Thesis

The occurrence of major vessels at possible front of neck airway access sites in children

submitted by

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Graz, 12th of September 2023

Affirmation in lieu of an Oath

I hereby formally declare that I have written the submitted thesis independently and without any illegitimate assistance from third parties. I confirm that I used no other than the declared sources for the preparation of this academic work. All used sources have been indicated as such and acknowledged by means of complete references in the text.

Graz, 12th of September 2023 *Esta Leimer eh.*

Foreword

Nothing shall be too difficult when separated into small parts.

Acknowledgements

First of all, I would like to say my sincere thanks to Dr. Heschl Stefan who offered me this project and supervised it throughout its development. It was a pleasure working on such an interesting topic. Knowing that this gain of knowledge will have an impact in medicine made me work passionately. Thank you for your guidance through the process of writing this thesis.

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Abbreviations

APDN	anterior-posterior diameter of the neck at cranial border
APDT	anterior-posterior diameter of the trachea at cranial border
BURP	backward-upward-rightward-pressure
caVDST	ventral distance between skin and trachea at caudal border
CICO	cannot intubate cannot oxygenate
crVDST	ventral distance between skin and trachea at cranial border
CT	computed tomography
DCCB	distance cranial to caudal border
DCRM	distance cranial border to mid
ENT	ear-nose-throat (surgeon)
eFONA	emergency Front of Neck Access
FONA	Front of Neck Access
MRI	magnetic resonance imaging
mVDST	ventral distance between skin and trachea at mid
OIAS	other important anatomical structure
PACS	Pictures Archiving and Communication System

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Zusammenfassung

Fragestellung

Ziel der Arbeit ist die Erfassung der altersabhängigen, topographischen Beziehung von großen Halsgefäßen und anderen wichtigen anatomischen Strukturen (=OIAS) zur Trachea an Stellen eines möglichen chirurgischen Atemweges bei Kindern. Damit soll das Risiko einer schweren Blutung, durch die Verletzung eines großen Gefäßes bei der Durchführung eines chirurgischen Atemweges (Konio- oder Tracheotomie), abschätzbar gemacht werden.

Methoden

Es wurden Computertomographie- und Magnetresonanztomographie Bilder (=CT- und MRT- Bilder) von Kindern im Alter von 0-18 Jahren retrospektiv betrachtet. Die Regionen anterior, links und rechts lateral der Trachea wurden kranial (kaudal des Cartilago thyroideum), mittig und kaudal (kranial des Sternum Oberrandes) auf das Vorkommen folgender Gefäße untersucht: Aa. Carotides communes, Truncus brachiozephalicus, Vv. brachiozephalicae, Vv. jugulares interiores/anteriores, Aortenbogen, Aa./Vv. subclaviae und weitere, nicht näher definierte Gefäße. Außerdem wurde die Lagebeziehung der Schilddrüse und des Ösophagus zur Trachea in den definierten Arealen betrachtet. Zusätzlich wurden umfangreiche Distanzmessungen durchgeführt.

Ergebnisse

Insgesamt wurden 310 Patient*innen untersucht, welche in sieben Altersgruppen unterteilt wurden. Insgesamt gab es 166 (54%) männliche Patienten. Es haben 235 (76%) MRT und 75 (24%) CT-Untersuchungen stattgefunden. Kranial anterior kam insgesamt in 109 Fällen (35%), mittig anterior in 124 Fällen (40%) und kaudal anterior in 295 Fällen (95%) mindestens ein Gefäß vor. Eine altersabhängige, signifikante Variabilität der Werte zeigte sich nicht.

Insgesamt war das häufigste Gefäß kranial anterior die rechte Vena jugularis anterior (36%), mittig anterior war dies ebenfalls die rechte Vena jugularis anterior (33%) und kaudal anterior war dies der Truncus brachiozephalicus (78%).

Eine interessante Beobachtung zeigte, dass der Aortenbogen im Bereich kaudal anterior bei Kindern unter 5 Jahren in 8% der Fälle vorkommt. Im Vergleich dazu, zeigte sich dieser bei Kindern über 5 Jahren nur in 1% der Fälle.

Bei der Berechnung des anterior-posterioren Durchmessers der Trachea wies dieser insgesamt einen Mittelwert von 10mm (Maximum=24mm, Minimum=3mm, Standard-abweichung=4mm) auf.

Schlussfolgerung

Diese Studie zeigt, dass bei einem signifikanten Anteil an pädiatrischen Patient*innen in jeglicher Altersgruppe, in einem für die chirurgische Atemwegssicherung relevanten Areal, mit einer hohen Wahrscheinlichkeit ein großes Gefäß verläuft. Das Risiko einer schweren Blutung kann bei der Durchführung, insbesondere kaudal, dadurch erhöht sein.

Abstract

Question

The focus of the study is to declare an age-dependent, topographical relation between big vessels or OIAS (=other important anatomical structure) to the trachea in sites of a possible front of neck access (=FONA) in children. This is done in order to improve the risk assessment of a possible major bleeding through the injury of a big vessel or OIAS during the establishment of a FONA (either coniotomy or tracheotomy).

Patients and methods

Computed tomography- and magnetic resonance imaging images (CT- and MRI images) of children between the age of 0-18 years were inspected retrospectively. The areas anterior, left and right lateral to the trachea have been checked in the cranial border (caudal of the thyroid cartilage), in the middle and in the caudal border (cranial of the sternum) on the prevalence of big vessels, for example, the carotid arteries, the brachiocephalic trunk, the innominate veins, the anterior and internal jugular veins, the aortic arch, the subclavian veins and arteries and further vessels, which were too small to characterize. Furthermore, the occurrence of the thyroid gland and the esophagus have been investigated. Additionally, some distance measurements were made, for example, the anterior-poster diameter of the trachea at the cranial border.

Results

Overall, the data of 310 patients was included, which was divided by age into 7 groups whereat group 2-7 contained the data of 50 patients respectively. Because of the rarity of data from group 1, it only contained the images of 10 patients. 166 (54%) male patients were found. 235 (76%) MRI and 75 (24%) CT images were examined. Within 109 cases (35%) in the area cranial anterior, within 124 cases (40%) in the middle anterior area and within 295 cases (95%) in the area caudal anterior, at least one big vessel or OIAS occurred.

The results were itemized by the age groups. With the Kruskal-Wallis test no age-dependent, significant difference could be shown. Overall, the most prevalent vessel in the cranial anterior area was the right anterior jugular vein (36%), as well as in the middle anterior area (33%), whereas caudal anterior the brachiocephalic trunk (78%) occurred most often.

Interestingly, the aortic arch occurred in the caudal anterior area in children under the age of 5 years in 8% of the cases. In comparison, within children over the age of 5 years the aortic arch only occurred in 1% of the cases.
The anterior-posterior diameter of the trachea showed a median of 10mm (maximum=24mm, minimum=3mm, standard deviation=4mm) and is therefore assumed to be very small.

Conclusion

This study reveals a significant number of pediatric patients in every age group who showed a high probability of having a big vessel or OIAS occurrence in the area of a possible surgical airway access site. Therefore, the risk of considerable bleeding as a complication is likely to be increased, especially at the caudal border.

Former publications

23rd of April 2022 Poster-Presentation at the AGN Congress Graz

1 Introduction

“Children are no small adults” – a sentence well known in pediatric medicine. While securing the pediatric airway, some peculiarities compared to securing the adult airway, as mentioned below, might occur. Therefore, guidelines exist to deliver a recommendation on how to deal with a difficult airway in children. As ultima ratio, in a “cannot intubate – cannot oxygenate” (=CICO) event, a Front of Neck Access (=FONA) is recommended. Unfortunately, the evidence on the execution of a FONA in children, for example, about possible complications such as severe bleeding or which technique should be used, is very little (1). So far, no documentation about the prevalence of big vessels or OIAS in children in sites of a possible FONA, maybe causing a bleeding complication, exists. Hence, increased knowledge about the anatomy of this area can have a profound impact on handling the case of a FONA situation in children. The idea of this study has been aligned to a study done in adults (2).

1.1 Pediatric neck anatomy

The neck is a complicated anatomical region containing several important structures. Therefore, it is very important to have a good knowledge about the anatomical structures when executing an invasive procedure at the neck (3,4). Within this study, the region anterior to the trachea, beginning at the height of the larynx all the way down to the manubrium, lies within special interest. The neck itself is divided by fascia and muscles into an anterior and posterior area. Anteriorly and in the muscular triangle the sternohyoid and sternothyroid muscles can be found. They lie underneath the platysma and the anterior jugular veins run in between. Behind the muscles the thyroid gland can be found, which is anterior and lateral to the trachea. It is usually found at the height of the 6^{th} or 7^{th} cervical vertebra and at the height of the 2^{nd} to 4^{th} tracheal cartilage. Especially the isthmus of the thyroid gland is found anterior to the trachea. Additionally, further caudal the carotid sheaths each containing a carotid artery, an internal jugular vein, a vagal nerve and lymph nodes can be found anterior to the trachea. In the area above the manubrium big vessels can occur anterior to the trachea, for example, the innominate veins, the anterior or internal jugular veins, the carotid arteries, the brachiocephalic trunk, the aortic arch. Lateral to the trachea, the carotid triangle is located where many important nerves and vessels run through (4,5). Overall, veins show a higher risk of injuries as they are more difficult to locate than arteries (4). This study investigates the prevalence of big vessels or OIAS in the anterior area of the trachea.

1.2 The pediatric airway

The pediatric airway differs in many aspects from the airway of adults (6,7). The anatomical and physiological differences are listed below.

1.2.1 Anatomy

The pediatric anatomy of the airway changes while growing up to adjust to the adult airway (8). Some of these differences are especially important while executing a FONA.

First, the pediatric head, especially the occiput, is proportionally bigger than in adults. This causes the neck to bend forward with the chin being pushed towards the sternum. To keep the airway open the head, larynx, neck and trachea should be positioned in one line. Therefore, no retroflexion is necessary. Additionally, the pediatric neck is shorter.

Furthermore, in children the larynx is positioned at a higher level. While in neonates it is leveled at the 2nd or 3rd cervical vertebra, it descends by age. Thus, the adult larynx is usually leveled at the 4th or 5th cervical vertebra (9). The angle between the larynx and the pharynx also differs, which results in the usefulness of straight shaped laryngoscopes for an easier display of the vocal cord level in case of an endotracheal intubation (10).

Moreover, the anatomical structures building and surrounding the airway are smaller, softer and weaker in children. With a higher risk of collapsing, an airway obstruction occurs (10). The anatomy of the pediatric airway includes small apertures of the nose and the proportionally large tongue, tonsils or lymphoid tissues. Plus, the epiglottis occurs rather small and soft compared to adults. Further, it is shaped as an omega and not in a parallel position to the trachea. All these factors cause easier airway obstructions, for example, through manipulation from the outside, and higher airway resistance, which could lead to a more difficult ventilation and/or intubation situation (9,10).

Next, the tightest level of the airway in adults is at the level of the vocal cords. However, this does not correspond to the pediatric airway. As mentioned before, the pediatric airway is rather soft and pliable and, therefore, tends to collapse. As mentioned in the review of Holzki et al. (11) it is difficult to define the tightest level in vivo, since the airway is constantly in motion due to respiration. In vitro studies suggest that the tightest level is at the ring-shaped cricoid cartilage outlet.

Overall, with small diameters in the pediatric airway, a local swelling or edema of the airway could already cause major breathing or ventilation problems (10). A more in-depth explanation can be found in the Hagen-Poiseuille equation.

Within the area of the neck several big vessels and other well perfused organs occur. Throughout growth little is known about the relation between them and the airway, especially regarding possible FONA sites.

1.2.2 Physiology

Besides the anatomical differences, some airway and respiration relevant physiological differences occur as well (6,7).

The basic metabolic rate in children is higher than in adults. This results in a higher oxygen demand which leads to a reduced oxygen reserve. The functional residual capacity of children is considerably reduced which causes a fast desaturation in case of missing oxygen supply. Furthermore, an increased carbon dioxide production occurs which induces a higher respiratory rate with an elevated alveolar ventilation.

Furthermore, the respiratory muscles in children contain very little type I muscle fibers especially in neonates and infants. Therefore, in case of high respiratory work fast exhaustion can occur. High respiratory work might originate from an increased respiratory resistance in case of an airway constriction or obstruction.

1.2.3 Influence of anatomical or physiological differences

Overall, the mentioned differences in anatomy and physiology can influence the handling of a difficult airway situation in children. On the one side, everything is diminutive, the tissue is soft, and it is difficult to handle the anatomy in case of a possible FONA. On the other side, with the differences in physiology, less time is available for doctors or other executers to establish a secure airway in children because of their reduced reserve. This stresses the importance of precisely knowing the surrounding structures such as big vessels or OIAS and being aware of possible complications, for example, considerable bleeding to accomplish a fast airway security during a FONA execution.

1.3 The FONA

In this study the definition of a FONA, as a front of neck access, is used. It is an invasive procedure to secure the airway without passing through the upper airway, but instead entering straight through the trachea and the surrounding structures. Establishing a FONA is a difficult procedure with a high failure risk and particularly challenging (12,13). However, it might be the only chance for a proper airway management (14). While several different techniques exist, no evidence could be found to define a proper recommendation (15,16). It is even more difficult as recommendations for the establishment of an adult FONA are non-transferable to children (15). Because of that, preferences of different doctors were used to declare suggestions (17). For the execution either a surgical airway under the use of a scalpel, a knife or a scissor can be used. Or a needle, wire-guided or cannula airway access could be executed. Overall, all of them are percutaneous airway accesses, which include passing through surrounding tissue, such as, skin, vessels, nerves and other organs. Several requirements for a proper FONA technique exist: the technique must be fast, simple, easy to execute, quickly trainable, with a high success and a low complication rate (18,19). The physicians need to be well-trained and to have a thorough knowledge about the anatomy and the technique.

1.3.1 Indications for a FONA

1.3.1.1 The difficult pediatric airway – a CICO event

Within several international guidelines and recommendations about the handling of a difficult pediatric airway, an eFONA (=emergency front of neck access) in case of a CICO event is listed. For example, the *ÖGARI (=Österreichische Gesellschaft für Anästhesiologie, Reanimation und Intensivmedizin)* (20)*,* the *Difficult Airway Society* from Great Britain (21), the *APAGBI (=the Association of Paediatric Anaesthesists* from Great Britain and Ireland) (22), the *AWMF (=Arbeitsgemeinschaft der wissenschaftlichen medizinischen Fachgesellschaften)* from Germany (23,24), the *Deutsche Gesellschaft für Anästhesiologie & Intensivmedizin* from Germany (25), the *Polish Society of Anesthesiology and Intensive Care* as well as *the Polish Neonatal Society* (26) and further studies (16,27,28) contain the recommendation for an eFONA access if necessary.

A difficult airway is defined by a conventionally trained anesthetist having difficulties with bag-mask-ventilation and/or endotracheal intubation (13,29). Overall, the handling of a difficult airway in children is geared to the handling of a difficult airway in adults (1,22,24–27,30). The worst-case scenario in a difficult pediatric airway would be the need of an eFONA in a CICO event, which is very rare (1,16,31–34).

In children, the airway can be subdivided in normal, impaired normal and known abnormal (8,35). A difficult airway in children with a normal airway anatomy hardly ever occurs (8,10). A known abnormal airway, however, can be caused by congenital defects, dysmorphism, facial burns, oral tumors, syndromes, a cleft palate or certain anatomical settings and is very likely to cause a difficult airway management (8,12,13,26,30,36). Same as in children with an impaired normal airway, which could, for instance, be caused by acute trauma, injuries, infections like croup or epiglottitis, edema, swelling, burns or anaphylaxis. Airway obstructions that can be localized in the upper airway are, for example, a laryngospasm, tumor or edema, and in the lower airway a bronchospasm or alveolar collapse. The obstruction could either be caused by a foreign body or it could be functional, for example, in case of opioid rigidity, inadequate anesthesia or missing muscle relaxation (8,22,35). Additionally, another cause for a difficult airway in children is the small anatomy which requires diminutive equipment with proper handling (26).

Several aspects should be considered when preparing for an eFONA in children. First, teamwork and communication as well as a special and frequent training for the whole team are of great importance to preserve good knowledge and expertise (12,13,27,30,37,38). Especially in case of an eFONA in children, it is crucial to be settled in the basics of anatomy and increase the awareness of the small anatomy in children. To reduce possible complications, such as severe bleeding, executers need to know about the relation between surrounding structures and the airway in possible FONA sites. Additionally, the risk for a surgical intervention in establishing a secure pediatric airway must be identified as early as possible. In neonates, for example, the following issues could indicate a high risk for a tracheotomy: prolonged respiratory support, low average birth weight or gestational age, prevalence of broncho pulmonal dysplasia, upper airway abnormalities or a great number of failed extubation events (31,39). Last but not least, the right equipment is compulsory. Airway trolleys have been designed to help in handling a difficult pediatric airway. It must contain all the equipment which might be necessary to follow present guidelines and should be organized in a consequential way (8,27,38). Physicians should have good knowledge about the equipment, the handling and which size to pick.

One should particularly focus on two aspects when handling a difficult pediatric airway: oxygenation and securing the airway for proper ventilation (8). There are several ways to secure a difficult airway, similar in children and adults (24,29,40). First, a bag-mask-ventilation can be executed. In case of difficulties, strategies such as repositioning the head, performing a two-hand-bag-mask-ventilation, or trying different sizes of the equipment should be used (8). Furthermore, assistant devices like a Guedel- or a Wendel-Tube could be used. The ventilation can be supported through passive oxygen delivery, for example, through a nasal oxygen application (12). Additionally, the anesthesia should be reviewed since inadequate anesthesia or missing muscle relaxation might cause difficulties in bag-mask-ventilation.

In case of difficulties executing an endotracheal intubation, the easiest step is to go back to bag-mask-ventilation which allows for more time. Afterwards, the equipment should be revised. Repositioning the head, applying pressure backward, upward and rightward (=BURP-Maneuver), using the right size of the equipment, the use of a Mandrin or a Bougie, changing to a straight or angulation intubation blade and using a cuffed or uncuffed endotracheal tube might further influence the handling of the airway management. Also, a video-laryngoscope like Airtraq© (Prodol Meditec, Getxo, Spain), C-Mac© (Karl Storz SE & Co KG, Tuttlingen, Germany), or GlideScope© (Verathon, Bothwell, USA) can be used (8,26,28,38). Overall, the less intubation attempts to achieve a secured airway the better (41).

After two failed attempts, a different pathway should be considered. Therefore, extra-glottic devices, such as Guedel- or Wendel-Tubes, laryngeal tubes or masks can be used. If this is not successful, either an endotracheal intubation under the use of fiberoptic tools, like video laryngoscopes, the Airtraq© (Prodol Meditec, Getxo, Spain) or a flexible or rigid bronchoscope should be considered next. Additionally, angulated, hyper-angulated or straight blades could be useful. Furthermore, the fiberoptic intubation could, on the one hand, be executed through an extra-glottic device or, on the other, with the patient being awake and breathing spontaneously (6,12,30,35,42).

In cases of an unanticipated difficult airway, which could, for example, occur in out-of-hospital-emergencies, severe complications tend to happen rather often (22). It is important that the team is very well-trained and the equipment easily accessible in a well-organized container (43). Furthermore, special guidelines for an out-of-hospital difficult airway management exist (44).

Finally, in case of a CICO event, an eFONA is recommended as the ultima ratio (18). A CICO event is very rare and defined as a failed endotracheal intubation and a failing face mask ventilation. It can occur in an anticipated and an unanticipated airway. Nowadays, it occurs less often since infection rates causing an impaired normal airway in children have decreased over the last years (45–47). Before the execution all other risk factors should have been clarified and nothing else could be able to influence the outcome (42). It is ought to be said though that the recommendation for a pediatric eFONA is fairly unassertive (6,25). Overall, the need of an eFONA is unlikely for a child with physiological anatomical proportions, since either an endotracheal intubation or at least bag-mask-ventilation is usually possible (8). But if not and even against all heavy complications that might occur, an eFONA in a CICO event might save the life of the child (14). In the end, the hope of an eFONA situation in children to not occur is tremendous (48).

1.3.1.2 Long-term ventilation

Over the years it has been detected that an overall change of indications for a FONA has occurred. While 30 years ago upper airway infections like Haemophiles Influenza or Diphtheria mainly caused the necessity of an eFONA, nowadays the prolonged ventilation in intensive care units is the main reason (45). Additionally, with the constant improvement of medicine artificial ventilation times have been prolonged, thereby, the indication of a "planned" FONA has increased as well (45–47,49). Congenital defects or dysmorphias could indicate a FONA in case of a long-term ventilation (36). That way it might be possible to predict the risk of the airway establishment with a FONA, since particular diseases like airway abnormalities, lung dysmorphias, neuromuscular diseases or afflictions of the central nerval system show a higher risk (31,39,50).

