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Harmonizing diversity: introducing a universal classification system and database concept for anatomical variations

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Abstract

Objectives: Despite the wide interest in studying anatomical variations of the human body, significant gaps and inconsistencies remain in the literature. The use of variable terminologies and inconsistent classification systems remain a few of the key contributors for this gap. Many of these challenges can be addressed by adopting a universal classification system alongside a standard database. This study introduces a practical approach for the classification of variations that can reduce miscommunications and ensure a thorough evaluation.

Methods: In this novel Universal Classification System, solid organ variations are categorized as variations in: measurements (size, weight, dimensions); shape; consistency (presence, absence, multiplication); variation in associated structures or ducts (origin, termination, branching, variation in supply and consistency); and variations in blood supply, lymph drainage and innervation. For nerves, lymph and blood vessels, variations are classified as variation in origin (level and mode of origin – normal or aberrant); variation in termination (level and way of termination as bifurcation, trifurcation, etc.); branching variations (origin, variation in supply and consistency); consistency; and site of supply. An additional category of 'other' includes variations that cannot be classified under the above categories (aplasia/absence, hypoplasia, fenestration, tortuosity, loops, etc.).

Results: Application of the proposed Universal Classification System demonstrated that anatomical variations can be systematically and consistently categorized across different organ systems. Based on these findings, a standardized database model was developed to store and manage variation data using the same classification framework. The results define the database structure, data entry and storage procedures, maintenance principles, and access protocols, providing a practical and reproducible tool for the standardized documentation and retrieval of anatomical variation data.

Conclusion: The findings of this study confirm that a universal classification system can effectively standardize the evaluation of anatomical variations. The resulting database framework translates this system into a practical and scalable tool, facilitating consistent reporting, data storage, and knowledge transfer. This approach contributes to a more coherent and accessible body of anatomical variation data for educational and clinical use.

Keywords: anatomical variations; database; universal classification system

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Introduction

It is undeniable that numerous inherent anatomical variations exist within the human body, often deviating from what we learn as the standard human body structure. Most of these remain asymptomatic and seemingly benign, while others can be associated with pathologies[1,2] and considered as developmental defect/ congenital defect or malformation then. However, both have the potential to complicate procedures and lead to misdiagnoses if not adequately understood.[3–5]

Despite the vast interest in research on anatomical variations, there remains a notable gap in the literature related to certain areas, in addition to the discrepancies in the reported data. This is probably because of the variation in prevalence across different populations and the possibility of being under-reported, where certain varia-

tions tend to be more prevalent among specific ethnic groups.[6]

Current evidence on variations primarily derives from cadaveric dissections, imaging studies,[7–9] and peri-operative findings.[10] However, the manner they are reported shows an inconsistency such as the use of different terminology and classification systems[10–33] The approaches seem to focus on specific variations they encounter, rather than actively observing the others. In a wide literature search on basilar artery termination patterns done using PubMed, Ovid MEDLINE, and Scopus databases, using the terms "(basilar OR vertebrobasilar OR (posterior AND circulation)) AND (anatomy OR termination OR trifurcation OR quadfurcation OR pentafurcation OR hexafurcation OR nonfurcation OR variation OR variant)"[10] we noted documented variation on reporting termination (shape of bifurcation and presence of trifurcation, quadrifurcation, pentafurcation, nonfurcation), variations on site of origin and termination, presence of fenestrations, duplications, presence of the band, the origin of other arteries (middle meningeal artery, persistent trigeminal artery, etc.), shape of the basilar artery, dolichoectatic artery, etc. Each study seemed to have focused on a few of the above variations without documented evidence of actively looking for others. Since anatomical variations tend to vary, some populations or geographical areas may lack certain variations. Hence even the absence of certain variations is worthwhile documenting.

One of the major limitations of the above is the lack of proper adherence to a standard classification system and a database. A simple and feasible classification system would help to conduct thorough evaluations and target the completeness of the structure under study. Lack of a proper approach in studies may lead to inadequate evidence and also create confusion among study data when performing any kind of review or a meta-analysis. The suggestion of a database has also been there for some time.[11,12] Even when creating such a database, a universal classification is eminent, to avoid repetition and miscommunication.

