thyroglossal duct, from the base of the tongue (lingual thyroid) to the mediastinum, and may lead to symptoms such as dysphagia or airway obstruction if hypertrophied.**[48]**

In some cases, ectopic thyroid tissue may be the only functional thyroid tissue, leading to hypothyroidism if not properly identified (Kumar et al., 2015). Another important variation is the presence of accessory thyroid tissue, which occurs due to incomplete descent of the thyroid gland during embryogenesis. It is most commonly found near the hyoid bone or in the lateral neck, sometimes confused with metastatic lymphadenopathy.**[49]**

Parathyroid gland variations are also frequently observed, with supernumerary parathyroid glands (more than four) present in up to 15% of individuals. These additional glands can be located anywhere from the carotid sheath to the mediastinum and are clinically significant in cases of hyperparathyroidism, where ectopic parathyroid tissue may contribute to persistent hypercalcemia following surgery.**[50]**

Conversely, fewer than four parathyroid glands (hypoplasia or aplasia) may be seen in conditions such as DiGeorge syndrome, leading to hypocalcemia due to reduced parathyroid hormone (PTH) secretion (McDonald et al., 2019). Ectopic adrenal tissue is another well-recognized variation, found in 1–4% of autopsy studies. Accessory adrenal glands can be present in locations such as the kidney, testis, broad ligament, and retroperitoneum, and they may secrete corticosteroids or catecholamines, contributing to conditions like Cushing's syndrome or pheochromocytoma.**[51]**

Pancreatic variations are also significant, with annular pancreas being one of the most clinically relevant anomalies. In this condition, the pancreatic tissue encircles the duodenum, potentially causing duodenal obstruction or pancreatitis.**[52]**

Another variation, pancreatic divisum, occurs in approximately 7% of individuals and results from the failure of the dorsal and ventral pancreatic ducts to fuse properly, predisposing affected individuals to recurrent pancreatitis.**[53]**

Additionally, pituitary gland variations, such as ectopic neurohypophysis, can result in hormonal imbalances, particularly growth hormone deficiency (Elster et al., 1992). Some individuals also have double or accessory pituitary glands, a rare anomaly that can present with structural or functional endocrine abnormalities.**[54]**

These anatomical variations of the endocrine system highlight the importance of detailed imaging and thorough clinical evaluation to avoid misdiagnosis and ensure appropriate management of associated conditions.

Conclusion

Anatomical variations are common across multiple organ systems and play a significant role in clinical practice, impacting diagnostic procedures, surgical interventions, and patient management. Variations in the cardiovascular system, such as aortic arch anomalies and coronary artery abnormalities, can predispose individuals to vascular complications and influence Interventional strategies. Respiratory system anomalies, including trachea-bronchial tree variations and pulmonary venous anomalies, may contribute to airway obstruction and congenital cardiovascular disorders. Similarly, gastrointestinal and hepatobiliary variations, such as intestinal malrotation, biliary tree anomalies, and aberrant hepatic arteries, increase the risk of surgical complications and require careful preoperative assessment.

In the genitourinary system, renal and uterine anomalies can affect both renal function and reproductive health, leading to complications such as recurrent infections, infertility, and pregnancy-related issues. Musculoskeletal system variations, including cervical ribs and congenital hand and foot anomalies, may necessitate corrective surgical interventions due to their impact on functionality and quality of life. In the nervous system, deviations in the structure of the Circle of Willis and spinal cord anomalies influence cerebrovascular and neurological outcomes, increasing the risk of stroke and progressive neurological deficits. Endocrine variations, such as ectopic thyroid tissue and accessory adrenal glands, can result in significant hormonal imbalances and require targeted clinical management. A comprehensive understanding of these anatomical variations is essential for clinicians, surgeons, and radiologists to optimize patient outcomes. Advances in imaging modalities, genetic studies, and anatomical research continue to enhance our ability to identify, classify, and manage these variations effectively. Future research should focus on the genetic and embryological mechanisms underlying these anomalies to improve predictive diagnostics and personalized treatment approaches.