In the end, even a planned FONA under best conditions has a high complication risk. Therefore, it is necessary to have the clinicians well-trained, with great expertise and knowledge (16,37,48) and a suitable equipment organized, for example, in a so-called "airway trolley" (51).

1.3.2 Locations of a FONA

Overall, there are two possible locations for a FONA, either a cricothyroidotomy or a tracheotomy. The former is executed at the level of the cricothyroid membrane, the latter is performed further caudal between two cartilages of the trachea.

According to the guidelines, a cricothyroidotomy is the recommended emergency access for a FONA in adults. There is a difference with the handling of the eFONA in children. While children over the age of 8 years should just be treated like adults, under the age of 8 only an informal suggestion exits for the establishment of a cricothyroidotomy (14,30), most suitable under the use of ultrasound to detect the right structures (33). In children under the age of one, however, the initial eFONA should be a tracheotomy under the use of direct visualization. The main reason is the small anatomy with the soft tissues. Especially the cricothyroid ligament occurs to be very soft at this age (30,33).

1.3.3 Techniques for the establishment of a FONA

There are different techniques in performing a FONA. First, the surgical percutaneous airway access, which is executed under the use of a scalpel, a knife or a scissor. A lower complication and failure rate could be seen using the surgical technique than in the cannula guided technique (15,52–54). It is recommended for children of all ages (30). Preferably, it is executed by an ear-nose-throat or pediatric surgeon (10,30,33,46,55,56). Several different pathways exist to perform the surgical airway. At the beginning, the right position needs to be located, which could be done either with palpation or ultrasound guided (33). Afterwards, the incision is made. So far, some evidence leans towards a longitudinal incision, considered as posing lower risk of injuring surrounding structures (19,55,57), but the investigation is not fully completed. Then, the trachea needs to be identified. Due to some bleeding, the vision might be blurred and therefore, palpation is needed (56) for identification. Afterwards it needs to be punctured. From there on, different practice ways exist. While the most requested way is the execution under the use of a Bougie (17), it could also be done with the typical rapid 4 step technique (19) or under the use of several different hooks to fixate the structures in place. The goal is to achieve a low complication rate while placing the endotracheal tube in the trachea for establishing the FONA (55). Therefore, good knowledge about the exact anatomy, especially about big vessels, would be compulsory to reduce the risk of a bleeding complication.

Second, executing a percutaneous puncture of the trachea can be used to establish a FONA (49,53). Executing a puncture technique is difficult in children, due to a long procedural time and a high complication rate (54,58). It needs to be done with extremely sharp cannulas since otherwise the soft tissues could be compressed and the access would be unsuccessful (8,52). A further risk of the cannula technique is an injury to the posterior tracheal wall or other nearby structures (15,52,58). It is usually executed under the use of air-aspiration, preferably in a two-person execution (59), as a positional monitoring. Several tools could be used for the puncture such as a cannula, a catheter over needle technique or wire guided like the Seldinger technique (55,60). Narrow and large bore tools can be differed (55). While narrow tools usually reduce the risk of tissue injuries as they do not cause distinct compression, large tools allow a higher flow. This introduces one of the main disadvantages of the puncture technique: due to the low flow through narrow tools, in most of the cases only oxygenation but no ventilation is possible (13,18,26,42,53,55). Because of difficulties in performing a proper expiration, hypercapnia and subsequently a potential barotrauma of the lung might occur(36,42,57). Therefore, it cannot be used as the final airway access. Furthermore, diverse systems for a quick airway access such as Quicktrach© (VBM Medizintechnik, Sulz a.N., Germany) or Melker© (Cook Medical, Bloomington, USA) exist, which show their limitations in little size variations or success rates (58). To sum up, there is little to no evidence for recommendations on which technique to use in case of a CICO (15,16,32,35,52).

1.3.4 Complications of a FONA

During the establishment of a FONA several complications can occur. Overall, there is a higher complication risk in smaller children (26). Thereby, early and late complications can be differed (50). Early complications could be the injury of the tracheal wall or surrounding structures (18,52), emphysema, pneumothorax or pneumomediastinum, or bleeding (30). There could be a minor bleeding, which could cause a vision loss making it more difficult to score the right structure. On the other hand, a major bleeding including a high blood loss causing a critical shortage in the blood flow could occur. Further late complications could be, for instance, a tracheal stenosis, cannula dislocation, intratracheal granuloma or infections (30,36,50).

2 Hypothesis and aim of the study

The aim of the study is to determine some pediatric airway dimensions and the occurrence rate of big vessels or a OIAS in the area of a potential FONA in children. In doing so, the awareness of the small pediatric anatomy should be risen. Additionally, the complication risk of a minor or major bleeding depending on the correspondent level of the FONA through the injury of a big vessel or OIAS should become more assessable.

3 Patients and methods

3.1 Patient data selection

In collaboration with the Department of Radiology, especially with the division for Pediatric Radiology, and the Department for Computer Sciences in Medicine data was collected.
At first gender equal data of children between the age of 0-18 years has been selected. The focus of the collection was on MRI (=magnetic resonance imaging) and CT (=computed tomography) scans which display the cervical and thoracic region. In total 512 scans have been found.

Afterwards, the included data was subdivided by age in seven groups as following:

- Group 1: 0-28 days
- Group 2: 29-365 days
- Group 3: 1-2 years
- Group 4: 3-5 years
- Group 5: 6-9 years
- Group 6: 10-13 years
- Group 7: 14-18 years

3.2 Measurements

3.2.1 Placing a grid

After considering in- and exclusion criteria and selecting the scans, they were further analyzed with the syngo.plaza system – a Picture Archiving and Communication system (=PACS) - from Siemens Healthineers©. To do so, the transversal and one other plane, either sagittal or coronal, were needed.

Furthermore, the cranial and caudal border were determined in the transversal plane. The cranial border was defined as the first slide caudal of the thyroid cartilage where, if necessary, a coniotomy through the cricothyroid ligament would take place. Therefore, the cranial border could be found in the transversal plane where the airway is losing its oval shape and continues in a round shape. The caudal border was the first slide cranial of the sternum. Additionally, the mid between the cranial and the caudal border was defined, and three levels were determined: the cranial border, the mid and the caudal border as shown in Figure 1.

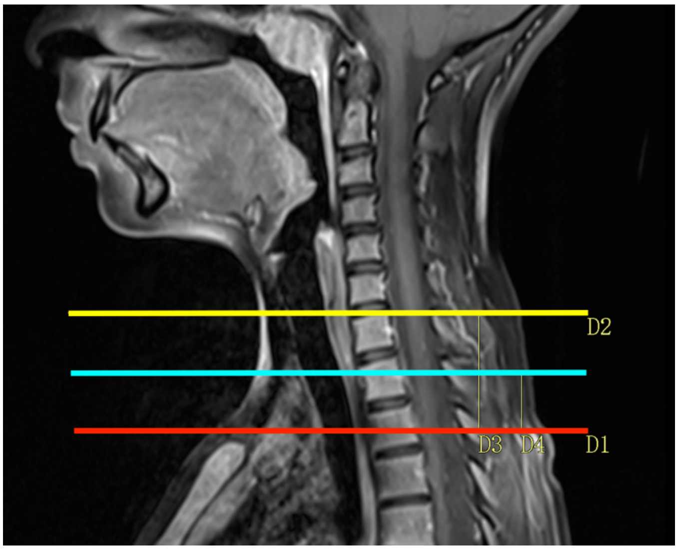
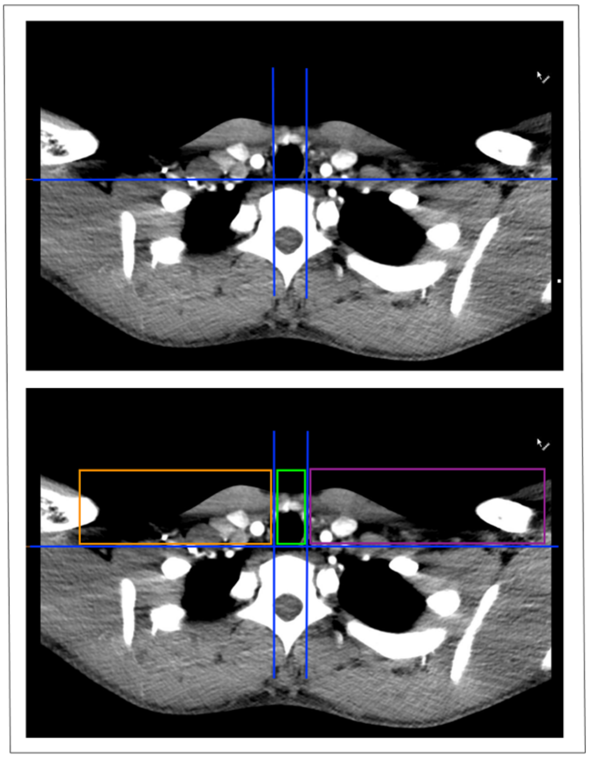


Figure 1: Defining three levels in sagittal plane
cranial border, mid and caudal border



Next a grid was placed at each level. First two sagittal lines were positioned. One each on the left and right side of the trachea. Both were tangent to the inside wall of the trachea, passing the neck in sagittal plane and were parallel to the spinous process. Afterwards a transversal line which was tangent to the dorsal inside wall of the trachea and 90° rotated to the sagittal lines was placed. That way three areas were determined: anterior, left, and right lateral to the trachea. This is shown in Figure 2.

Figure 2: The placed grid and its divided areas: anterior, left lateral and right lateral to the trachea

Therefore, each scan could be divided in 9 areas as following:

- Cranial anterior
- Cranial left lateral
- Cranial right lateral
- Mid anterior
- Mid left lateral
- Mid right lateral
- Caudal anterior
- Caudal left lateral
- Caudal right lateral

3.2.2 Overview calculations

After placing the grid some calculations were made to illustrate the anatomical proportions. First of all, the distance between the cranial and the caudal border, which were also marked in the second plane, was measured. By dividing the distance cranial to caudal border (=DCCB) into two, the mid was defined. This was called the distance between the cranial border and mid (=DCRM). Thereby, a more continuous tracking of the alignment of the vessels and the surrounding structures was possible.

In addition, different measurements were made at the cranial border, the mid and the caudal border. At the cranial border the anterior-posterior diameter of the neck was measured. It needs to be noted that this was measured only at the level of the cranial border, since the neck can be clearly confined to its surrounding structures at this level. Furthermore, the anterior-posterior diameter of the trachea was measured. It was assumed that the diameter of the trachea does not change remarkably within the inspected area.

Considered as the distance which would need to be cut through or punctured to reach the lumen of the trachea as part of a surgical airway access, the distance between the skin and the trachea was measured. First this measurement was done at the cranial border, afterwards it was measured at the mid and at the caudal border. This was important, as the trachea lies further underneath the skin the more caudal of the neck it is measured. An example for the performed measurements at each level is pictured in Figure 3.

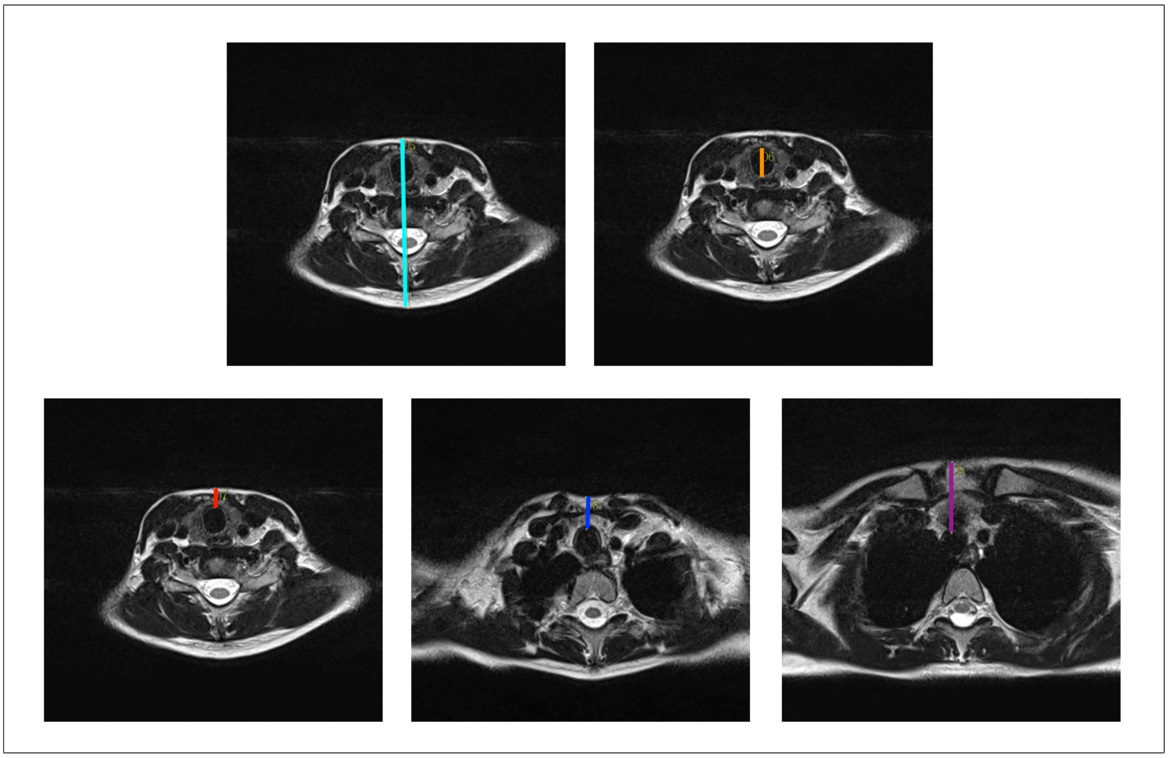


Figure 3: Measurements at each level: anterior-posterior diameter of the neck, anterior-posterior diameter of the trachea, cranial, mid and caudal ventral distance between skin and trachea

3.2.3 Description of positional relationships

Furthermore, the positions of relevant vessels and anatomical structures to the trachea were determined and documented. This was executed under the regional conditions of the placed grid in nine areas, which are displayed in Figure 1 and 2. Each area was examined for the presence of the following vessels and OIAS as demonstrated in Table 1.

List of examined vessels and OIAS	
Left common carotid artery	Left anterior jugular vein
Right common carotid artery	Right anterior jugular vein
Brachiocephalic trunk	Aortic arch
Left innominate vein	Left subclavian artery
Right innominate vein	Right subclavian artery
Left internal jugular vein	Left subclavian vein
Right internal jugular vein	Right subclavian vein
	Thyroid gland

Table 1: List of examined vessels and OIAS

It must be said, that the isthmus and the lobes have been defined as the thyroid gland, no difference between them has been documented. The thyroid gland must occur anterior to the trachea at some point along to the trachea. It did not occur in 100% of the patients within the investigational site since the isthmus might be higher or lower than that.

While collecting the original data, additional information, for example, the position of vessels too small to characterize and the esophagus has been detected. During the processing of the data, they have been neglected because of irrelevancy. It has been assumed that in case of an injury it could only cause minor bleeding followed by poor vision or secondary complication. While this would be not ideal, it would not influence the primary airway management. Therefore, they were classified as not clinically relevant and not further analyzed. For the anatomical overview, however, it offered an interesting insight.

3.2.4 Anatomical variety

The occurrence of relevant anatomical varieties has been documented. An anatomical variety was named relevant if it could cause a major complication while executing a surgical airway such as a tracheotomy or coniotomy.

For example:

- a variety in vessel separations or confluences
- the occurrence of another big vessel such as a vertebral artery or vein or the vena cava superior in the inspected area
- unusual positional relationships of the anatomical structures

3.3 Ethics votum

The ethics committee of the Medical University of Graz reviewed the study and approved the realization of it without any rejections pursuant to EK33-528 ex 20/21.

3.4 Statistical analysis

The statistical analysis was executed with Windows Excel© Version 2021.
The main approach of this study was a thorough descriptive analysis of the data which has been documented in the Windows Excel© charts.
First, the overall distance measurements were illustrated with histograms, which can be found in the appendix. Furthermore, the distance measurements of each group were examined with the Kolmogorov-Smirnov-Test, whether or not they occurred in a normal distribution. Afterwards values such as the arithmetic mean, the maximum, the minimum and standard deviations of the distance measurements were calculated.
Next, the occurrence of big vessels or OIAS has been analyzed, absolute and relative frequencies and subsequently probabilities were calculated. A 95%-Clopper-Pearson-Interval was calculated to declare a 95%-confidence interval.
Furthermore, a comparison between the groups was conducted. Since the data of the distance measurements was unconnected and mainly normally distributed, the Kruskal-Wallis-Test was used to detect a potential significant difference.
During the analysis of the occurrence of big vessels with bar graphs, differences between younger and older children, but not between the groups, have been eye-catching. Therefore, to compare the groups considering the occurrence of big vessels or OIAS, they were summarized into two bigger groups (group 1 = 0d-5a; group 2 = 6a-18a). Afterwards, the Chi-Squared-Test was used to look for a significant difference. If any occurred, further testing with the Chi-Squared-Test between each of the groups, potentially focusing on just one vessel, was conducted.

4 Results

4.1 Patients collective and main characteristics

In total, 512 scans were initially collected, therefrom, 202 of the scans were excluded, because they matched the following exclusion criteria:

- The investigation-relevant region or parts of it were not shown (80)
- Scans of the same patient only at a different age (61)
- Pathological anatomy (43) – where either a large mass (40), a preexisting tracheostoma (2) or a tracheal fistula (1) was detected
- The data was not found in the image processing system (13)
- Insufficient image quality (8)

Thereupon, 310 scans were included in the study. This is shown in Figure 4.

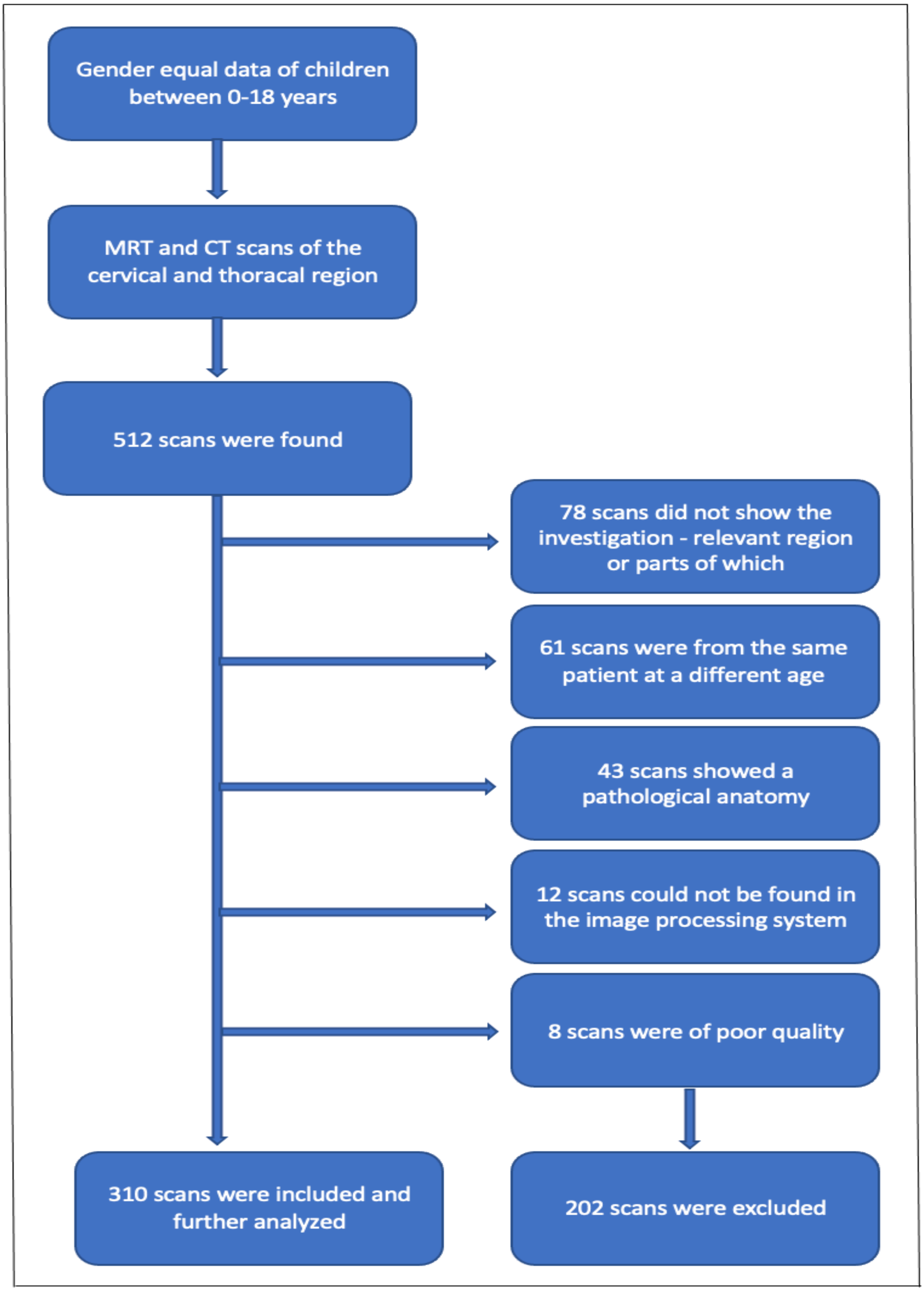


Figure 4: Flow chart on inclusion and exclusion of detected data

All the included scans (310) were divided into seven groups as described in Table 2.