Though few studies have put forward classification systems for specific anatomical regions like the circle of Willis,[12] spleen,[13] bile duct,[14] etc., many anatomical regions and structures do not have a proper way of recording. Even regarding the ones that have been published, we noted a poor adherence. The presence of several classification systems for the same structure can be observed for structures such as the biliary system. A Cohort study done by Deka et al.[15] in 2014 compared six such selected classification systems of biliary anatomy, namely Couinaud (1957), Huang (1996), Karakas (2008), Choi (2003), Champetier (1994), and Ohkubo (2004). This revealed, despite the merits and demerits of each classification system, none of them were ideal to include everything.[15] Such inability to classify certain newly discovered anatomical variations under any of the previously described classification systems is another problem. This is further observed in the recent literature describing the variations of the sciatic nerve, in which more than 7 variations have been discovered that cannot be classified under the Beaton and Anson classification system (1937) of the sciatic nerve.[16,17]

Another problem to be encountered with structure or region-specific classification systems is the absence of a standardized approach for analysing the variations when approaching a novel structure or area in anatomy, which also can be addressed by a specific classification system, proposed below. Such approach would enhance completeness, minimize bias in analysis and increase clarity in reporting variations. Even with the acknowledged significance, there is still no universal classification system for their reporting.[18] A universal classification system (UCS) may serve as a standard classification method; to facilitate proper communication and global understanding; to level the ground for all possible user groups trying to enrich themselves with any information; and to prevent any misunderstandings and differences caused by the use of different terms and ways of classifying the information.

The objective of this study is to address inconsistencies in the reporting of anatomical variations by proposing a unified classification system and an associated database framework that enables systematic evaluation, storage, and retrieval of variation data. The proposed UCS is designed to ensure standardization, allowing the structural model to be operationalized across different anatomical systems and facilitating cooperation and data exchange between institutions and countries. In addition, the system is conceived to be flexible, enabling adaptation to future changes in technology, knowledge, and clinical or educational contexts, thereby maintaining long-term relevance and functionality. Finally, the classification aims to provide comprehensive coverage within its defined scope, ensuring that all relevant anatomical variations can be consistently classified without omission.

Materials and Methods

We have taken two approaches depending on the type of organ: one for solid organs and the other for nerves, lymph vessels, or vessels. The classifications are summarised in **Figures 1** and **2**.