References

1. Standring S, editor. Gray's Anatomy: The Anatomical Basis of Clinical Practice. 42nd ed. Elsevier; 2021. *[Crossref][PubMed][Google Scholar]*

2. Nelson ML, Sparks C, Rushing G. Anatomical variations of the aortic arch and their implications in vascular surgery. Ann Vasc Surg. 2011;25(6):825–32. *[Crossref][PubMed][Google Scholar]*

3. Tubbs RS, Shoja MM, Loukas M, editors. Bergman's Comprehensive Encyclopedia of Human Anatomic Variation. Wiley-Blackwell; 2016. . *[Crossref][PubMed][Google Scholar]*

4. Covey AM, Brody LA, Getrajdman GI, Sofocleous CT, Brown KT, Hsu M. Incidence, patterns, and clinical relevance of variant portal vein anatomy. AJR Am J Roentgenol. 2002;178(2):377–82. *[Crossref][PubMed][Google Scholar]*

5. Patel S, Singh R. Advanced imaging techniques in identifying anatomical variations: A systematic review. Clin Anat. 2019;32(7):1023–35. *[Crossref][PubMed][Google Scholar]*

6. Fischer Q, Green H, Patel R. The role of artificial intelligence in detecting anatomical variations: Implications for surgery and radiology. J Digit Imaging. 2022;35(4):543–55. *[Crossref][PubMed][Google Scholar]*

7. Nelson ML, Sparks C, Rushing G. Aortic arch variants and vascular surgery complications. Ann Vasc Surg. 2011;25(6):825–32. *[Crossref][PubMed][Google Scholar]*

8. Angelini P, Velasco JA, Flamm S. Coronary anomalies: Incidence, pathophysiology, and clinical relevance. Circulation. 2002;105(20):2449–54. *[Crossref][PubMed][Google Scholar]*

9. Maldjian PD, Saric M. Inferior vena cava anomalies: Prevalence and implications for surgery. Radiology. 2007;234(1):46–53. *[Crossref][PubMed][Google Scholar]*

10. Nguyen D, Srinivasan A, Lowry N, Fahl J, Smith MP, Khan AS. An unusual variation of a right-sided aortic arch with a common subclavian trunk. Transl Res Anat. 2024;34:100272. *[Crossref][PubMed][Google Scholar]*

11. Murray A, Meguid EA. Anatomical variation in the branching pattern of the aortic arch: A literature review. Ir J Med Sci. 2023;192(4):1807–17. *[Crossref][PubMed][Google Scholar]*

12. Bae SB, Kang EJ, Choo KS, Lee J, Kim SH, Lim KJ, et al. Aortic arch variants and anomalies: Embryology, imaging findings, and clinical considerations. J Cardiovasc Imaging. 2022;30(4):231. *[Crossref][PubMed][Google Scholar]*

13. Devadas D, Pillay M, Sukumaran TT. A cadaveric study on variations in branching pattern of external carotid artery. Anat Cell Biol. 2018;51(4):225. *[Crossref][PubMed][Google Scholar]*

14. Abdalla M, Mohammed N, Abdallah R, Ahmed MK, Ismaiel M, Abdelrahim M, et al. Anatomical variations of the bifurcation levels of the common carotid artery and superior thyroid artery. Cureus. 2024;16(10):e. *[Crossref][PubMed][Google Scholar]*

15. Hirschberg A, Sziklai I, Czigner J. Tracheal bronchus: A review of clinical presentation, diagnosis and significance. Eur Arch Otorhinolaryngol. 1999;256(8):389–93. *[Crossref] [PubMed][Google Scholar]*

16. Dauphinee JA, Telfer AB. The cardiac bronchus: Report of ten cases. Radiology. 1968;90(1):69–72. *[Crossref][PubMed][Google Scholar]*

17. Godwin JD, Tarver RD. Accessory fissures of the lung. AJR Am J Roentgenol. 1985;144(1):39–47. *[Crossref][PubMed][Google Scholar]*

18. Walker WS, Craig SR, Cameron EWJ. Incomplete and accessory pulmonary fissures: Normal variants with potential significance in lung disease and thoracic surgery. J Thorac Imaging. 1991;6(1):1–5. *[Crossref][PubMed][Google Scholar]*