Number of the group	Age	Number of scans
Group 1	0-28 days	10 scans
Group 2	29-365 days	50 scans
Group 3	1-2 years	50 scans
Group 4	3-5 years	50 scans
Group 5	6-9 years	50 scans
Group 6	10-13 years	50 scans
Group 7	14-18 years	50 scans

Table 2: Overview of groups considering age and number of scans

In the end, each group was supposed to contain 50 patients. In group 2-7 this number was attained. In group 1, however, not enough scans could be found in the data collection system of the Medical University Graz. The main reason was the young age of less than 29 days, which is defined as the age of a newborn. Therefore, group 1 only contains 10 scans.

Within the 310 included scans, 166 (53.55%) patients were documented male. Furthermore, the type of scan was documented as following: 235 (75.80%) MRI scans and 75 (24.19%) CT scans. A higher percentage of CT scans was not available due to scarcity of CT scans of children in the inquired age range. The distribution of gender and type of scan was different in each group. This is shown in Table 3.

Age	Male	Female	MRI	CT	Total Result
14-18a	26(52%)	24(48%)	25(50%)	25(50%)	50(100%)
10-13a	26(52%)	24(48%)	39(78%)	11(22%)	50(100%)
6-9a	26(52%)	24(48%)	37(74%)	13(26%)	50(100%)
3-5a	35(70%)	15(30%)	39(78%)	11(22%)	50(100%)
1-2a	23(46%)	27(54%)	39(78%)	11(22%)	50(100%)
29-365d	24(48%)	26(52%)	47(94%)	3(6%)	50(100%)
0-28d	6(60%)	4(40%)	9(90%)	1(10%)	10(100%)
Total Result	**166(54%)**	**144(46%)**	**235(76%)**	**75(24%)**	**310(100%)**

Table 3: Main characteristics and their distribution in group 1-7

4.2 Distances

The following distances were measured as they were assumed to be clinically relevant.

4.2.1 Distance caudal to cranial border (=DCCB)

Considering the Kolmogorov-Smirnov-Test the DCCB could be assumed to have a normal distribution. Overall the mean of the DCCB was 45mm with a maximum of 95mm and a minimum of 10mm. Furthermore, the standard deviation was 1.

The values of the different age groups are displayed in Figure 5. The distribution by age with the exact values can be found in the appendix.

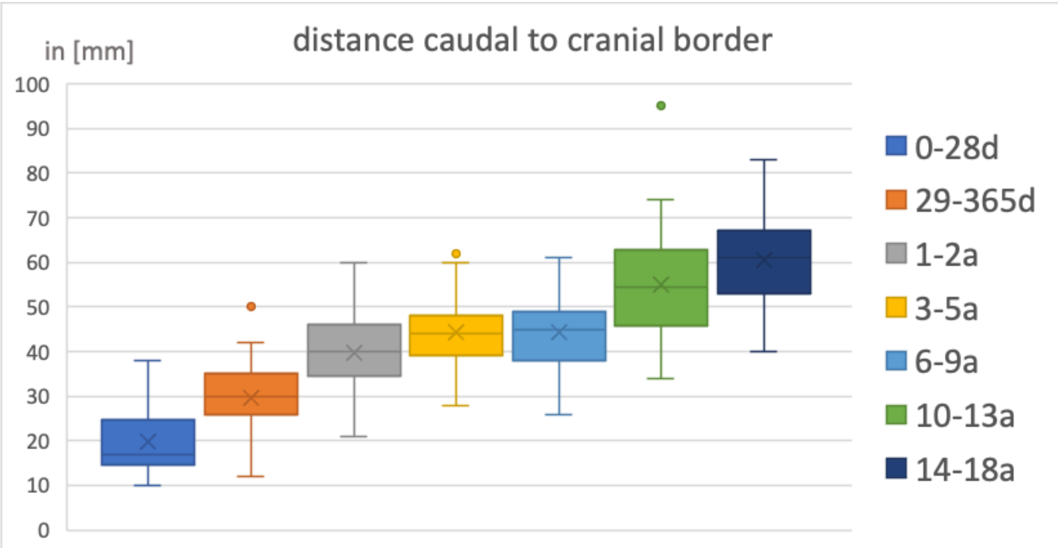


Figure 5: Boxplots to DCCB in mm in comparison of the different groups of age

4.2.2 Distance cranial border to mid (=DCRM)

Considering the Kolmogorov-Smirnov-Test the DCRM could be assumed to have a normal distribution. Within all patients the mean of the DCRM was 23mm with a maximum of 48mm and a minimum of 5mm. The standard deviation was 7mm. The values of the different age groups are displayed in Figure 6. The distribution by age with the exact values can be found in the appendix.

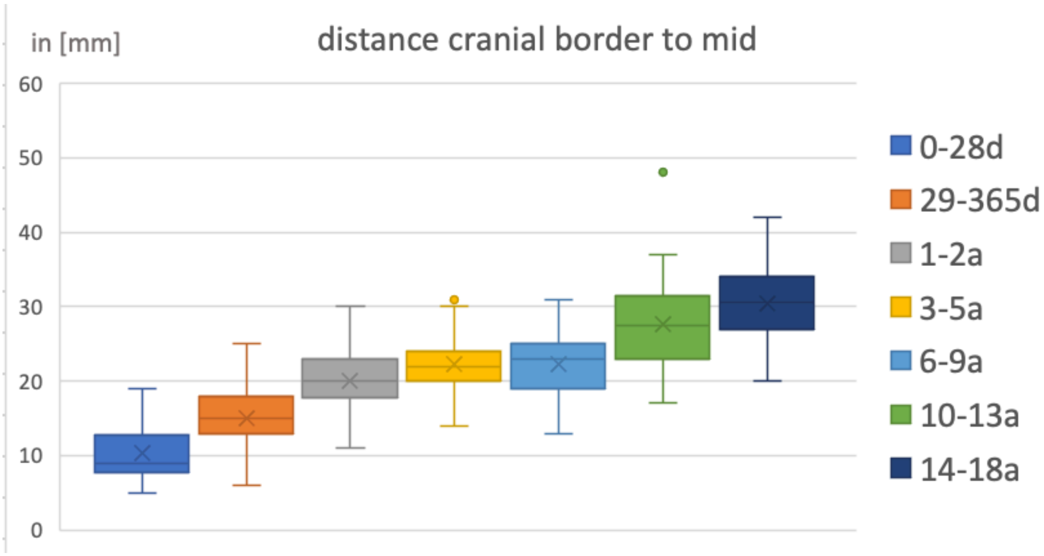


Figure 6: Boxplot to DCRM in mm in comparison of the different groups of age

4.2.3 Anterior-posterior diameter of the neck (=APDN)

Considering the Kolmogorov-Smirnov-Test the APDN could be assumed to have a normal distribution. Overall, the mean was 83mm with a maximum of 152mm and a minimum of 45mm. The standard deviation was 20mm. The values of the different age groups are displayed in Figure 7. The distribution by age with the exact values can be found in the appendix.

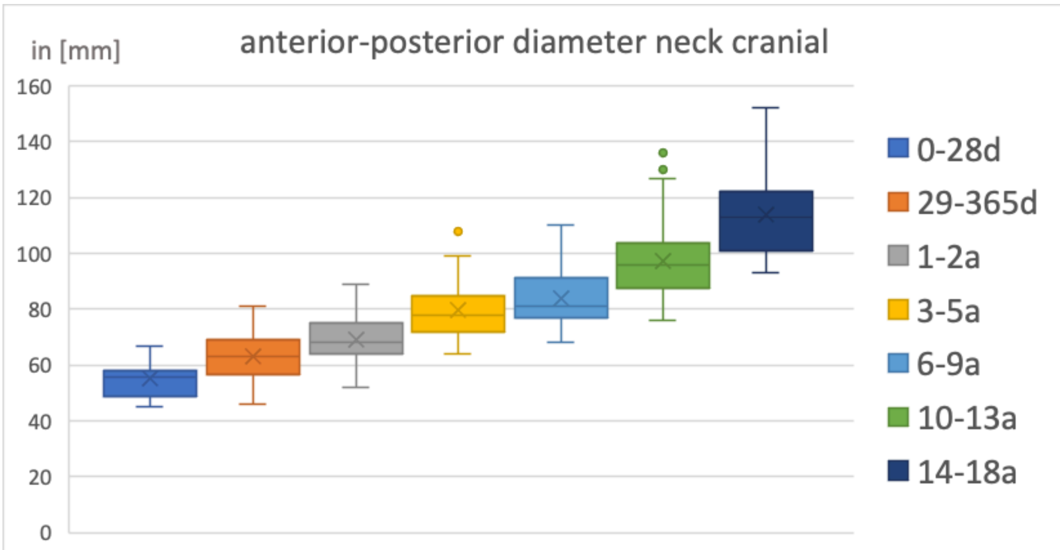


Figure 7: Boxplot to APDN in mm in comparison of the different groups of age

4.2.4 Anterior-posterior diameter of the trachea (=APDT)

Considering the Kolmogorov-Smirnov-Test the APDT could be assumed to have a normal distribution. Within all patients the mean was 10mm with a maximum of 24mm and a minimum of 3mm. The standard deviation was 4mm. The values of the different age groups are displayed in Figure 8. The distribution by age with the exact values can be found in the appendix.

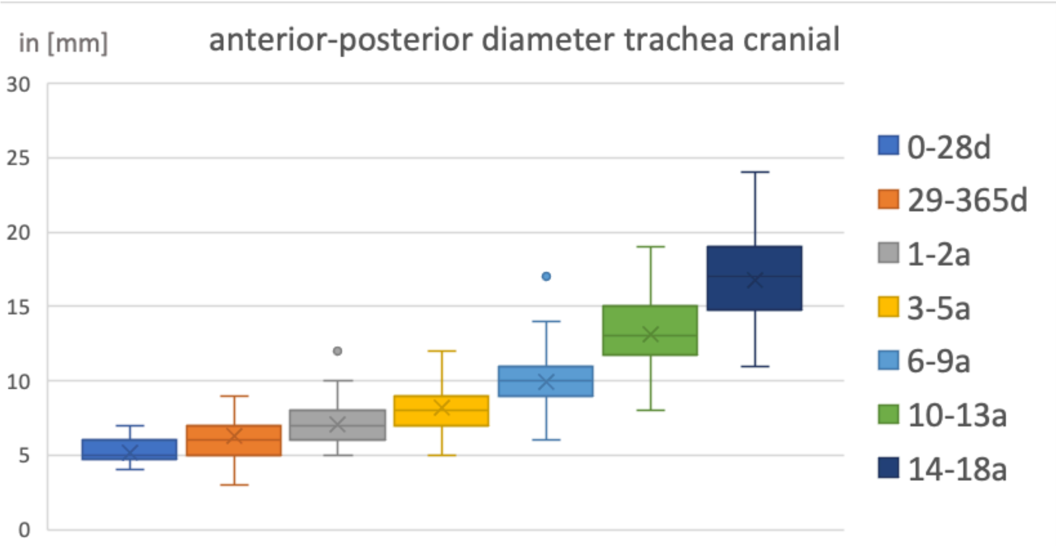


Figure 8: Boxplot to APDT in mm in comparison of the different groups of age

4.2.5 Cranial ventral distance skin to trachea (=crVDST)

Although the boxplot seems left-shifted, considering the Kolmogorov-Smirnov-Test the crVDST could be assumed to have a normal distribution. Overall, the mean was 8mm with a maximum of 22mm and a minimum of 3mm. The standard deviation was 3mm. The values of the different age groups are displayed in Figure 9. The distribution by age with the exact values can be found in the appendix.

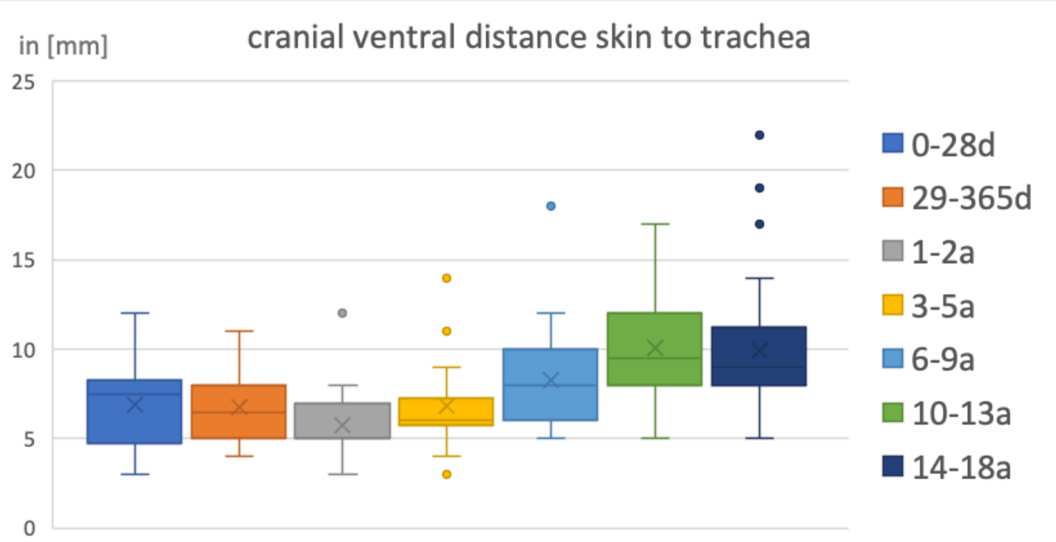


Figure 9: Boxplot to crVDST in mm in comparison of the different groups of age

4.2.6 Mid ventral distance skin to trachea (=mVDST)

Although the boxplot seems left-shifted, considering the Kolmogorov-Smirnov-Test the mVDST could be assumed to have a normal distribution. Within all patients the mean was 13mm with a maximum of 37mm and a minimum of 4mm. The standard deviation was 5mm. The values of the different age groups are displayed in Figure 10. The distribution by age with the exact values can be found in the appendix.

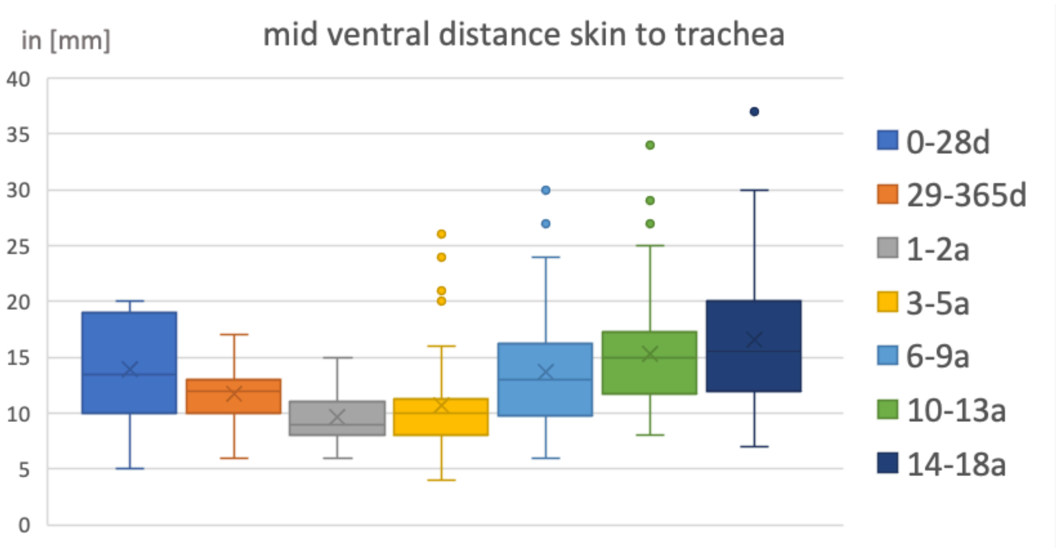


Figure 10: Boxplot to mVDST in mm in comparison of the different groups of age

4.2.7 Caudal ventral distance skin to trachea (=caVDST)

Although the boxplot seems left-shifted, considering the Kolmogorov-Smirnov-Test the caVDST could be assumed to have a normal distribution. Overall, the mean was 32mm with a maximum of 81mm and a minimum of 16mm. The standard deviation was 9mm. The values of the different age groups are displayed in Figure 11. The distribution by age with the exact values can be found in the appendix.

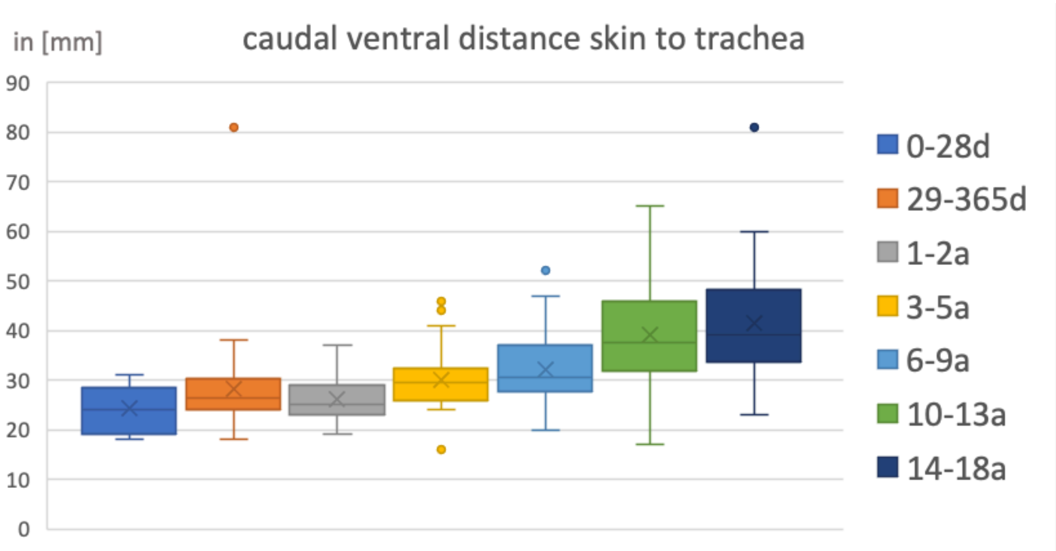


Figure 11: Boxplot to caVDST in mm in comparison of the different groups of age

4.3 *Occurrence of big vessels and OIAS in certain areas*

4.3.1 Cranial anterior

Within all groups, any kind of big vessel or OIAS in the area cranial anterior occurred in 35% [95% CI 30-41].

In 17% it was only one big vessel or OIAS, in 16% there were two and in 2% there were three big vessels or OIAS detected in the cranial anterior area.

The vessels or OIAS which were detected in that area were the following:

- Left anterior jugular vein (18%)
- Right anterior jugular vein (26%)
- thyroid gland (11%)

The results vary by age and, therefore, differ in each group. This is shown in Figure 12.