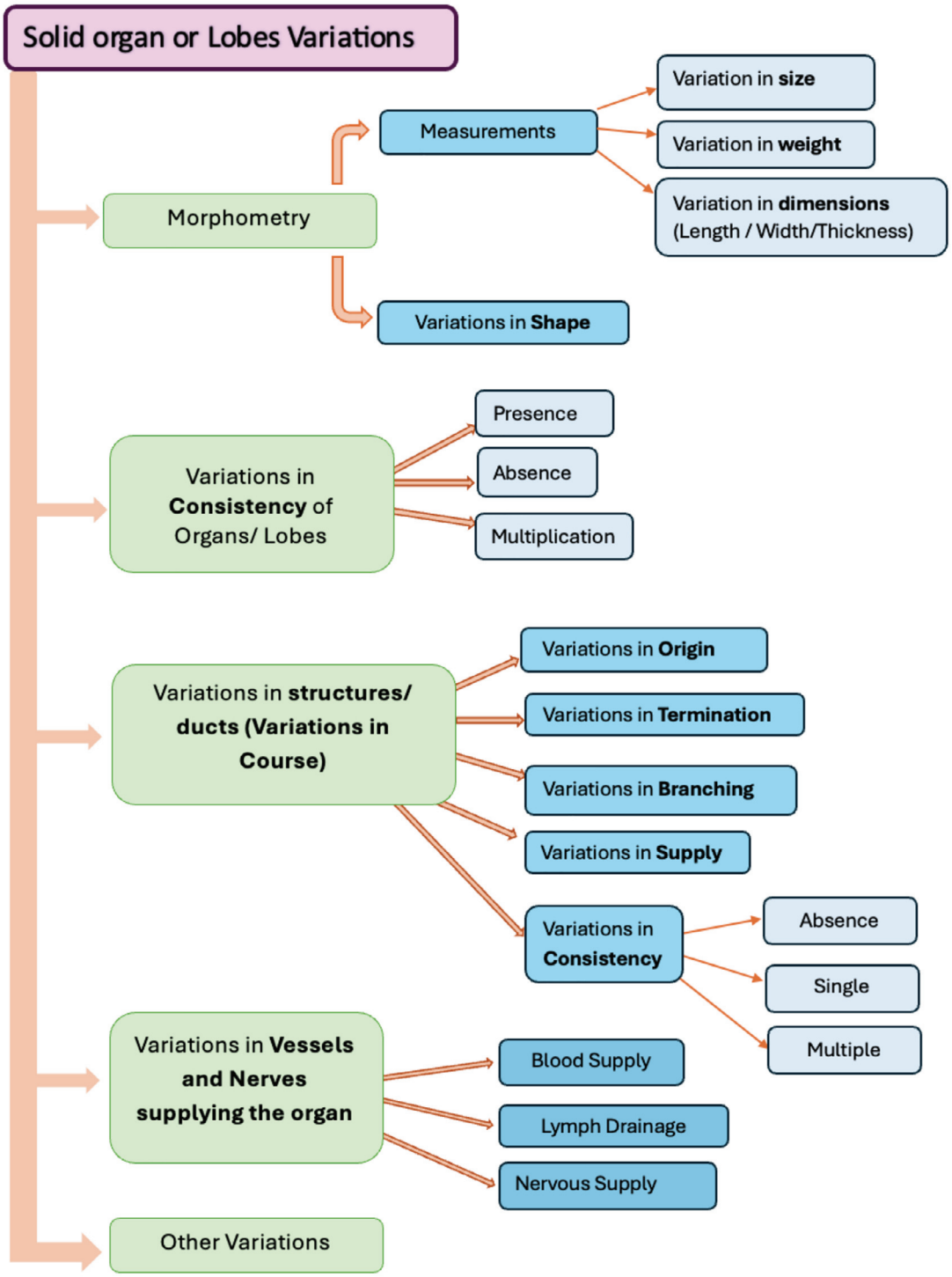


Figure 1. UCS (Universal classification System) for solid organ or lobe variations.

As previously mentioned, a universal classification system should have the capacity to encompass all anatomical variations of a given organ. Our proposed system aims to achieve this with the highest possible accuracy. An additional category of 'Other' will include minor variations and unanticipated variations that the investigator may come across during the study. For example, this category will include variations in anatom-

ical location and orientation, such as rotated organs; differences in the demarcations of organs or lobes; variations in impressions, and other unexpected variations they would come across. UCS can be repeatedly applied within itself for smaller segments of the main structure that is been studied. This way, lobes, lobules, segments, and similar subparts of the studied structures can also be included.

The category 'other' (**Figure 2**) could include variations in the orientation of nerves and vessels, such as unusual routes, differences in their spatial relationships with adjacent structures and variations in communications. In a case where too many variations are identified about a branch of the studied structure, the classification can be reapplied.

The UCS applicability is evident when applying to anatomical variation data from previous literature.[21–27] A descriptive anatomy study regarding the anatomical variations of the lumbar plexus can be taken to illustrate the application of the proposed classification. According to this study, the anatomical variations included the absence of iliohypogastric nerve (absence/single/ multiple), an early split of the genitofemoral nerve into genital and femoral branches (branching variation), an aberrant segmental origin for the lateral femoral cutaneous nerve (variation in origin), bifurcation of the lateral femoral nerve prior to exiting the pelvic cavity (other), early bifurcation of the femoral nerve into two to three portions/branches separated by psoas major muscle fibres (branching variations), the presence of a single anterior femoral cutaneous nerve rather than the normal presentation of two separate anterior femoral cutaneous branches, and the presence of an accessory obturator nerve (absence/ single/ multiple).[23]

With the rising trend of reporting anatomical variants over the past two decades, reporting them without sound knowledge about the existing literature and classification systems have contributed to a significant information noise.[18] Anatomical variations within the current medical paradigm are still extremely fragmented, with they being contained within various studies and varying forms of publications. The existing databases primarily concentrate on individual anatomical structures relying on non-standardized case studies that lack statistical power and reproducibility.[28] They do not offer a comprehensive, standardized reporting framework applicable globally, that hinders effective communication and understanding across various disciplines.[29]

Centralised databases have already transformed the fortunes of many disciplines, and genomics is one prime example through its repositories like EBI databases.[30] Recent advances in imaging and data management empower us to consider a similar centralised database for anatomical variations, enabling large-scale studies and better surgical planning, medical education, and training.