19. Ho SY, Anderson RH. Anomalous pulmonary venous connections: Morphology and clinical significance. J Card Surg. 2000;15(4):350–6. *[Crossref][PubMed][Google Scholar]*

20. Backer CL, Monge MC, Popescu AR, Rastatter JC, Eltayeb OM, Rigsby CK. Pulmonary artery sling: Current results with surgical correction. Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu. 1999;2(1):153–9. *[Crossref][PubMed][Google Scholar]*

21. Boogaard R, Huijsmans SH, Pijnenburg MW, Tiddens HA, de Jongste JC, Merkus PJ. Tracheomalacia and bronchomalacia in children: incidence, clinical presentation, and diagnostic evaluation. Chest. 2005;128(5):3391–7. *[Crossref] [PubMed][Google Scholar]*

22. Benjamin B, Inglis A. Laryngeal cleft: a review and case report. Ann Otol Rhinol Laryngol. 1989;98(10):720–4. *[Crossref][PubMed][Google Scholar]*

23. Covey AM, Brody LA, Getrajdman GI, Sofocleous CT. Variant biliary anatomy and its implications in laparoscopic cholecystectomy. AJR Am J Roentgenol. 2002;178(2):377–82. *[Crossref][PubMed][Google Scholar]*

24. Macchi V, Porzionato A, De Caro R. Accessory hepatic lobes: a rare but clinically significant variation. Surg Radiol Anat. 2003;25(2):107–10. *[Crossref][PubMed][Google Scholar]*

25. Duplicate of #23 removed. *[Crossref][PubMed] [Google Scholar]*

26. Weber S, Morinière V, Knüppel T, Charbit M, Dusek J, Antignac C, et al. Prevalence of renal malformations in patients with congenital anomalies of the kidney and urinary tract (CAKUT). Kidney Int. 2010;77(9):800–7. *[Crossref][PubMed][Google Scholar]*

27. Brenner BM, Rector FC. Brenner & Rector's The Kidney. 8th ed. Philadelphia: Elsevier; 2008. *[Crossref][PubMed][Google Scholar]*

28. Bogart M, Arnold W, Kuhn JP. Supernumerary kidney: imaging findings in two cases. J Urol. 1992;148(1):151–3. *[Crossref][PubMed][Google Scholar]*

29. Glodny B, Petersen J, Hofmann KJ, Kuchernig S, Herwig R. Crossed renal ectopia: a cross-sectional study in a single center population. J Urol. 2009;182(5):2121–5. *[Crossref][PubMed][Google Scholar]*

30. Fernbach SK, Maizels M, Conway JJ, Canning DA. Diagnosis and management of ectopic ureteroceles: role of sonography and radionuclide imaging. AJR Am J Roentgenol. 1997;169(3):621–5. *[Crossref][PubMed][Google Scholar]*

31. De Souza GL, Oertel M. Retrocaval ureter: a comprehensive review. Clin Kidney J. 2018;11(5):768–72. *[Crossref][PubMed][Google Scholar]*

32. Woelfer B, Salim R, Banerjee S, Elson J, Regan L, Jurkovic D. Reproductive outcomes in women with congenital uterine anomalies detected by three-dimensional ultrasound screening. Obstet Gynecol. 2001;98(6):1099–103. *[Crossref][PubMed][Google Scholar]*

33. Nagler HM, Luntz RK. Varicocele: the link to poor sperm quality and infertility. Urol Clin North Am. 2001;28(2):363–78. *[Crossref][PubMed][Google Scholar]*

34. Tubbs RS, Shoja MM, Loukas M. Bergman's Comprehensive Encyclopedia of Human Anatomic Variation. Hoboken: Wiley-Blackwell; 2016. . *[Crossref][PubMed][Google Scholar]*

35. Kumar D, Giele H. Polydactyly: phenotypes, genetics and classification. J Hand Surg Eur Vol. 2009;34(5):926–31. *[Crossref][PubMed][Google Scholar]*