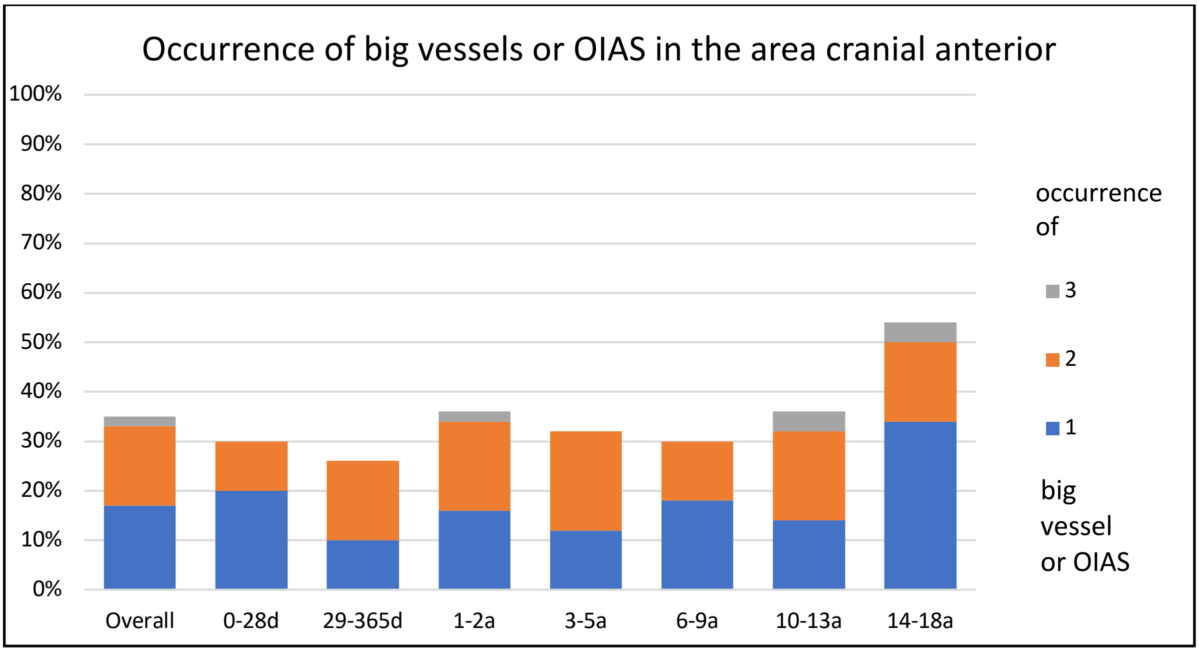


Figure 12: Occurrence of big vessels or OIAS in the area cranial anterior

The table including the exact number in percent of the occurrences can be found in the appendix.

The kind of vessels which occurred in the cranial anterior area in each group are summarized in Figure 13. Furthermore, the exact percentages of the occurrence of the vessels or OIAS of each group can be found in the appendix.

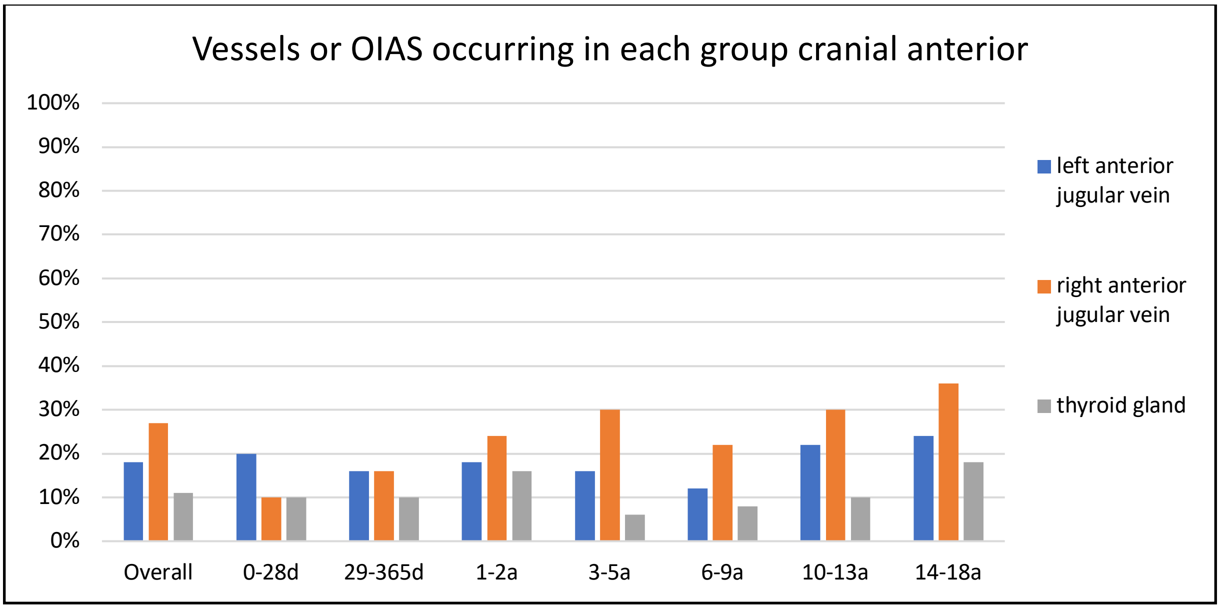


Figure 13: Occurrence of the vessels or OIAS in each group in cranial anterior

4.3.2 Cranial left lateral

Within all groups, any kind of big vessel or OIAS in the area cranial left lateral occurred in 99% [95% CI 98-99].

In 11% it was only one big vessel or OIAS, in 32% there were two, in 27% there were three and in 30% there were four big vessels or OIAS detected in the cranial left lateral area.

The vessels or OIAS which were detected in that area were the following:

- Left common carotid artery (50%)
- Left internal jugular vein (55%)
- Left anterior jugular vein (74%)
- Thyroid gland (97%)

The results vary by age and, therefore, differ in each group. This is shown in Figure 14.

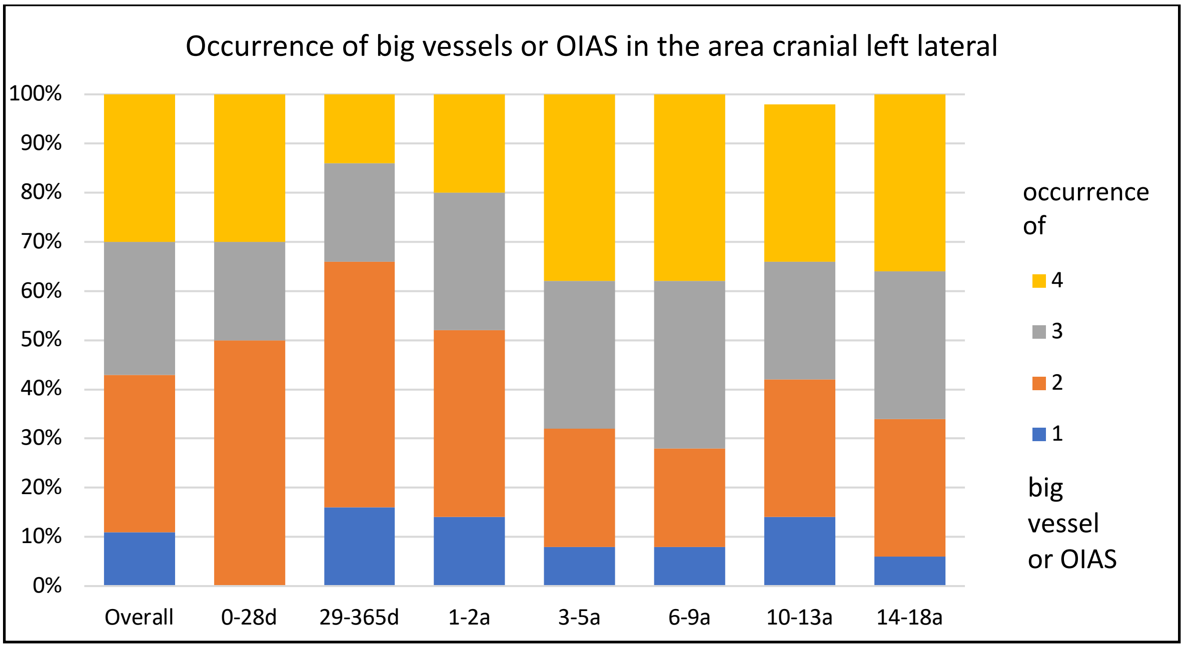


Figure 14: Occurrence of big vessels or OIAS in the area cranial left lateral

The table including the exact number in percent of the occurrences can be found in the appendix.

The kind of vessels which occurred in the cranial left lateral area in each group are summarized in Figure 15. Furthermore, the exact percentages of the occurrence of the vessels or OIAS of each group can be found in the appendix.

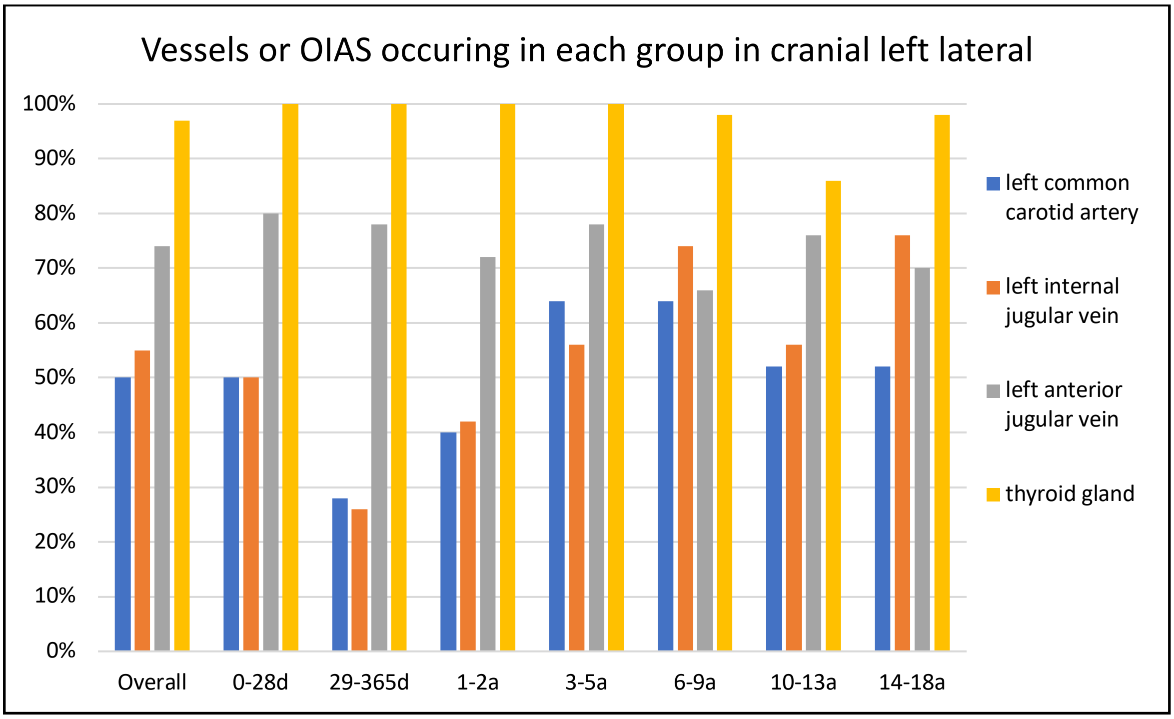


Figure 15: Occurrence of the vessels or OIAS in each group in cranial left lateral

4.3.3 Cranial right lateral

Within all groups, any kind of big vessel or OIAS in the area cranial anterior occurred in 99% [95% CI 97-99].

In 10% it was only one big vessel or OIAS, in 31% there were two, in 29% there were three and in 30% there were four big vessels or OIAS detected in the cranial right lateral area.

The vessels or OIAS which were detected in that area were the following:

- Right common carotid artery (58%)
- Right internal jugular vein (57%)
- Right anterior jugular vein (65%)
- Thyroid gland (98%)

The results vary by age and, therefore, differ in each group. This is shown in Figure 16.

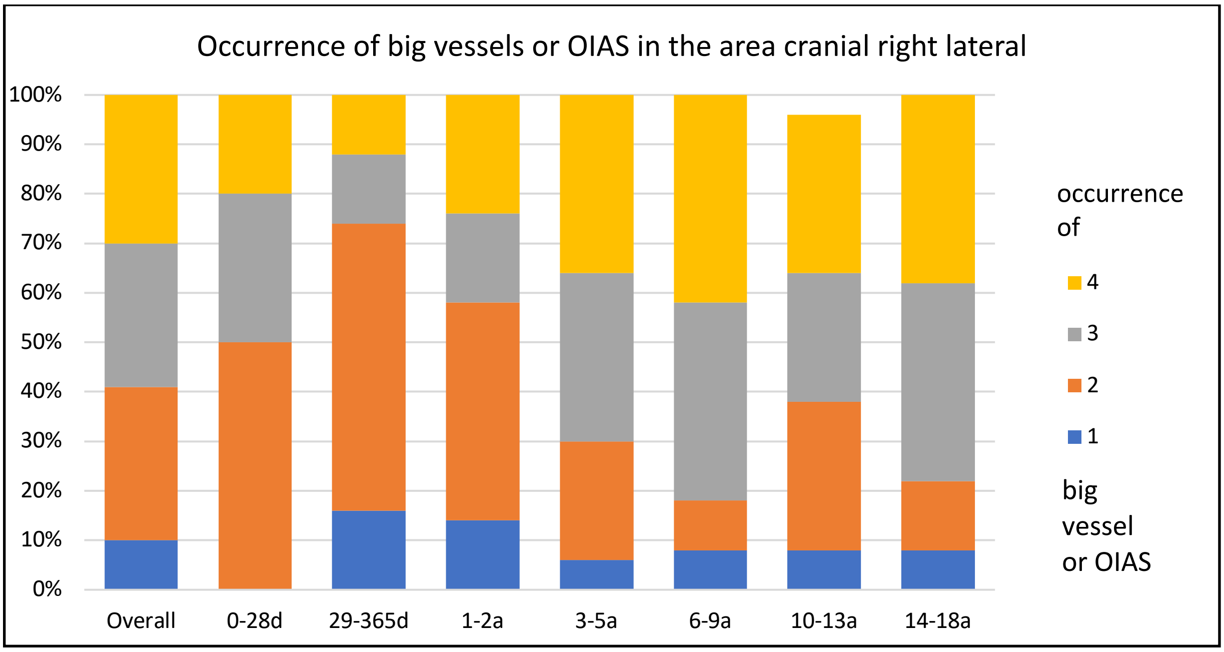


Figure 16: Occurrence of big vessels or OIAS in the area cranial right lateral

The table including the exact number in percent of the occurrences can be found in the appendix.

The kind of vessels which occurred in the cranial right lateral area in each group are summarized in Figure 17. Furthermore, the exact percentages of the occurrence of the vessels or OIAS of each group can be found in the appendix.

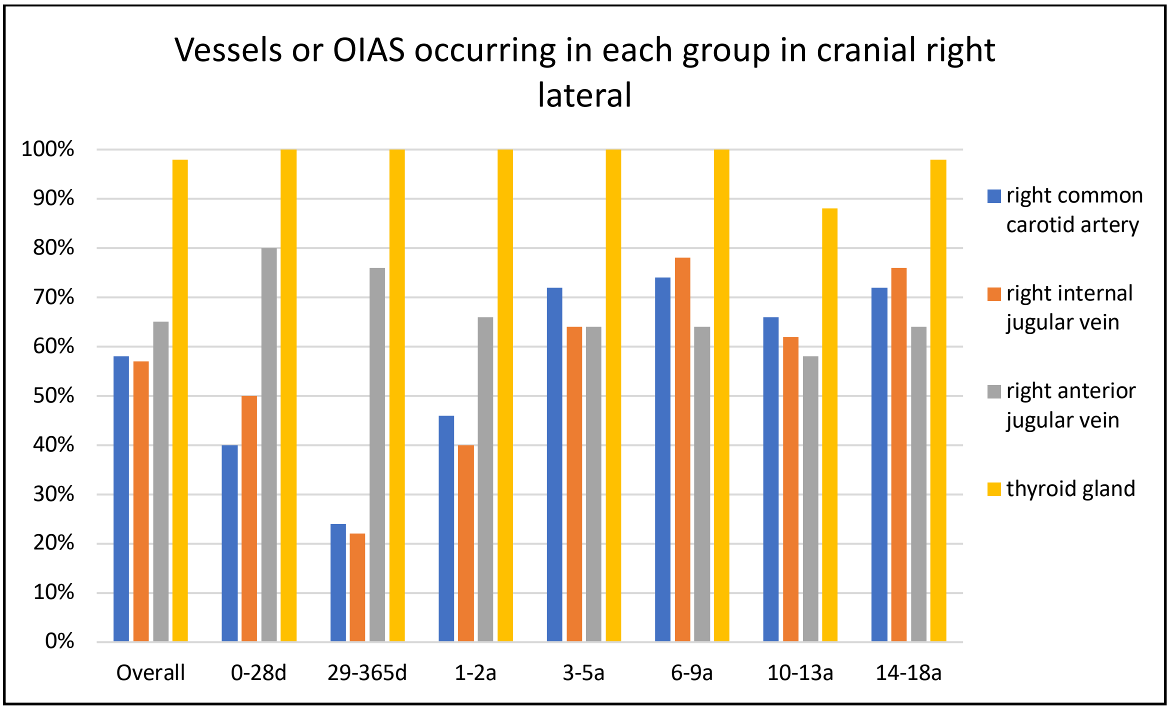


Figure 17: Occurrence of the vessels or OIAS in each group in cranial right lateral

4.3.4 Mid anterior

Within all groups, any kind of big vessel or OIAS in the area mid anterior occurred in 40% [95% CI 35-46].

In 25% it was only one big vessel or OIAS, in 13% there were two and in 2% there were three big vessels or OIAS detected in the mid anterior area.

The vessels or OIAS which were detected in that area were the following:

- Right common carotid artery (3%)
- Brachiocephalic trunk (1%)
- Left anterior jugular vein (14%)
- Right anterior jugular vein (33%)
- Thyroid gland (6%)

The results vary by age and, therefore, differ in each group. This is shown in Figure 18.

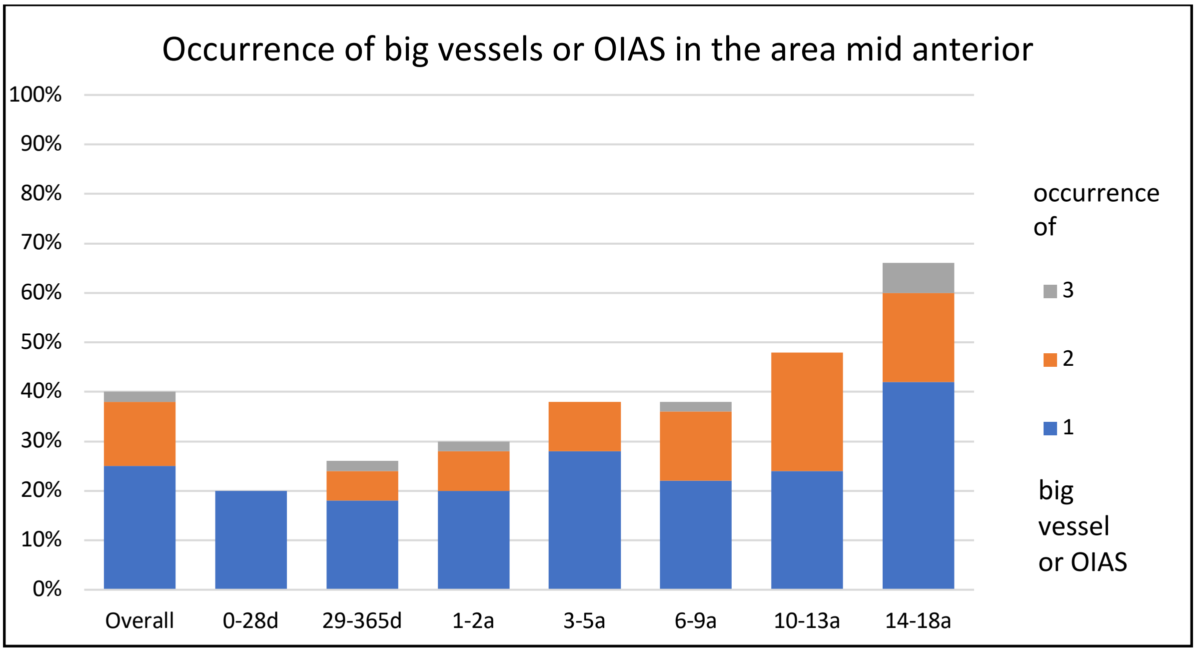


Figure 18: Occurrence of big vessels or OIAS in the area mid anterior

The table including the exact number in percent of the occurrences can be found in the appendix.

The kind of vessels which occurred in the mid anterior area in each group are summarized in Figure 19. Furthermore, the exact percentages of the occurrence of the vessels or OIAS of each group can be found in the appendix.