In the current literature case reports play a minor role in meta-analytical data. But if they are included in a database, where they can be grouped based on different confounding factors, an adequate sample size could easily be achieved for evaluation. Therefore, creating a database registry with up-to-date information will prevent any confusion about those variations and will avoid the repetition of data and miscommunication. This will eventually facilitate the provision of proper education on variant anatomy to the training clinicians and the provision of the best possible care to the patients.[11]

The proposed database of anatomical variations will be designed as a centralized database, accessible via the web, utilizing a contemporary Database Management System (DBMS). A relational DBMS platform, such as PostgreSQL or MySQL, could be employed because of its great capabilities for use with complex queries and large datasets. On the other hand, a NoSQL option, like MongoDB, could also be considered since it is flexible for handling unstructured data, which might be useful for storing different anatomical information.[31]

The database's architecture will be organized hierarchically, as in a representational data model, reflecting the organisation of anatomical systems. This will facilitate intuitive navigation along with efficient data retrieval. The database schema will embed the universal classification system proposed in this paper, ensuring standardisation across all records.

Results

The Proposed database schema will organize and standardize the reporting of anatomical variations in solid organs and structures such as nerves, blood vessels, and lymph vessels. The key components would be; organs table; lobes table; morphometry table; consistency table; structural variations table; blood, lymph vessels and nerve supply table; origin and termination variations table; and branching variations table (**Figure 3**).

Each organ (and its potential lobes, segments, or further subdivisions) will be uniquely identified by an 'Id'