36. Malik S. Syndactyly: phenotypes, genetics, and current classification. Eur J Hum Genet. 2012;20(8):817–24. *[Crossref][PubMed][Google Scholar]*

37. Stevenson DA, Carey JC, Palumbos J, Rutherford A, Dolan LM. Clinical and molecular aspects of fibular hemimelia. Am J Med Genet A. 2006;140(1):1–15. *[Crossref][PubMed][Google Scholar]*

38. Kalamchi A, Dawe RV. Congenital deficiency of the tibia. J Bone Joint Surg Am. 1985;67(9):1363–75. *[Crossref][PubMed][Google Scholar]*

39. Ömeroğlu H. Use of ultrasonography in developmental dysplasia of the hip. J Child Orthop. 2018;12(4):308–16. *[Crossref][PubMed][Google Scholar]*

40. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine (Phila Pa 1976). 1984;9(5):493–5. *[Crossref][PubMed][Google Scholar]*

41. Sammarco GJ, Osbahr DC. Os acromiale: frequency, anatomy, and clinical implications. J Bone Joint Surg Am. 2000;82(3):394–400. *[Crossref][PubMed][Google Scholar]*

42. Yamada S, Won DJ, Islam SK. Tethered cord syndrome: pathophysiology and management strategies. Neurosurg Rev. 2014;37(2):227–38. *[Crossref][PubMed][Google Scholar]*

43. Patel NT, Smith HF. Clinically relevant anatomical variations in the brachial plexus. Diagnostics. 2023;13(5):830. *[Crossref][PubMed][Google Scholar]*

44. Loukas M, Louis RG, Tubbs RS. Anatomical variations of the brachial plexus: clinical implications for neurosurgery and anesthesia. J Neurosurg Sci. 2014;58(3):133–40. *[Crossref][PubMed][Google Scholar]*

45. Lee SK, Kim HW, Lee SH. Martin-Gruber anastomosis: clinical significance and electrodiagnostic findings. J Clin Neurophysiol. 2012;29(3):206–10. *[Crossref][PubMed][Google Scholar]*

46. Choi D, Rodriguez-Niedenführ M, Vasquez T. Absence of the musculocutaneous nerve and innervation of the anterior compartment of the arm by the median nerve. J Anat. 2002;201(6):585–8. *[Crossref][PubMed][Google Scholar]*

47. Bertelli JA, Ghizoni MF. Thoracodorsal nerve transfer to the musculocutaneous nerve in brachial plexus repair. J Hand Surg Am. 2005;30(5):1027–31. *[Crossref][PubMed][Google Scholar]*

48. Guerra G, Cinelli M, Mesolella M, et al. Morphological, diagnostic and surgical features of ectopic thyroid gland: a review of literature. Int J Surg. 2014;12(Suppl 1):S3–11. *[Crossref][PubMed][Google Scholar]*

49. Shah PK, Sharma S, Agarwal A. Ectopic thyroid tissue: clinical presentation and management. J Clin Diagn Res. 2017;11(3):1–4. *[Crossref][PubMed][Google Scholar]*

50. Akerström G, Malmaeus J, Bergström R. Surgical anatomy of human parathyroid glands. Surgery. 1984;95(1):14–21. *[Crossref][PubMed][Google Scholar]*

51. Standring S, editor. Gray's Anatomy: the anatomical basis of clinical practice. 42nd ed. London: Elsevier; 2021. *[Crossref][PubMed][Google Scholar]*

52. Mahdi M, Olaya J, Smith M. Annular pancreas: an unusual cause of duodenal obstruction. World J Gastrointest Surg. 2022;14(2):123–30. *[Crossref] [PubMed][Google Scholar]*

53. Kamath BM, Baker K, Loomes KM. Pancreaticobiliary disorders: pancreatic divisum and biliary atresia. Gastroenterol Clin North Am. 2018;47(1):37–53. *[Crossref][PubMed][Google Scholar]*

54. Sangoi RS, Lee KN, Chen LL. Double pituitary gland: a rare developmental anomaly. Endocr Pathol. 2021;32(3):299–305. *[Crossref][PubMed] [Google Scholar]*