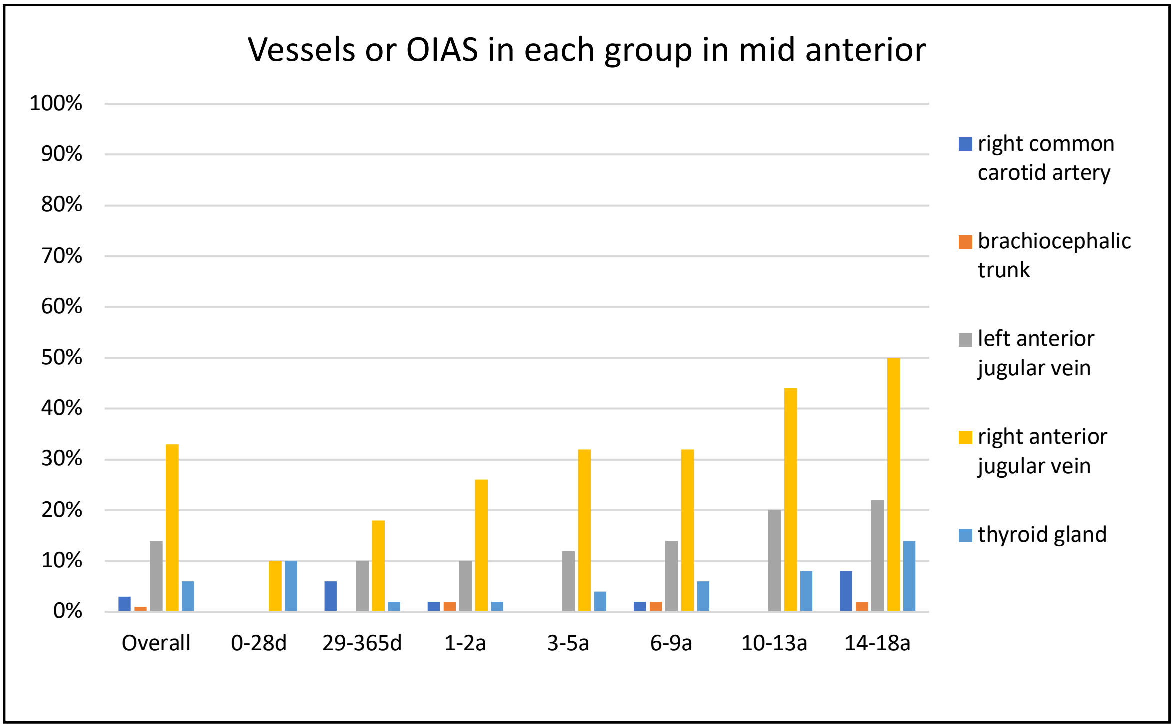


Figure 19: Occurrence of the vessels or OIAS in each group in mid anterior

4.3.5 Mid left lateral

Within all groups, any kind of big vessel or OIAS in the area mid left lateral occurred in 100% [95% CI 98-100].

In 1% there was only one big vessel or OIAS, in 28% there were two, in 57% there were three, in 13% there were four and in 1% there were five big vessels or OIAS detected in the mid left lateral area.

The vessels or OIAS which were detected in that area were the following:

- Left common carotid artery (99%)
- Left innominate vein (1%)
- Left internal jugular vein (99%)
- Left anterior jugular vein (65%)
- Left subclavian artery (3%)
- Left subclavian vein (3%)
- Thyroid gland (6%)

The results vary by age and, therefore, differ in each group. This is shown in Figure 20.

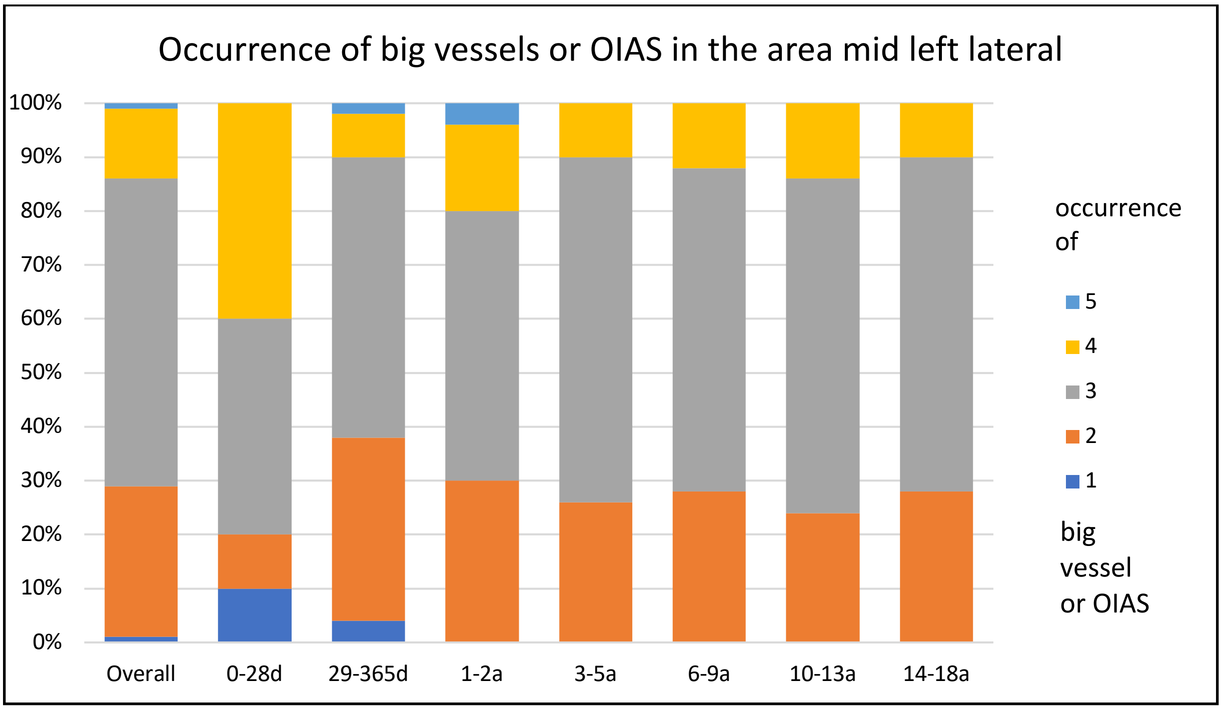


Figure 20: Occurrence of big vessels or OIAS in the area mid left lateral

The table including the exact number in percent of the occurrences can be found in the appendix.

The kind of vessels which occurred in the mid left lateral area in each group are summarized in Figure 21. Furthermore, the exact percentages of the occurrence of the vessels or OIAS of each group can be found in the appendix.

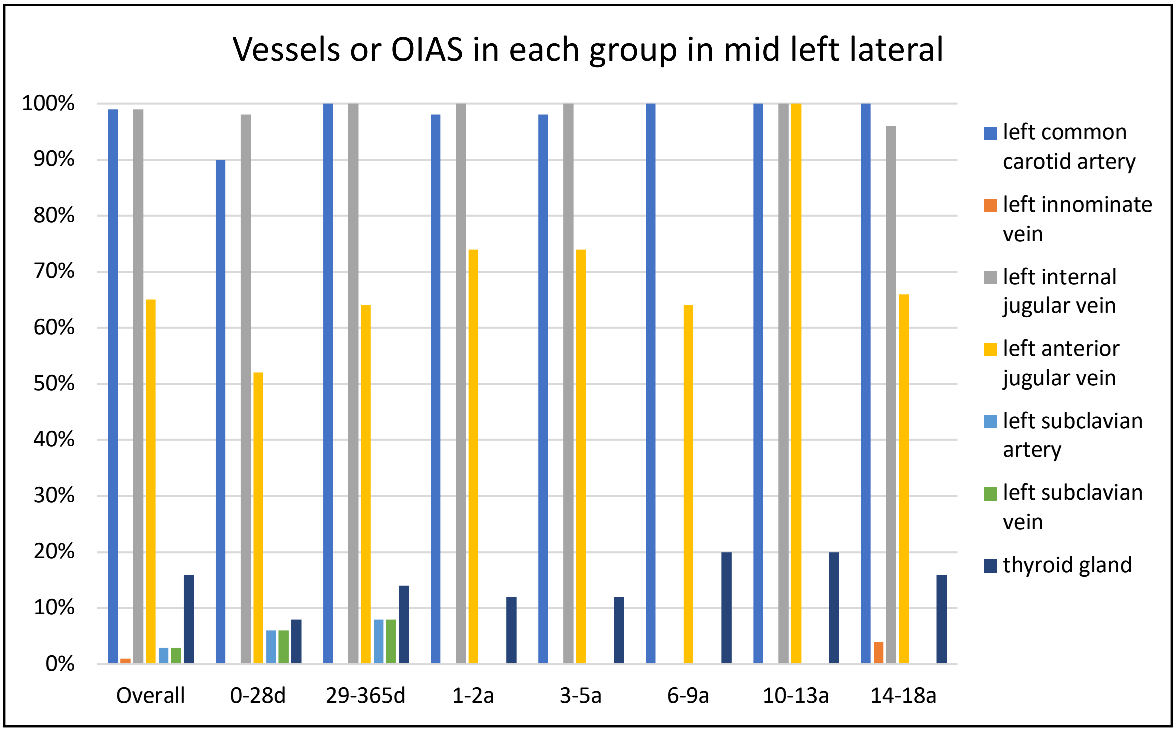


Figure 21: Occurrence of the vessels or OIAS in each group in mid left lateral

4.3.6 Mid right lateral

Within all groups, any kind of big vessel or OIAS in the area mid right lateral occurred in 100% [95% CI 98-100].

In 1% there was only one big vessel or OIAS, in 36% there were two, in 51% there were three, in 10% there were four and in 1% there were five big vessels or OIAS detected in the mid right lateral area.

The vessels or OIAS which were detected in that area were the following:

- Right common carotid artery (97%)
- Brachiocephalic trunk (2%)
- Right innominate vein (3%)
- Right internal jugular vein (97%)
- Right anterior jugular vein (55%)
- Right subclavian artery (4%)
- Right subclavian vein (4%)
- Thyroid gland (12%)

The results vary by age and, therefore, differ in each group. This is shown in Figure 22.

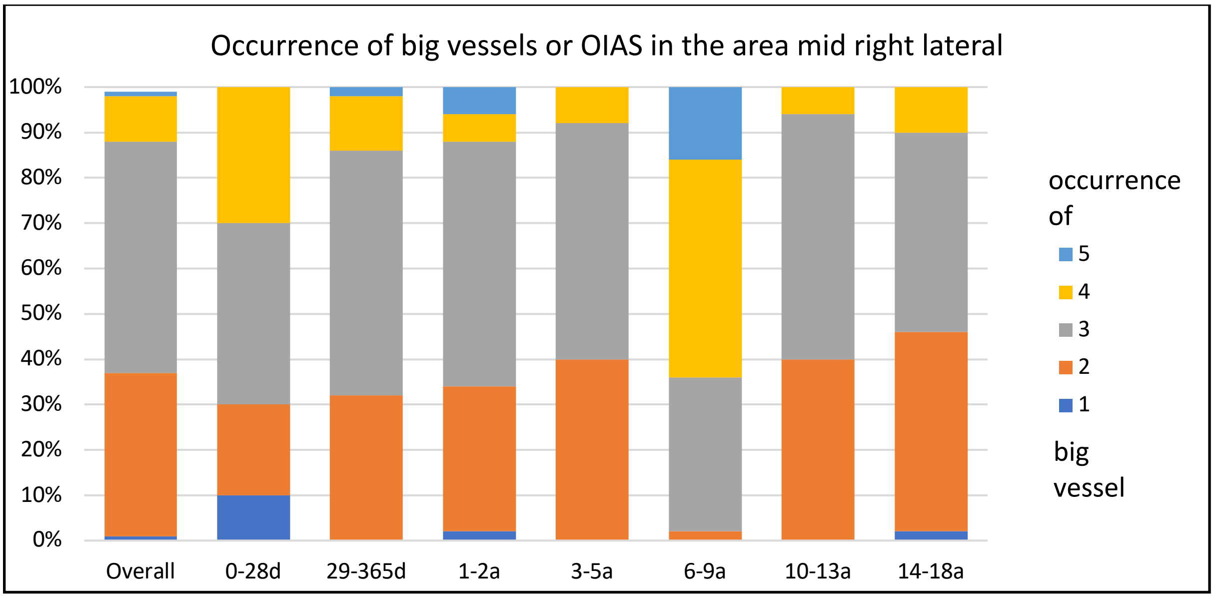


Figure 22: Occurrence of big vessels or OIAS in the area mid right lateral

The table including the exact number in percentage of the occurrences can be found in the appendix.

The kind of vessels which occurred in the mid right lateral area in each group are summarized in Figure 23. Furthermore, the exact percentages of the occurrence of the vessels or OIAS of each group can be found in the appendix.

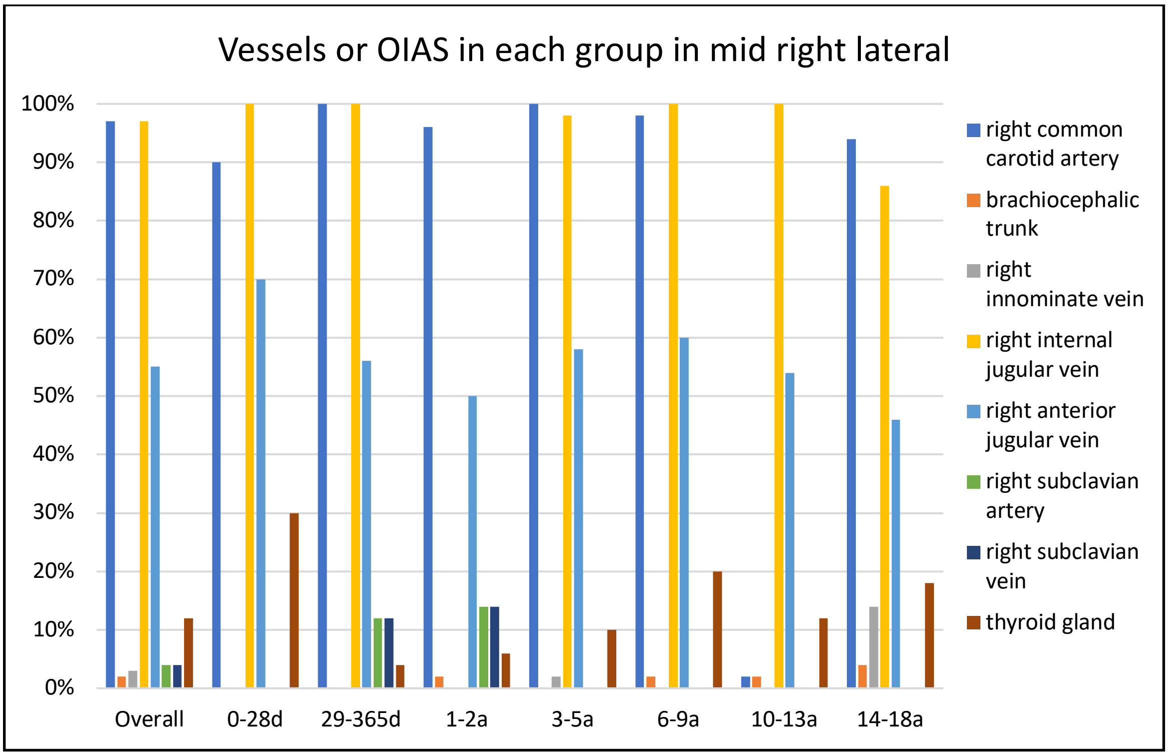


Figure 23: Occurrence of the vessels or OIAS in each group in mid right lateral

4.3.7 Caudal anterior

Within all groups, any kind of big vessel or OIAS in the area caudal anterior occurred in 95% [95% CI 91-97].

In 52% it was only one big vessel or OIAS, in 41% there were two and in 2% there were three big vessels or OIAS detected in the caudal anterior area.

The vessels or OIAS which were detected in that area were the following:

- Left common carotid artery (1%)
- Right common carotid artery (1%)
- Brachiocephalic trunk (78%)
- Left innominate vein (51%)
- Right innominate vein (3%)
- Left anterior jugular vein (1%)
- Right anterior jugular vein (1%)
- Aortic arch (5%)
- Left subclavian artery (1%)

The results vary by age and, therefore, differ in each group. This is shown in Figure 24.

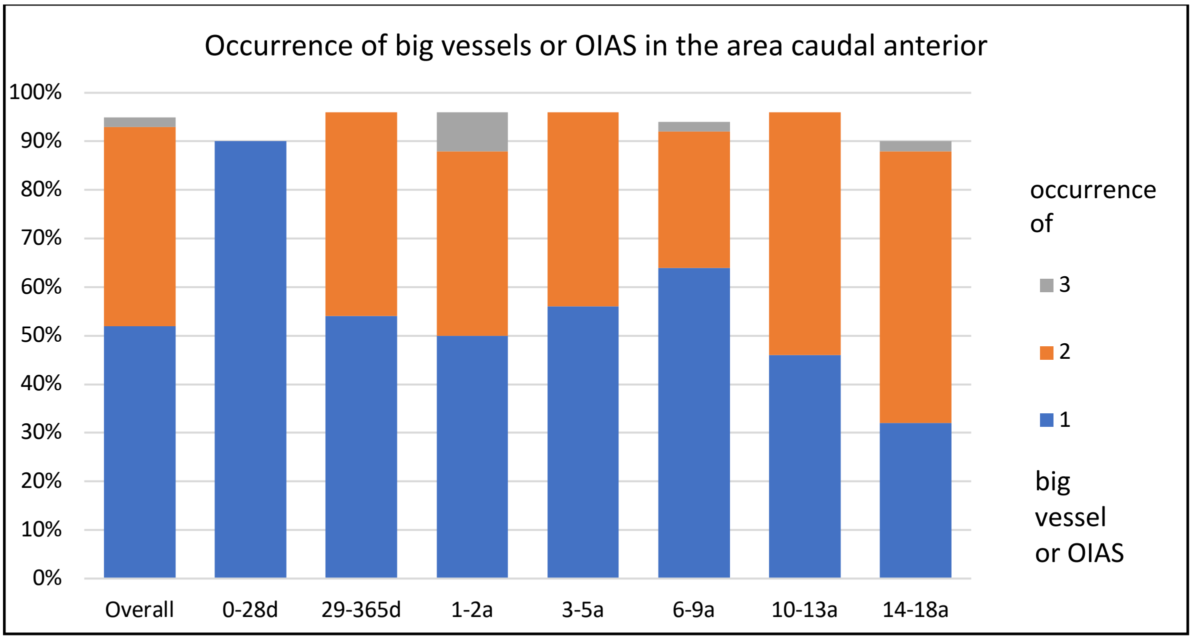


Figure 24: Occurrence of big vessels or OIAS in the area caudal anterior

The table including the exact number in percentage of the occurrences can be found in the appendix.

The kind of vessels which occurred in the caudal anterior area in each group are summarized in Figure 25. Furthermore, the exact percentages of the occurrence of the vessels or OIAS of each group can be found in the appendix.

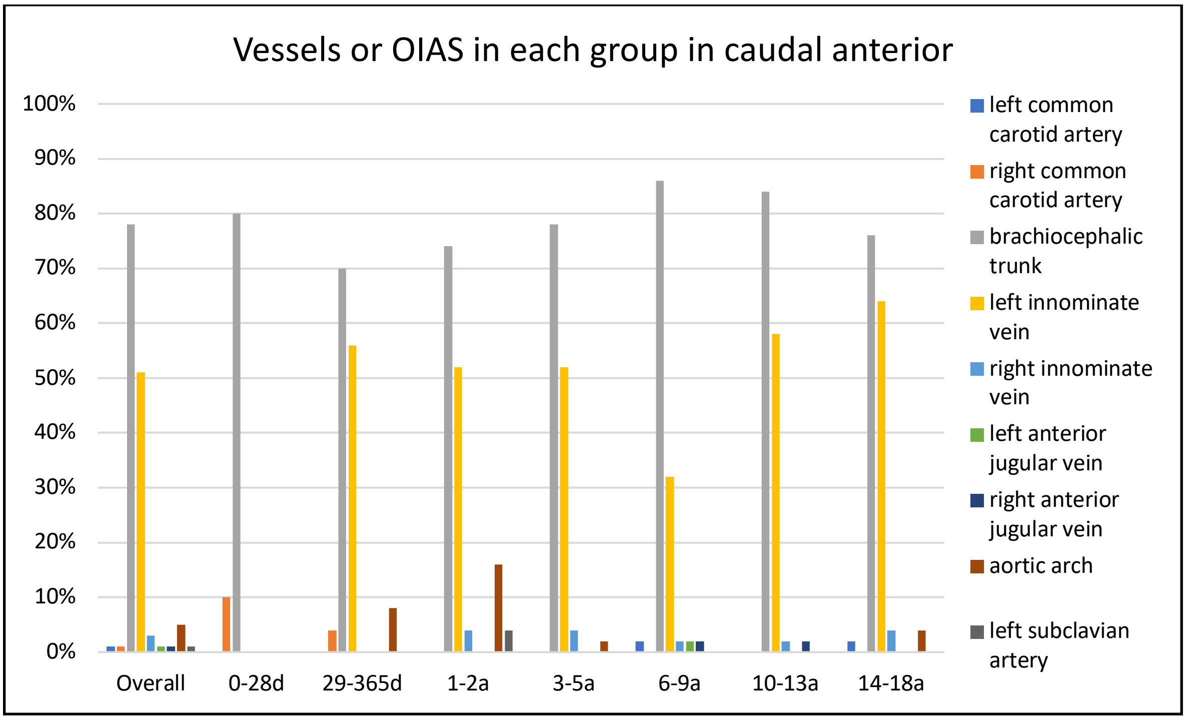


Figure 25: Occurrence of the vessels or OIAS in each group in caudal anterior

4.3.8 Caudal left lateral

Within all groups, any kind of big vessel or OIAS in the area caudal left lateral occurred in 99% [95% CI 97-100].