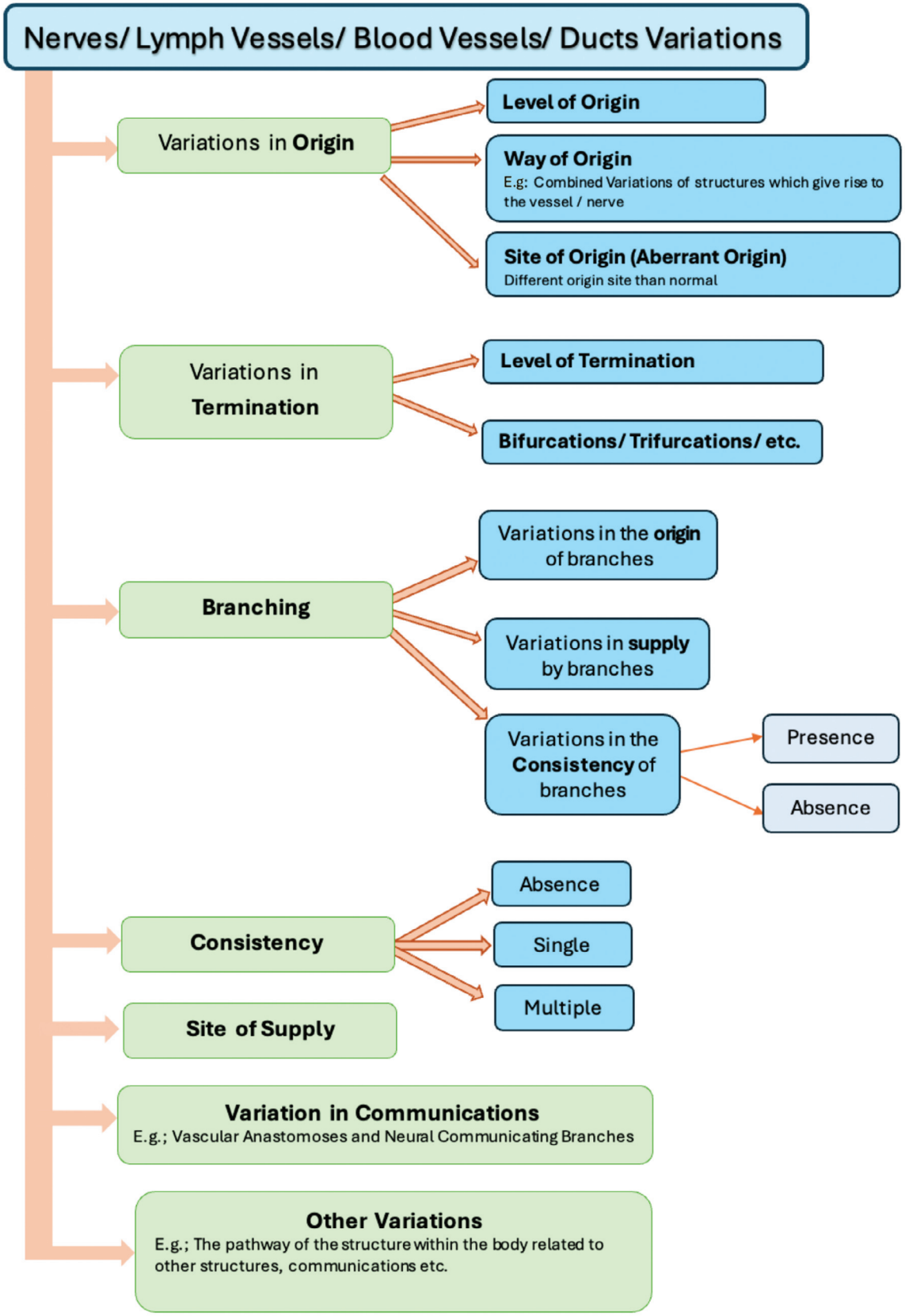


Figure 2. UCS (Universal classification System) for nerves, lymph vessels, and vessels variations.

(identification) and classified by name and type. The type distinguishes between solid organs (e.g., liver, kidney) and other structures like nerves, lymph vessels, and blood vessels. The proposed schema (**Figure 3**) indicates several foreign key relationships, enabling variations to be linked to the correct organ and, where necessary, to the correct lobe. It ensures that each variation is accurately attributed to its corresponding anatomical entity. For instance, the 'Morphometry', 'Consistency', and 'Structural Variations' tables, all reference the organs and lobes tables through foreign keys. Similar coding and tracking mechanisms are applied to the rest of the UCS and are summarised in **Figure 3**.

Discussion

The proposed database will collect data from various sources such as anatomical variations observed in cadaveric studies, imaging studies, intraoperative observations, systematic compilation of variations reported in published research, and population studies. This will provide a diverse data set, capturing both rare and common variations across different populations.

A structured data submission and validation process will improve the database's integrity and reliability. New entries will be submitted through a standardized web-based form which will improve uniformity in data formatting and thoroughness of information. A multi-step validation process will be implemented. Additional automated assessments will function as preliminary evaluations for the thoroughness of data and compliance with the classification framework. A panel of anatomists and relevant specialists will conduct an expert review to verify the accuracy and clinical relevance of the data submitted. A step of literature cross-referencing and statistical evaluation of the data will follow.

Once verified, the data entries shall be included in the master database, while entries requiring further verification will be flagged for further checking. Regular audits