In 7% there was one big vessel or OIAS, in 34% there were two, in 55% there were three and in 3% there were four big vessels or OIAS detected in the caudal left lateral area.

The vessels or OIAS which were detected in that area were the following:

- Left common carotid artery (84%)
- Brachiocephalic trunk (57%)
- Left innominate vein (98%)
- Left internal jugular vein (1%)
- Left anterior jugular vein (1%)
- Aortic arch (8%)
- Left subclavian vein (4%)

The results vary by age and, therefore, differ in each group. This is shown in Figure 26.

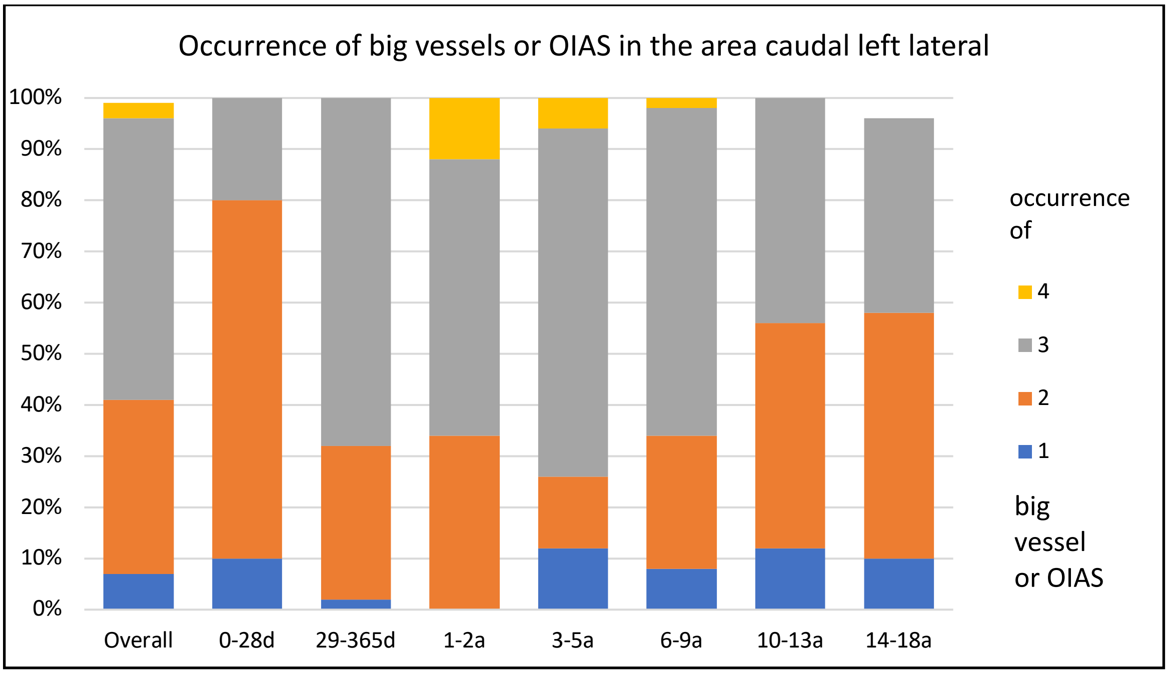


Figure 26: Occurrence of big vessels or OIAS in the area caudal left lateral

The table including the exact number in percentage of the occurrences can be found in the appendix.

The kind of vessels which occurred in the caudal left lateral area in each group are summarized in Figure 27. Furthermore, the exact percentages of the occurrence of the vessels or OIAS of each group can be found in the appendix.

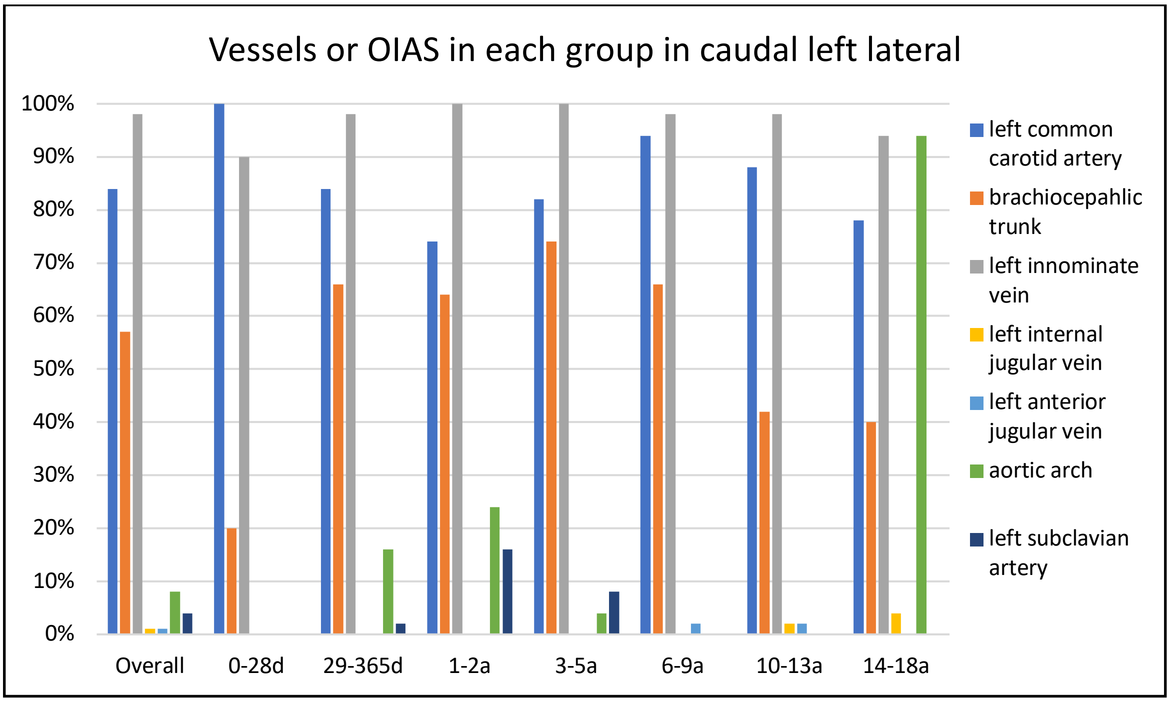


Figure 27: Occurrence of the vessels or OIAS in each group in caudal left lateral

4.3.9 Caudal right lateral

Within all groups, any kind of big vessel or OIAS in the area caudal right lateral occurred in 99% [95% CI 97-99].

In 33% there was one big vessel or OIAS, in 60% there were two, in 6% there were three and in 1% there were four big vessels or OIAS detected in the caudal right lateral area.

The vessels or OIAS which were detected in that area were the following:

- Left common carotid artery (1%)
- Right common carotid artery (3%)
- Brachiocephalic trunk (42%)
- Left innominate vein (25%)
- Right innominate vein (98%)
- Right internal jugular vein (1%)
- Right anterior jugular vein (1%)
- Aortic arch (1%)
- Right subclavian artery (1%)
- Right subclavian vein (1%)

The results vary by age and, therefore, differ in each group. This is shown in Figure 28.

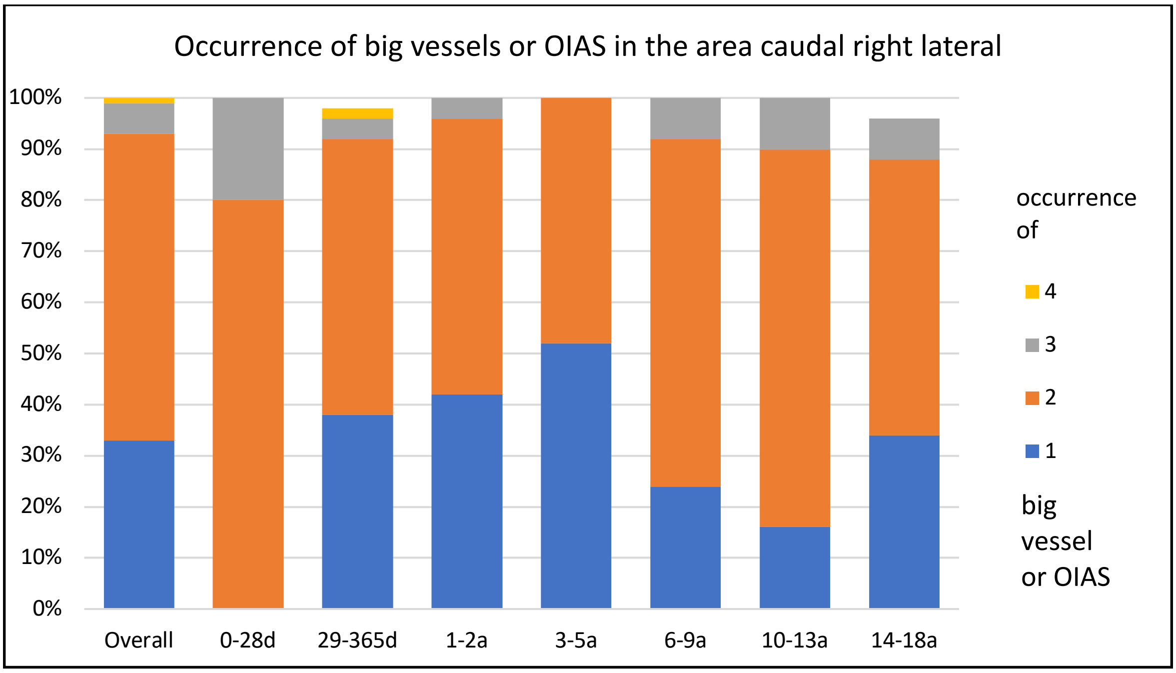


Figure 28: Occurrence of big vessels or OIAS in the area caudal right lateral

The table including the exact number in percentage of the occurrences can be found in the appendix.

The kind of vessels which occurred in the caudal right lateral area in each group are summarized in Figure 29. Furthermore, the exact percentages of the occurrence of the vessels or OIAS of each group can be found in the appendix.

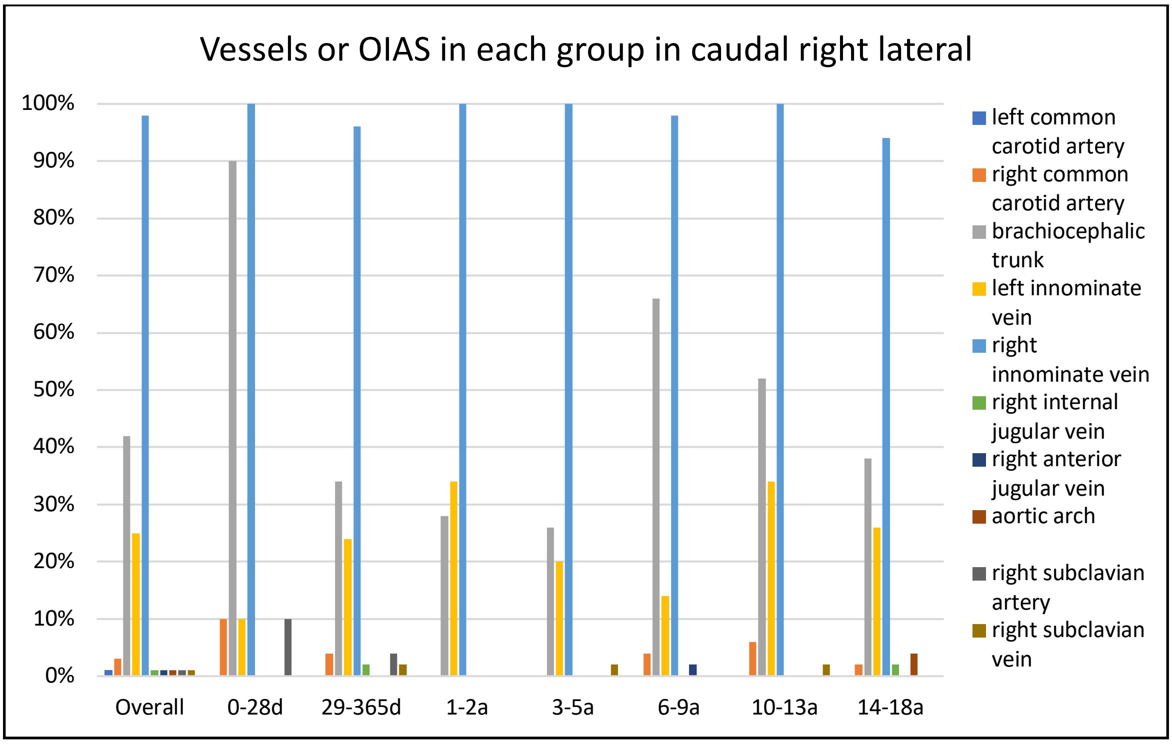


Figure 29: Occurrence of the vessels or OIAS in each group in caudal right lateral

4.4 Comparison of the groups

4.4.1 Distance measurements

Under the use of the Kruskal-Wallis Test a significant difference within all parameters of the overviewing calculations (distance cranial to caudal border, distance cranial border to mid, anterior-posterior diameter of the neck, anterior-posterior diameter of the trachea, cranial, mid and caudal ventral distance between skin and trachea) could be shown.

4.4.2 Occurrence of big vessels and OIAS in certain areas

Considering the Chi-squared-test performed on the two summarized groups (group 1 = 0d – 5a; group 2 = 5a – 18a), no significant differences were shown in most of the areas.

There were two exceptions. First, in the area mid anterior a significant difference between the groups was detected. There have been more vessels or OIAS in older children than in younger children (group 1 = 0d – 5a; group 2 = 5a – 18a).

Additionally, there has been further testing in the area mid anterior on which vessels or OIAS occurred more often. That way a significant difference in the occurrence rate of the left anterior jugular vein (p = 0,028) and the right anterior jugular vein (p = 0,001) in the area mid anterior was proven. Both vessels occurred more often in older than in younger children.

Second, a significant difference between the occurrence rate of the aortic arch in the caudal anterior area has been detected (p = 0,00535). It was more likely to find the aortic arch in the caudal anterior area in younger children.

4.5 Anatomical variabilities

Table 4 gives an overview of the distribution of anatomical variabilities within the overall study group.

Age	Amount of anatomical variabilites	Gender	
		Male	Female
14-18a	2(4%)	0(0%)	2(8%)
10-13a	0(0%)	0(0%)	0(0%)
6-9a	2(4%)	1(4%)	1(4%)
3-5a	2(4%)	2(6%)	0(0%)
1-2a	4(8%)	2(9%)	2(7%)
29-365d	2(4%)	2(8%)	0(0%)
0-28d	0(0%)	0(0%)	0(0%)
Total Result	**12(5%)**	**7(4%)**	**5(3%)**

Table 4: Overview of anatomical variabilities within the overall study group

Furthermore, there were three kinds of anatomical variabilities, which could occur solitary or in combination with one of the other variations. They are listed and explained in the following.

4.5.1 Unusual pathways of vessels

In 7 out of 12 anatomical variabilities, the vessels which usually take a well described, common course through the investigated area ran a different way. This is called an unusual pathway of vessels. The following variabilities were found:

- Four times there was one common trunk for the left common carotid artery and the brachiocephalic trunk, with a separate left subclavian artery, separating from the aortic arch on the left side of the trachea with the brachiocephalic trunk crossing the trachea anterior at the caudal border. Once it also included an additional vessel and one time an additional vessel and any other variety.
- One time the left common carotid artery and the left subclavian artery originated in one common trunk while the brachiocephalic trunk as well separated from the aortic arch on the left side of the trachea and crossed the trachea and the esophagus posterior. Also, an additional vessel occurred.
- One time the right common carotid artery crossed the trachea anterior at mid after separating from a common trunk with the left carotid common artery, while the right subclavian artery, which also originated at the left side of the trachea, crossed the trachea posterior at the caudal border.
- One time the left common carotid artery crossed the trachea anterior at the caudal border after originating from one common trunk with the brachiocephalic trunk at the right side of the trachea. At the same time the left innominate vein formed an arch anterior to the trachea and was thereby displayed twice at the caudal border.

4.5.2 Additional vessels

It was documented that sometimes vessels, which are known to not run through the investigated area, but are usually around or behind it, passed uncommonly through the investigated area. Additionally, sometimes there were new vessels formed. Those variabilities were defined as additional vessels and are mentioned as following:

- One time the left vertebral artery occurred left lateral to the trachea at the caudal border.

- One time the right vertebral artery occurred right lateral to the trachea at mid. Additionally, there occurred an uncommon pathway of vessels, where the left common carotid artery and the brachiocephalic trunk originated in one common trunk from the aortic arch, while the left subclavian artery arose separately.
- One time there was an early separation of the left common carotid artery into the internal and external left carotid artery already at the cranial border. At the same time, the unusual pathway of vessels considering the common trunk for the left subclavian artery and left common carotid artery occurred.
- One time the right common carotid artery has never been formed, while the internal and external right carotid artery originated right from the brachiocephalic trunk. This occurred with an unusual pathway of vessel and another variety at the same time.
- One time the vena cava superior was already formed by the left innominate vein and the right innominate vein on the right side of the trachea at the caudal border.
- One time the left anterior jugular vein and the right anterior jugular vein reached the caudal border, where they built an arch and afterwards, they confluenced with the left innominate vein.
- One time a big venous vessel anterior to the trachea at the caudal border was detected, which could not be identified any closer.

4.5.3 Any other variety

Furthermore, there were variabilities which did not consist of vessel varieties but included OIAS in the investigated area. Those are the following:

- Two times the trachea occurred left shifted. One time an unusual pathway of vessels and an additional vessel existed simultaneously.

5 Discussion

5.1 Comparison between children and adults in vessel anatomy

The study from Weightman et al. published in 2018 demonstrates the prevalence of major vessels in sites of a FONA in adults (2). However, this study differs from the one presented in this paper in several factors. First, Weightman's study was a prospective study and a certain position in the CT scan could be maintained. In the retrospective pediatric study this was not the case. It is uncertain how this might influence the results.

Second, contrary to the pediatric study, within the adult study the area lateral to the trachea was not examined for vessels. Considering the small anatomy and the soft tissues in pediatric patients, it seemed adequate to do so in the pediatric study. Thereby, in at least 99% of the investigated cases a major vessel or OIAS could be found, which is allegeable by the physiological topography of the neck.

Third, in the adult study, only major vessels like the brachiocephalic trunk, the left and right carotid artery, as well as the left and right innominate vein have been analyzed. The little number of checked vessels is listed as a limitation of the adult study. The present study, however, focused on additional big vessels or OIAS, which results in a higher prevalence of vessels in the inspected area. Especially in the area anterior to the trachea, in potential sites of a FONA, a higher frequency of big vessels or OIAS was detected. Therefore, this study has been executed in more detail and predicting a bleeding risk might be more accurate than in the study of Weightman et al. (2). However, it remains unsure how much of a bleeding those vessels would cause.

In the suprasternal notch, in 53% [95% CI 48-57] of the investigated cases big vessels or OIAS occurred in adults, while in children the rate was at around 95% [95% CI 91-97]. Therefore, another calculation was made which only included vessels which have been investigated in the adult study. Interestingly, the occurrence rate in children was still at around 94% [95% CI 91-96]. This was similar in all age groups. In adults as in children, the most common vessel was the brachiocephalic trunk. Although, in 51% of the pediatric patients the left innominate vein crossed to the right side just above the manubrium. In the adult study, it is described that the innominate vein regularly crosses behind the manubrium. It is also worth mentioning, that in children, especially under the age of 5 years, the aortic arch could also be found in the suprasternal notch with an overall chance of 5%.

Furthermore, the adult study showed that in none of the patients a major vessel could be found in front of the cricothyroid membrane. In contrast, in 35% [95% CI 31-40] of the pediatric patients big vessels or OIAS could be found at this position. However, those were only the left and right anterior jugularis vein or the thyroid gland, structures which were not reviewed in the adult study. With an additional calculation, which only included vessels which have been investigated in the adult study, it could be shown that in none of the cases a major vessel could be found in the cranial anterior area as well.
Additionally, a comparison between the prevalence of a major vessel and clinical features such as sex, age and anatomical distances like the length or width of the trachea has been made in the adult study. Only one correlation was discovered: in case of the occurrence of a long trachea above the sternum, a larger number of vessels in the suprasternal notch and above could be found. Such a comparison has not been made in the pediatric study, but would certainly be a great enhancement for the clinical implementation of the study results.

5.2 Pediatric airway dimension and its clinical relevance

By using a systemic literature search Dave et al. (61) wanted to develop a presentation of pediatric airway dimension data from the larynx, trachea and main stem bronchi diameters from the fetus to adolescents. Their goal was to present a general classification which might be useful for airway management. Unfortunately, it was impossible to compile standard reference values because of the heterogeneity of the investigated data. Nonetheless, such reference values would be helpful to recommend certain standardized values, for example, for tube diameters, intubation depth, cuff depth or outer cuff diameter, in relation to the age of the child. With the present study, a significant difference between the age groups was detectable in every distance measurement, therefore, a general classification would be possible. This is enabled by the coherent investigation method. The significant difference within the groups is assumed to be explainable by the physiological growth of children.
The anterior-posterior diameter of the trachea (=APDT) occurred to be a clinically relevant value since it could influence the choice of the ideal method for the establishment of a FONA. According to the study of Koers et al. (15) a scalpel-guided tracheotomy would be the preferred method for a FONA execution. Within their study, they found minimal values of the APDT of 5mm. In the present study, a minimum of the APDT of 3mm was detected. It is questionable, whether the difference of 2 mm could have made an impact on the success rate of the FONA executions and whether it would have changed the recommendation.

Additionally, the success of performing a scalpel-guided tracheotomy on a trachea with a diameter of 3mm including proper ventilation is as well questionable.
Moreover, the ventral distance skin to trachea (=VDST) at different levels lies in the focus of further clinical interest. An increase of the VDST towards the caudal border was detected. At the cranial border the VDST is rather small, with a minimum of 3mm. A very short VDST is assumedly dangerous since any cut with a knife or a percutaneous puncture could easily be too deep. However, when the trachea was bedded further underneath the skin towards the caudal border there were more surrounding structures or tissue anterior to the trachea. On the one hand, this might add a difficulty in detecting the trachea through palpation, on the other hand, it might include more surrounding structures to possibly be injured. Furthermore, some outliners with a higher VDST than average were found, especially in children over the age of 3. In those cases, obesity might be an explanation for the outliners.

5.3 Occurrence of big vessels or OIAS at possible FONA sites, the risk of a bleeding complication and its influence on the execution of a FONA

The main goal of this study was to determine the occurrence of big vessels or OIAS in potential FONA sites in children. In doing so, possible complications while performing either a cricothyroidotomy or a tracheotomy with a scalpel- or needle/cannula-guided-technique can hopefully be prevented.
Bleeding as a complication has been documented in a study from Mutzbauer at el. to occur in about 40% of executed FONA in adults (56). It is additionally listed as a leading complication while executing the procedure in children (10,19,30,53,60,62). A minor bleeding could cause sight problems and difficulties in navigating through anatomical structures. This could immensely raise the emotional stress factor while establishing a FONA on a child (52). Furthermore, extensive bleeding can occur in case of the injury of a major vessel or OIAS. The injury of the aortic arch, the brachiocephalic trunk but also an innominate vein could undoubtedly cause heavy bleeding (2). Then again, some vessels or OIAS, like the anterior jugular veins or the well perfused thyroid gland, are often underestimated but still dangerous (63). It can be assumed that the high occurrence rates of big vessels or OIAS found in this study, indicate a high risk of a bleeding complication in case of a FONA execution.

Additionally, it could be shown that there is an overall higher complication rate, the younger the children are (46). Further, the study suggests that a success rate in establishing a FONA is associated with the confidence of the executer (37) which rises by the age of the children. Within this study, we were able to detect a higher occurrence rate of the aortic arch in the area caudal anterior to the trachea under the age of 5; this results in another drawback considering the execution of a FONA in young children. However, it must be mentioned that considering the Chi-square test no significant difference between the two summarized groups (group 1 = 0d – 5a; group 2 = 5a – 18a) could be found within most of the parameters. This can be explained by the consistency of anatomical structures with the increase of age. It can be assumed that the higher complication rate, which occurs in younger children, originates from the softer and smaller tissue, which stabilizes and grows by age.
In contrast to the FONA in adults (49), some studies recommend performing a tracheotomy instead of a cricothyroidotomy in infants and neonates (14,30). The main reason are the small and soft anatomical structures, which would not allow regular equipment being used without further complications (54,57). It might be difficult, for example, to insert an endotracheal tube. In case of an emergency, though, an intravenous catheter with an extremely sharp cannula could be used (8,52). By connecting the adapter of a small endotracheal tube to the intravenous catheter oxygenation could be established. Unfortunately, regular ventilation could not be performed and the airway access would only be temporary. On the one side, the tracheotomy could be performed straight away, which could save time. On the other side, with establishing oxygenation first, the urgent tracheotomy could be done better arranged and on a lower stress level (57). It could be determined that in 95% [95% CI 91-97] of children of all ages there are more vessels occurring in the caudal area than further cranial 35% [95% CI 31-40]. For this reason, executing a tracheotomy has, compared to a cricothyroidotomy, a higher risk of a big vessel or OIAS occurrence, which might cause a bleeding complication. Additionally, major vessels like the aortic arch occurred in the caudal area with a significantly higher frequency, especially in children until the age of 5 years. Still, the above-mentioned recommendation tends towards a tracheotomy especially in younger and smaller children (14,30). In the end, following the recommendation to rather execute a tracheotomy in neonates and infants might prelude a higher risk for a bleeding complication. Thus, the setting must be considered. In case of an eFONA very little preparation is possible, an inexpertly executer might be on site and the necessary equipment might not be available. In such situations a higher risk of complications can be assumed. On

the other hand, an elective procedure done in an operating theatre performed by a perfectly prepared surgeon with the right equipment could be declared less risky. Especially, to avoid bleeding as a complication, imaging the vessels in the area of a FONA could be helpful to evaluate the risk of a possible complication. At this point it should be mentioned, that within the study the caudal border was defined just above the manubrium. The occurrence rates further up the neck as a possible site for a tracheotomy have not been inspected.

Currently, there is no guideline which declares the right method for establishing a FONA in a pediatric patient. Because of the soft tissue, small anatomical structures and the possibility of the trachea to be fully compressed, some studies recommend executing the FONA scalpel-guided (14,15,32,52,54,58). Unfortunately, all these studies base their results on experiments with piglet or rabbit cadavers. Therefore, bleeding as a complication could only partly be implicated. Other studies hypothesized less vessel or OIAS injuries while establishing the FONA through a needle technique (28,53). The risk of a wall injury through a needle technique could be reduced through the two-operator-technique, where the needle is inserted under air-aspiration for a positional reassurance (59).

Furthermore, when executing a scalpel guided FONA, some studies suggest that it is important to perform a vertical rather than a horizontal incision (57). That way, sliding off to the lateral side of the trachea should be prevented. As defined in the present study, at least 99% of the time big vessels or OIAS occur laterally to the trachea, which supports the recommendation towards a vertical incision. On the other hand, the anterior jugular veins occurred most commonly anterior and are running parallel to the trachea. There might be a higher risk of a longitudinal injury of the anterior jugular veins which might also cause major bleeding. It would need further studies to give a proper recommendation which direction of the incision should be used.

Furthermore, the execution of a FONA in a child is not performed routinely. Therefore, the stress level is assumedly high and profound knowledge and expertise about the local anatomy and the equipment is even more important. Especially, the physiological vessel anatomy in form of a certain landmark or prevalence of big vessels or OIAS should be every executers expertise. Additionally, as an aggravating factor the anatomical settings in each individual differ. Within the study in 5% of the patients some anatomical varieties were found. Thus, unusual pathways of vessels could be assumed to prelude a higher risk of a bleeding complication. This can be explained by the unusual pathways crossing the trachea anterior at one point in all cases. Therefore, while executing a FONA in an assumedly safe area, a vessel with an unusual pathway might run through. Unfortunately, this cannot be seen from the outside. On the other hand, additional vessels have only been detected lateral to the trachea, which should not be the site of a FONA anyways and can, therefore, be assumed to not influence the risk of a bleeding complication. In cases of a left shifted trachea, the anterior area of the trachea was still determined as anterior, therefore, this would not influence the risk of a bleeding complication either. Eventually, some vessel malformations might occur as well in this area (64).

Considering the results of this study, knowing the anatomy of each individual child would be a massive improvement to the quality of the treatment. To do so, using ultrasound for the airway management has become increasingly popular (19). So far, it has been used in elective cases to identify the anatomical structures or to anticipate a difficult airway (65–67). In case of a FONA, ultrasound has already been used to detect the cricothyroid ligament. Compared to palpation, the use of ultrasound took slightly longer, but was highly accurate and easily performed even by fairly-poorly-trained physicians (19,68). Using ultrasound could, therefore, be very useful in detecting structures such as big vessels or OIAS surrounding the trachea (69,70). Especially, anterior of the trachea, the site of a potential FONA (2), vessels compared to the airway should be easily detectable. Also, anatomical varieties, which might cause unpleasant surprises during the execution, could be determined (71). However, further studies would still need to be done.

Different situations would need different actions. In case of an unexpected difficult airway, especially, in neonates and infants a tracheotomy would be the recommended choice (14,30). As mentioned before, it might be beneficial to establish rather quick oxygenation via a cricothyroidotomy and execute an urgent tracheotomy afterwards but with a lower stress level. In case of an expected difficult airway the need of a FONA already is fairly unlikely. Nevertheless, and considering the high occurrence rate of big vessels or OIAS in this study, getting an imaging about the anatomical situation before can be very useful. Especially, because the etiology of an expected difficult airway would be an airway which is either impaired normal or known abnormal. Therefore, physiological anatomy should not be anticipated anyways. As mentioned above, this could be done under the use of ultrasound. Additionally, in case of an elective tracheotomy, good preparation should be presumed and imaging should be done in advance in order to gain knowledge about the relation of the trachea to big vessels or OIAS of the individual (71).

But, who should do what in different situations? First of all, training of the team or the individual executer would be the most important (38). In a pre-hospital eFONA situation, which by itself would lead to a high stress level, the emergency physician would be the executer. With a look at the study results establishing a secure airway through a cricothyroidotomy would have a lower risk of a bleeding complication because of a smaller occurrence rate of big vessels or OIAS. In an in-hospital FONA situation it is as well important to have a well-trained team and adequate equipment (27,38). Overall, it can be said that a FONA is preferably executed by a surgeon, especially an ENT surgeon, with experience in pediatric surgeries in the area of the neck (22,36,46). It can be assumed that a thorough knowledge about the anatomy of the area exists. Additionally, the handling of the small and soft tissue in pediatric patients should be known. The surgical percutaneous airway access should not be done by a pediatric anesthetist though because of too little training. In the absence of a suitable surgeon the FONA should rather be executed needle- or cannula guided and could also be done by pediatric anesthetist (27). It can only be assumed that a surgical percutaneous airway access might lead to a higher risk of a bleeding complication because of the small anatomy even when executed by a surgeon. It can be assumed that a needle- or cannula guided might not harm big vessels or OIAS as much, but the executer would still need a wide knowledge about the anatomy of the individual. Within this study it is difficult to define what the best option would be. Knowledge about the anatomy of the individual in the selected FONA site would be necessary.

To sum up, the hope of a FONA, especially an eFONA situation in a child to not occur is tremendous among regular physicians (48). The stress level is very high and most physicians are poorly trained for this high-risk intervention (32). With this study, the high occurrence rate of big vessels or OIAS, which could possibly cause a minor or major bleeding complication, underlines the high risk of this intervention. However, regardless of all difficulties, recommending a FONA can be the last chance to save the life of a child (14).

5.4 Strengths and limitations

5.4.1 Strengths

First of all, the study was done with data of real children. No animals have been used. Thereby, the anatomical structures were accurate and measured just in the way they would occur in children of all ages. Additionally, due to the selection criteria, the generalizability of the results can be assumed to be rather high.

5.4.2 Limitations

First of all, the study was a radiological study and can, therefore, only deliver anatomical, but no clinical information. However, a prospective clinical trial would not be feasible for this topic, therefore, studies like the one presented in this paper are important.

The study was single centered in Austria. There might be anatomical differences between children of different origins. A multi-centered study could offer more information about the diversity of the data.

Additionally, the small number of included scans can be considered a limitation. Furthermore, the data processing was done by evaluating MRT and CT scans. Therefore, the information has only been collected only through radiological images.

5.5 Conclusion

Within this study, an overview of pediatric airway dimensions was provided and a high occurrence rate of big vessels or OIAS in the area anterior to the trachea in children was found. The prevalence of the big vessels or OIAS increased towards the caudal border of the investigated area. The gathered information could be especially useful for the execution of a FONA in children. The data about the pediatric airway dimensions can be used for choosing the right material. Furthermore, it can help to increase the awareness of physicians about the potentially very small airway in children. The high prevalence of big vessels or OIAS should be considered during the execution of a FONA to assess the risk of a major or minor bleeding complication, especially towards the caudal border. This potential site of a tracheotomy would be more likely recommended in neonates and infants, but so far, the bleeding risk has not been included in those recommendations. Further investigations would be necessary to offer a proper recommendation on the right method and the right site of a FONA. Furthermore, it would be interesting, if big vessels or OIAS could be visualized in advance, for example, by using an ultrasound. Thereby, physicians would have an increased understanding of the individual anatomy and could better assess the potential bleeding risk.

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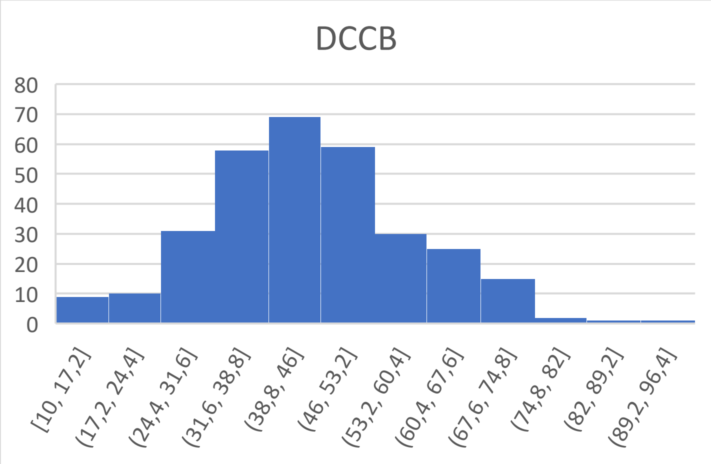
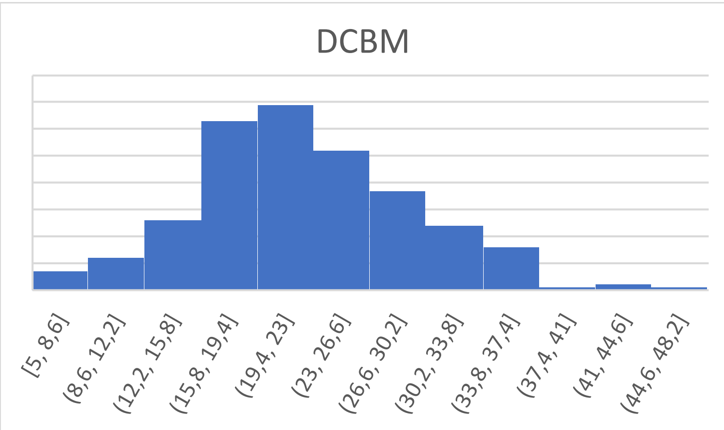
7 Appendix

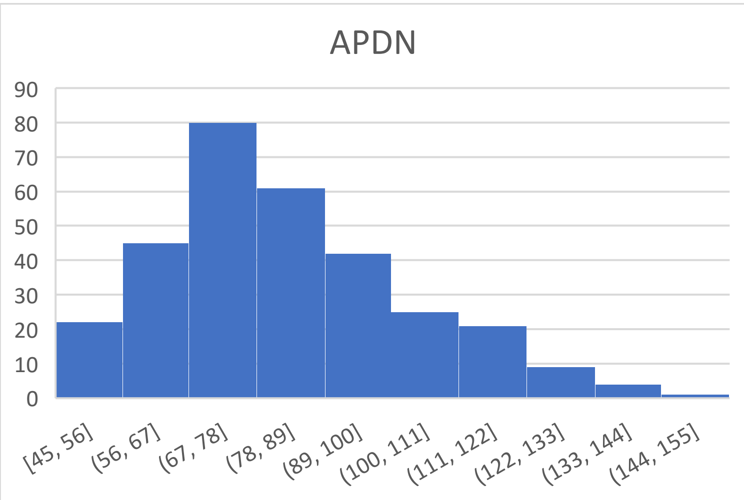
7.1 Histograms of distance measurements



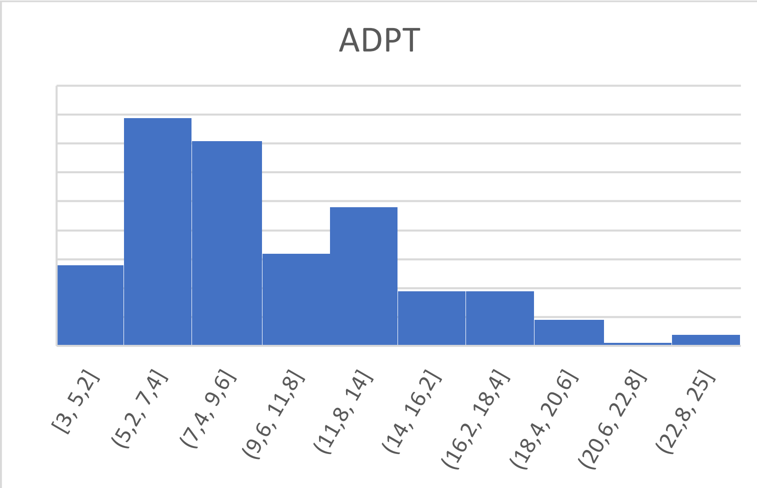
Appendix 1: Histogram on DCCB in mm



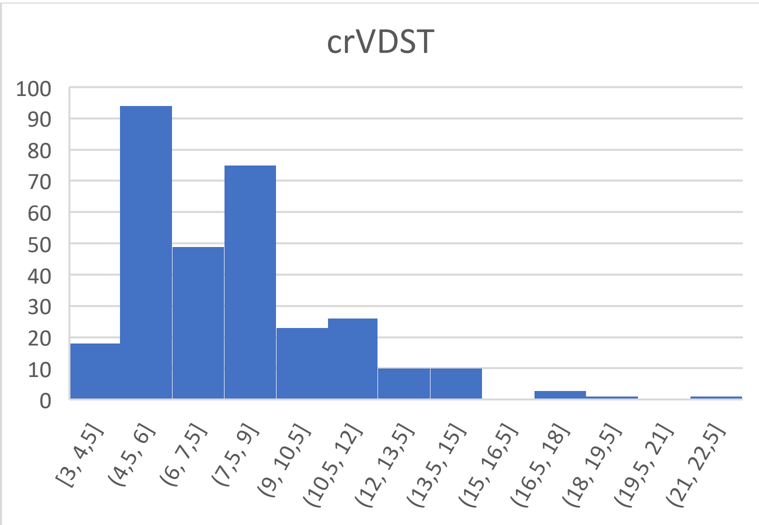
Appendix 2: Histogram on DCBM in mm



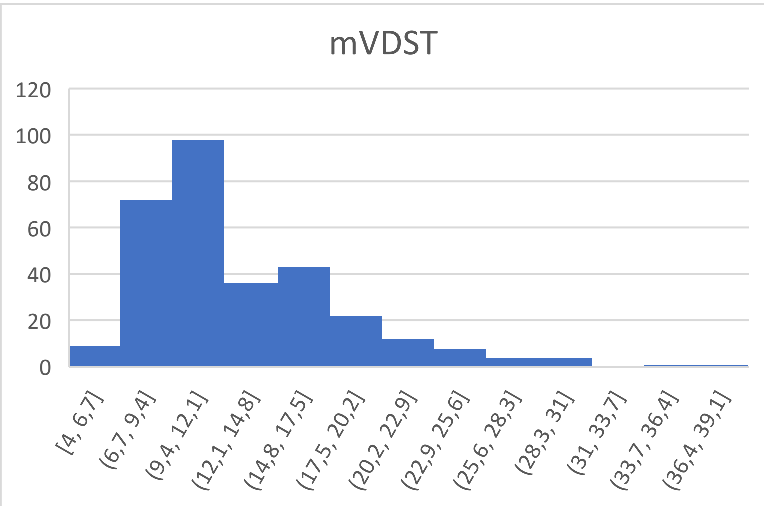
Appendix 3: Histogram on APDN in mm



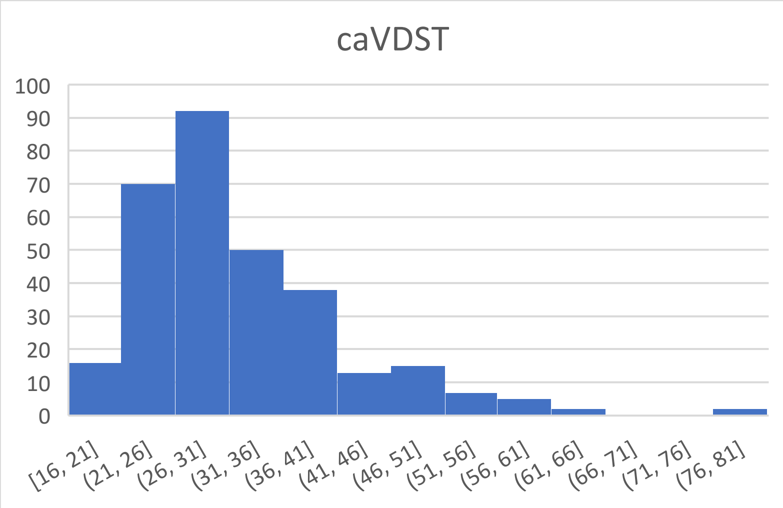
Appendix 4: Histogram on APDT in mm



Appendix 5: Histogram on crVDST in mm



Appendix 6: Histogram on mVDST in mm



Appendix 7: Histogram on caVDST in mm

7.2 Tables on exact values of overviewing measurements in each group

DCCB [mm]				
	Mean	Maximum	Minimum	Standard deviation
Overall	45	95	10	14
0-28d	20	38	10	9
29-365d	30	50	12	7
1-2a	40	60	21	8
3-5a	44	62	28	7
6-9a	44	61	26	8
10-13a	55	95	34	12
14-18a	60	83	40	10