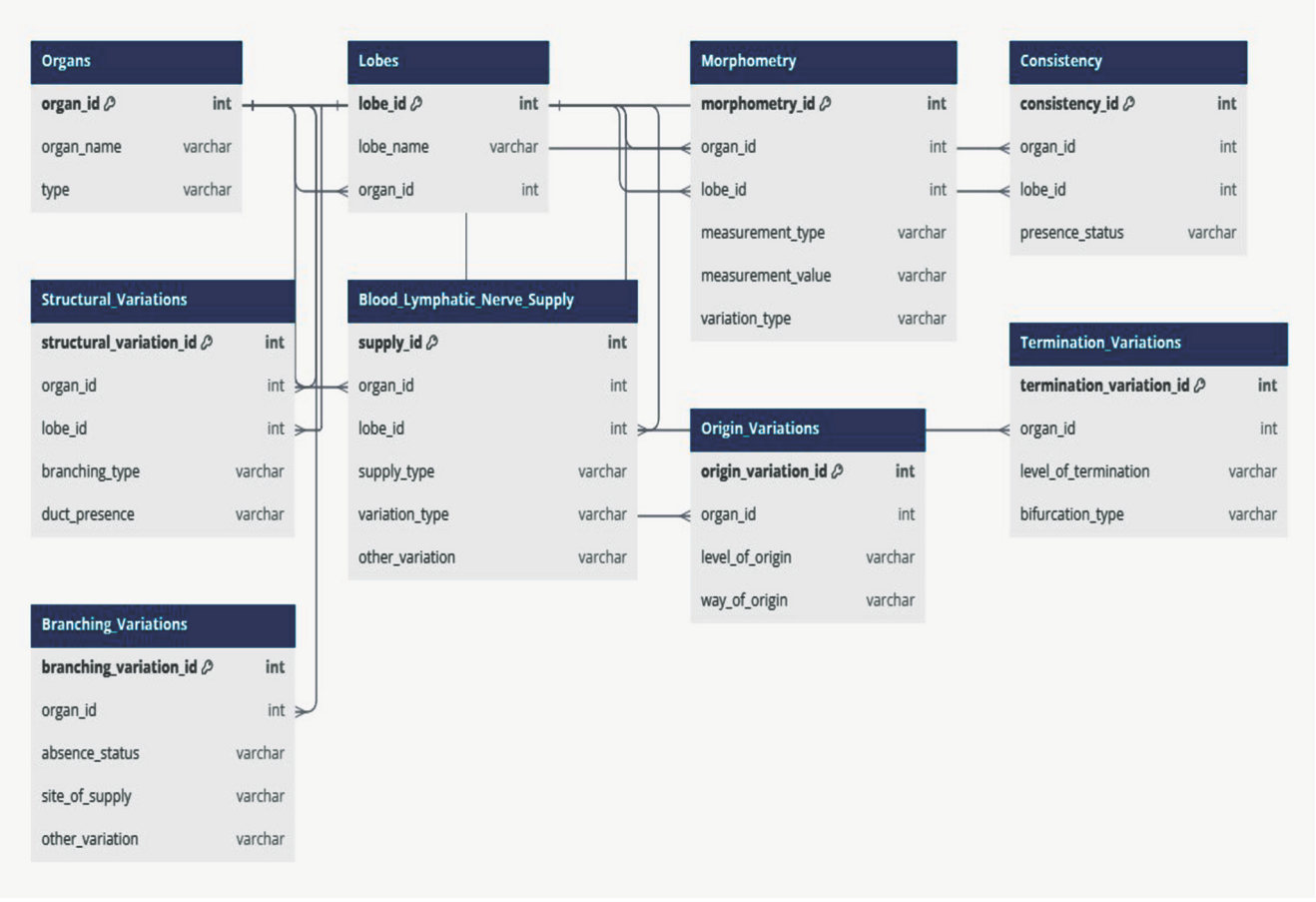


Figure 3. Schema of the database demonstrating the relationships.

and updates will be implemented to keep the information in this database continuously updated and relevant.

We suggest to incorporate multi-level access into the database to meet the needs of different users as follows.

- **Basic access:** Open to all users, providing general information on anatomical variations.
- **Research access:** Enhanced capabilities for academic researchers, including advanced search and data export options.
- **Clinical access:** Customized interfaces for healthcare professionals, focusing on clinically relevant information and potential surgical consequences.

A user-friendly web interface featuring intuitive search functions and data visualization tools will be the database's front end. A complete application programme interface (API) for integrating with other medical databases and research tools, offering programmatic access and supporting third-party app development for interdisciplinary research. The database will be set to integrate collaborative functionalities, including discussion forums and annotation tools, thereby facilitating knowledge exchange among users. By integrating a solid framework, various data sources, comprehensive validation methodologies, and adaptable access alternatives, this proposed centralized database is designed to serve as an essential tool in research and clinical utilization of anatomical variations.

Conclusion

Exploration of anatomical variations is fundamental for understanding human anatomy and improving clinical practices. Despite the significant interest in this field, current literature reveals notable gaps, particularly inconsistent reporting and classification of these variations that hinder the ability to comprehensively document and analyse anatomical differences across diverse populations.

The establishment of our Universal Classification System (UCS) will not only standardize the terminology and classification methods but also provide a flexible framework to ensure completeness in reporting and accommodate future discoveries in anatomical variations. By creating the proposed robust database registry that includes up-to-date information on anatomical variants, we can enhance the completeness of our evidence and facilitate better communication among researchers, clinicians, and educators, ultimately enriching the field of anatomy.

Conflict of Interest

There is no conflict of interest to declare

Author Contributions

SBS: manuscript writing, final editing of the text; DJ: manuscript writing, conceptualization, conveying the database technical notion in written form, final editing of the text; PW: data curation; AW: manuscript writing, conveying the database technical notion in written form; RM: manuscript writing, data curation; UN: manuscript writing, data curation; OJ: manuscript writing, final editing of the text; DJ (senior author): manuscript writing, final editing of the text.

Ethics Approval

This study did not require approval from an institutional ethics committee as it did not involve human participants, patient data, or identifiable biological material. Nevertheless, the study was planned and conducted in accordance with the principles of the Declaration of Helsinki.

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