Appendix 8: Exact values of the DCCB in mm in each group

DCRM [mm]				
	Mean	Maximum	Minimum	Standard deviation
Overall	23	48	5	7
0-28d	10	19	5	4
29-365d	15	25	6	3
1-2a	20	30	11	4
3-5a	22	31	14	4
6-9a	22	31	13	4
10-13a	28	48	17	6
14-18a	30	42	20	5

Appendix 9: Exact values of the DCRM in mm in each group

APDN [mm]				
	Mean	Maximum	Minimum	Standard deviation
Overall	83	152	45	20
0-28d	55	67	45	7
29-365d	63	81	46	9
1-2a	69	89	52	8
3-5a	79	108	64	8
6-9a	84	110	68	9
10-13a	97	136	76	13
14-18a	114	152	93	13

Appendix 10: Exact values of the APDN in mm in each group

APDT [mm]				
	Mean	Maximum	Minimum	Standard deviation
Overall	10	24	3	4
0-28d	5	7	4	1
29-365d	6	9	3	1
1-2a	7	12	5	1
3-5a	8	12	5	1
6-9a	10	19	5	2
10-13a	13	19	8	1
14-18a	17	24	11	3

Appendix 11: Exact values of the APDT in mm in each group

crVDST [mm]				
	Mean	Maximum	Minimum	Standard deviation
Overall	8	22	3	3
0-28d	7	12	3	3
29-365d	7	11	4	2
1-2a	6	12	3	2
3-5a	7	14	3	2
6-9a	8	18	5	2
10-13a	10	19	5	3
14-18a	10	22	5	3

Appendix 12: Exact values of the crVDST in mm in each group

mVDST [mm]				
	Mean	Maximum	Minimum	Standard deviation
Overall	13	37	4	5
0-28d	14	20	5	5
29-365d	12	17	6	3
1-2a	10	22	6	3
3-5a	11	26	4	5
6-9a	14	30	6	5
10-13a	15	34	8	6
14-18a	17	37	7	6

Appendix 13: Exact values of the mVDST in mm in each group

caVDST [mm]				
	Mean	Maximum	Minimum	Standard deviation
Overall	32	81	16	9
0-28d	24	31	18	5
29-365d	27	38	18	5
1-2a	26	41	19	4
3-5a	30	44	16	5
6-9a	32	52	20	7
10-13a	39	65	17	10
14-18a	42	81	23	11

Appendix 14: Exact values of the caVDST in mm in each group

7.3 Tables on occurrences of big vessels or OIAS

Occurrence of big vessels or OIAS in the area cranial anterior							
	Any	0	1	2	3	4	5
Overall n=310	35%	65%	17%	2%	0%	0%	0%
0-28d n=10	30%	70%	20%	10%	0%	0%	0%
29-365d n=50	26%	74%	10%	16%	0%	0%	0%
1-2a n=50	36%	64%	16%	18%	2%	0%	0%
3-5a n=50	32%	68%	12%	20%	0%	0%	0%
6-9a n=50	30%	70%	18%	12%	0%	0%	0%
10-13a n=50	36%	64%	14%	18%	4%	0%	0%
14-18a n=50	54%	46%	34%	16%	4%	0%	0%

Appendix 15: Overview on the age distribution within the occurrence of big vessels or OIAS in the area cranial anterior

Occurrence of big vessels or OIAS in the area cranial left lateral							
	Any	0	1	2	3	4	5
Overall n=310	99%	1%	11%	32%	27%	30%	0%
0-28d n=10	100%	0%	0%	50%	20%	30%	0%
29-365d n=50	100%	0%	16%	50%	20%	14%	0%
1-2a n=50	100%	0%	14%	38%	28%	20%	0%
3-5a n=50	100%	0%	8%	24%	30%	38%	0%
6-9a n=50	100%	0%	8%	20%	34%	38%	0%
10-13a n=50	98%	2%	14%	28%	24%	32%	0%
14-18a n=50	100%	0%	6%	28%	30%	36%	0%

Appendix 16: Overview on the age distribution within the occurrence of big vessels or OIAS in the area cranial left lateral

Occurrence of big vessels or OIAS in the area cranial right lateral							
	Any	0	1	2	3	4	5
Overall n=310	99%	1%	10%	31%	29%	30%	0%
0-28d n=10	100%	0%	0%	50%	30%	20%	0%
29-365d n=50	100%	0%	16%	58%	14%	12%	0%
1-2a n=50	100%	0%	14%	44%	18%	24%	0%
3-5a n=50	100%	0%	6%	24%	34%	36%	0%
6-9a n=50	100%	0%	8%	10%	40%	42%	0%
10-13a n=50	96%	4%	8%	30%	26%	32%	0%
14-18a n=50	100%	0%	8%	14%	40%	38%	0%

Appendix 17: Overview on the age distribution within the occurrence of big vessels or OIAS in the area cranial right lateral

Occurrence of big vessels or OIAS in the area mid anterior							
	Any	0	1	2	3	4	5
Overall n=310	40%	60%	25%	13%	2%	0%	0%
0-28d n=10	20%	80%	20%	0%	0%	0%	0%
29-365d n=50	26%	74%	18%	6%	2%	0%	0%
1-2a n=50	30%	70%	20%	8%	2%	0%	0%
3-5a n=50	38%	62%	28%	10%	0%	0%	0%
6-9a n=50	38%	62%	22%	14%	2%	0%	0%
10-13a n=50	48%	52%	24%	24%	0%	0%	0%
14-18a n=50	66%	34%	42%	18%	6%	0%	0%

Appendix 18: Overview on the age distribution within the occurrence of big vessels or OIAS in the area mid anterior

Occurrence of big vessels or OIAS in the area mid left lateral							
	Any	0	1	2	3	4	5
Overall n=310	100%	0%	1%	28%	57%	13%	1%
0-28d n=10	100%	0%	10%	10%	40%	40%	0%
29-365d n=50	100%	0%	4%	34%	52%	8%	2%
1-2a n=50	100%	0%	0%	30%	50%	16%	4%
3-5a n=50	100%	0%	0%	26%	64%	10%	0%
6-9a n=50	100%	0%	0%	28%	60%	12%	0%
10-13a n=50	100%	0%	0%	24%	62%	14%	0%
14-18a n=50	100%	0%	0%	28%	62%	10%	0%

Appendix 19: Overview on the age distribution within the occurrence of big vessels or OIAS in the area mid left lateral

Occurrence of big vessels or OIAS in the area mid right lateral							
	Any	0	1	2	3	4	5
Overall n=310	100%	0%	1%	36%	52%	10%	1%
0-28d n=10	100%	0%	10%	20%	40%	30%	0%
29-365d n=50	100%	0%	0%	32%	54%	12%	2%
1-2a n=50	100%	0%	2%	32%	54%	6%	6%
3-5a n=50	100%	0%	0%	40%	52%	8%	0%
6-9a n=50	100%	0%	0%	2%	34%	48%	16%
10-13a n=50	100%	0%	0%	40%	54%	6%	0%
14-18a n=50	100%	0%	2%	44%	44%	10%	0%

Appendix 20: Overview on the age distribution within the occurrence of big vessels or OIAS in the area mid right lateral

Occurrence of big vessels or OIAS in the area caudal anterior							
	Any	0	1	2	3	4	5
Overall n=310	95%	5%	52%	41%	2%	0%	0%
0-28d n=10	90%	10%	90%	0%	0%	0%	0%
29-365d n=50	96%	4%	54%	42%	0%	0%	0%
1-2a n=50	96%	4%	50%	38%	8%	0%	0%
3-5a n=50	96%	4%	56%	40%	0%	0%	0%
6-9a n=50	94%	6%	64%	28%	2%	0%	0%
10-13a n=50	96%	4%	46%	50%	0%	0%	0%
14-18a n=50	90%	10%	32%	56%	2%	0%	0%

Appendix 21: Overview on the age distribution within the occurrence of big vessels or OIAS in the area caudal anterior

Occurrence of big vessels or OIAS in the area caudal left lateral							
	Any	0	1	2	3	4	5
Overall n=310	99%	1%	7%	34%	55%	3%	0%
0-28d n=10	100%	0%	10%	70%	20%	0%	0%
29-365d n=50	100%	0%	2%	30%	68%	0%	0%
1-2a n=50	100%	0%	0%	34%	54%	12%	0%
3-5a n=50	100%	0%	12%	14%	68%	6%	0%
6-9a n=50	100%	0%	8%	26%	64%	2%	0%
10-13a n=50	100%	0%	12%	44%	44%	0%	0%
14-18a n=50	96%	4%	10%	48%	38%	0%	0%

Appendix 22: Overview on the age distribution within the occurrence of big vessels or OIAS in the area caudal left lateral

Occurrence of big vessels or OIAS in the area caudal right lateral							
	Any	0	1	2	3	4	5
Overall n=310	99%	1%	33%	60%	6%	1%	0%
0-28d n=10	100%	0%	0%	80%	20%	0%	0%
29-365d n=50	98%	2%	38%	54%	4%	2%	0%
1-2a n=50	100%	0%	42%	54%	4%	0%	0%
3-5a n=50	100%	0%	52%	48%	0%	0%	0%
6-9a n=50	100%	0%	24%	68%	8%	0%	0%
10-13a n=50	100%	0%	16%	74%	10%	0%	0%
14-18a n=50	96%	4%	34%	54%	8%	0%	0%

Appendix 23: Overview on the age distribution within the occurrence of big vessels or OIAS in the area caudal right lateral

Tables on occurrences of each vessel or OIAS in each group

7.3.1 Abbreviations

AA	aortic arch
BCT	brachiocephalic trunk
LAJV	left anterior jugular vein
LCCA	left common carotid artery
LIJV	left internal jugular vein
LIV	left innominate vein
LSA	left subclavian artery
LSV	left subclavian vein
RAJV	right anterior jugular vein
RCCA	right common carotid artery
RIJV	right internal jugular vein
RIV	right innominate vein
RSA	right subclavian artery
RSV	right subclavian vein
TG	thyroid gland

7.3.2 Tables

Kind of vessel occurring cranial anterior overall and in Group 1-3			
Overall	Group 1	Group 2	Group 3
LAJV (18%) RAJV (27%) TG (11%)	LAJV (20%) RAJV (10%) TG (10%)	LAJV (16%) RAJV (16%) TG (10%)	LAJV (18%) RAJV (24%) TG (16%)

Appendix 24: Kind of vessel occurring in the area cranial anterior overall and in group 1-3

Kind of vessel cranial anterior occurring in Group 4-7			
Group 4	Group 5	Group 6	Group 7
LAJV (16%) RAJV (30%) TG (6%)	LAJV (12%) RAJV (22%) TG (8%)	LAJV (22%) RAJV (30%) TG (10%)	LAJV (24%) RAJV (36%) TG (18%)

Appendix 25: Kind of vessel occurring in the area cranial anterior in group 4-7

Kind of vessel occurring cranial left lateral overall and in Group 1-3			
Overall	Group 1	Group 2	Group 3
LCCA (50%) LIJV (55%) LAJV (74%) TG (97%)	LCCA (50%) LIJV (50%) LAJV (80%) TG (100%)	LCCA (28%) LIJV (26%) LAJV (78%) TG (100%)	LCCA (40%) LIJV (42%) LAJV (72%) TG (100%)

Appendix 26: Kind of vessel occurring in the area cranial left lateral overall and in group 1-3

Kind of vessel occurring cranial left lateral in Group 4-7			
Group 4	Group 5	Group 6	Group 7
LCCA (64%) LIJV (56%) LAJV (78%) TG (100%)	LCCA (64%) LIJV (74%) LAJV (66%) TG (98%)	LCCA (52%) LIJV (56%) LAJV (76%) TG (86%)	LCCA (52%) LIJV (76%) LAJV (70%) TG (98%)

Appendix 27: Kind of vessel occurring in the area cranial left lateral in group 4-7

Kind of vessel occurring cranial right lateral overall and in Group 1-3			
Overall	Group 1	Group 2	Group 3
RCCA (58%) RIJV (57%) RAJV (65%) TG (98%)	RCCA (40%) RIJV (50%) RAJV (80%) TG (100%)	RCCA (24%) RIJV (22%) RAJV (76%) TG (100%)	RCCA (46%) RIJV (40%) RAJV (66%) TG (100%)

Appendix 28: Kind of vessel occurring in the area cranial right lateral overall and in group 1-3

Kind of vessel occurring cranial right lateral in Group 4-7			
Group 4	Group 5	Group 6	Group 7
RCCA (72%) RIJV (64%) RAJV (64%) TG (100%)	RCCA (74%) RIJV (78%) RAJV (64%) TG (100%)	RCCA (66%) RIJV (62%) RAJV (58%) TG (88%)	RCCA (72%) RIJV (76%) RAJV (64%) TG (98%)

Appendix 29: Kind of vessel occurring in the area cranial right lateral in group 4-7

Kind of vessel occurring mid anterior overall and in Group 1-3			
Overall	Group 1	Group 2	Group 3
RCCA (3%) BCT (1%) LAJV (14%) RAJV (33%) TG (6%)	RAJV (10%) TG (10%)	RCCA (6%) LAJV (10%) RAJV (18%) TG (2%)	RCCA (2%) BCT (2%) LAJV (10%) RAJV (26%) TG (2%)

Appendix 30: Kind of vessel occurring in the area mid anterior overall and in group 1-3

Kind of vessel occurring mid anterior in Group 4-7			
Group 4	Group 5	Group 6	Group 7
LAJV (12%) RAJV (32%) TG (4%)	RCCA (2%) BCT (2%) LAJV (14%) RAJV (32%) TG (6%)	LAJV (20%) RAJV (44%) TG (8%)	RCCA (8%) BCT (2%) LAJV (22%) RAJV (50%) TG (14%)

Appendix 31: Kind of vessel occurring in the area mid anterior in group 4-7

Kind of vessel occurring mid left lateral overall and in Group 1-3			
Overall	Group 1	Group 2	Group 3
LCCA (99%) LIV (1%) LIJV (99%) LAJV (65%) LSA (3%) LSV (3%) TG (16%)	LCCA (90%) LIJV (100%) LAJV (80%) TG (40%)	LCCA (96%) LIJV (98%) LAJV (52%) LSA (6%) LSV (6%) TG (8%)	LCCA (100%) LIJV (100%) LAJV (64%) LSA (8%) LSV (8%) TG (14%)

Appendix 32: Kind of vessel occurring in the area mid left lateral overall and in group 1-3

Kind of vessel occurring mid left lateral in Group 4-7			
Group 4	Group 5	Group 6	Group 7
LCCA (98%) LIJV (100%) LAJV (74%) TG (12%)	LCCA (100%) LAJV (64%) TG (20%)	LCCA (100%) LIJV (100%) LAJV (70%) TG (20%)	LCCA (100%) LIV (4%) LIJA (96%) LAJV (66%) TG (16%)

Appendix 33: Kind of vessel occurring in the area mid left lateral in group 4-7

Kind of vessel occurring mid right lateral overall and in Group 1-3			
Overall	Group 1	Group 2	Group 3
RCCA (97%) BCT (2%) RIV (3%) RIJV (97%) RAJV (55%) RSA (4%) RSV (4%) TG (12%)	RCCA (90%) RIJV (100%) RAJV (70%) TG (30%)	RCCA (100%) RIJV (100%) RAJV (56%) RSA (12%) RSV (12%) TG (4%)	RCCA (96%) BCT (2%) RAJV (50%) RSA (14%) RSV (14%) TG (6%)

Appendix 34: Kind of vessel occurring in the area mid right lateral overall and in group 1-3

Kind of vessel occurring mid right lateral in Group 4-7			
Group 4	Group 5	Group 6	Group 7
RCCA (100%) RIV (2%) RIJV (98%) RAJV (58%) TG (10%)	RCCA (98%) BCT (2%) RIJV (100%) RAJV (60%) TG (20%)	RCCA (2%) BCT (2%) RIJV (100%) RAJV (54%) TG (12%)	RCCA (94%) BCT (4%) RIV (14%) RIJV (86%) RAJV (46%) TG (18%)

Appendix 35: Kind of vessel occurring in the area mid right lateral in group 4-7

Kind of vessel occurring overall caudal anterior and in Group 1-3			
Overall	Group 1	Group 2	Group 3
LCCA (1%) RCCA (1%) BCT (78%) LIV (51%) RIV (3%) LAJV (1%) RAJV (1%) AA (5%) LSA (1%)	RCCA (10%) BCT (80%)	RCCA (4%) BCT (70%) LIV (56%) AA (8%)	BCT (74%) LIV (52%) RIV (4%) AA (16%) LSA (4%)

Appendix 36: Kind of vessel occurring in the area caudal anterior overall and in group 1-3

Kind of vessel occurring caudal anterior in Group 4-7			
Group 4	Group 5	Group 6	Group 7
BCT (78%) LIV (52%) RIV (4%) AA (2%)	LCCA (2%) BCT (86%) LIV (32%) RIV (2%) LAJV (2%) RAJV (2%)	BCT (84%) LIV (58%) RIV (2%) RAJV (2%)	LCCA (2%) BCT (76%) LIV (64%) RIV (4%) AA (4%)

Appendix 37: Kind of vessel occurring in the area caudal anterior in group 4-7

Kind of vessel occurring overall and in Group 1-3			
Overall	Group 1	Group 2	Group 3
LCCA (84%) BCT (57%) LIV (98%) LIJV (1%) LAJV (1%) AA (8%) LSA (4%)	LCCA (100%) BCT (20%) LIV (90%)	LCCA (84%) BCT (66%) LIV (98%) AA (16%) LSA (2%)	LCCA (74%) BCT (64%) LIV (100%) AA (24%) LSA (16%)

Appendix 38: Kind of vessel occurring in the area caudal left lateral overall and in group 1-3

Kind of vessel occurring in Group 4-7			
Group 4	Group 5	Group 6	Group 7
LCCA (82%) BCT (74%) LIV (100%) AA (4%) LSA (8%)	LCCA (94%) BCT (66%) LIV (98%) LAJV (2%)	LCCA (88%) BCT (42%) LIV (98%) LIJV (2%) LAJV (2%)	LCCA (78%) BCT (40%) LIV (94%) LIJV (4%) AA (94%)

Appendix 39: Kind of vessel occurring in the area caudal left lateral in group 4-7

Kind of vessel occurring overall and in Group 1-3			
Overall	Group 1	Group 2	Group 3
LCCA (1%) RCCA (3%) BCT (42%) LIV (25%) RIV (98%) RIJV (1%) RAJV (1%) AA (1%) RSA (1%) RSV (1%)	RCCA (10%) BCT (90%) LIV (10%) RIV (100%) RSA (10%)	RCCA (4%) BCT (34%) LIV (24%) RIV (96%) RIJV (2%) RSA (4%) RSV (2%)	BCT (28%) LIV (34%) RIV (100%)

Appendix 40: Kind of vessel occurring in the area caudal right lateral overall and in group 1-3

Kind of vessel occurring in Group 4-7			
Group 4	Group 5	Group 6	Group 7
BCT (26%) LIV (20%) RIV (100%) RSV (2%)	RCCA (4%) BCT (66%) LIV (14%) RIV (98%) RAJV (2%)	RCCA (6%) BCT (52%) LIV (34%) RIV (100%) RSV (2%)	RCCA (2%) BCT (38%) LIV (26%) RIV (94%) RIJV (2%) AA (4%)

Appendix 41: Kind of vessel occurring in the area caudal right lateral in group 4-7