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Clinical paper

Working with estimation-formulas to predict nasopharyngeal airway insertion depth in children: Looking at magnetic resonance images – A prospective observational study (WEND:LI-Study)

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Abstract

Objective: To determine the accuracy of the recently proposed landmark-method 'nostril-to-tragus minus 10 mm' and compare with ERC-recommended distances for nasopharyngeal airway length sizing in children.

Method: We conducted a prospective observational study in sedated children < 12 years. Nasopharyngeal airways were inserted following 'nostril-to-tragus minus 10 mm'. Primary outcome was the rate of nasopharyngeal airway tips between soft palate and epiglottis on magnetic resonance imaging (MRI) indicated for medical reasons. An optimal placement was defined when the tip lied within 25–75% of the total soft palate-to-epiglottis distance. Between 0–100% of this distance, placement was still considered acceptable, below 0% too proximal or above 100% too distal. Secondary outcomes were the rate of adverse events, the qualitative positions of airway tips, and the comparison of ´nostril-to-tragus minus 10 mm´ with the ERC-recommended distances 'nostril-to-angle of the mandible' and 'nostril-to-tragus' with objective MRI measurements.

Results: We analysed 92 patients with a mean age of 4.3 years. Nasopharyngeal airways were optimally placed in 37.0% (8.7% too proximal-77.2% acceptable-14.1% too distal). Three qualitative malpositions, but no airway-associated adverse event occurred. Objective measurements on MRI revealed the probability of 40.2% optimally placed nasopharyngeal airways (5.4%–67.4%–27.2%) for 'nostril-to-tragus minus 10 mm', 38.0% (17.4%–58.7%–23.9%) for 'nostril-to-mandible' and 13.0% (0%–28.3%–71.7%) for 'nostril-to-tragus', respectively.

Conclusion: No landmark-method predicted nasopharyngeal airway position reliably. 'Nostril-to-tragus minus 10 mm' seems the least inaccurate one and could be a valuable approximation until another estimation-formula proves more accurate. During insertion, careful clinical evaluation of airway patency is crucial.

Registered clinical trial: German Clinical Trials Register; DRKS00021007.

Keywords: Children, Paediatric resuscitation, Paediatric life support, Airway obstruction, Nasopharyngeal airway, Sizing

Abbreviations: AE, adverse events, ERC, European Resuscitation Council, MRI, magnetic resonance imaging, NE, Nares-Epiglottis distance, NM, Nares-Mandible distance, NPA, nasopharyngeal airway, NT, Nares-Tragus distance

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Introduction

Children are prone to upper airway obstruction, when conscious level and pharyngeal muscle tone are reduced due to anaesthetics, critical illness, or traumatic injury resulting in an increased risk of morbidity and mortality.[1] Nasopharyngeal airway adjuncts (NPA) can help maintaining the airway patency by separating the soft palate from the oropharynx when placed in the correct position.[2] Ideally, the NPA tip must lie in the hypopharynx distal to the soft palate and proximal to the epiglottis.[2,3]

The 2015 European Resuscitation Council (ERC) Guidelines recommended a landmark-method for estimation of NPA length sizing from nostril to the ipsilateral mandible (NM).[4] In contrast, the 2015 European Paediatric Advanced Life Support Course Manual proposed the distance from nostril to tragus (NT).[5] In the recent 2021 ERC Paediatric Life Support guidelines the NT-distance is recommended.[6] Both distances lack clinical evidence and have also been proven to be different.[7,8] Analysing objective distance measurements on magnetic resonance imaging (MRI) scans, Johnson et al. concluded that NT minus 10 mm (NT-10) would lead to a higher rate of correct placements.[8] None of these measurements and distances have been validated in a paediatric, clinical study.[7]

We prospectively investigated the rate of correctly placed NPA in sedated children by MRI when applying NT-10 with the hypothesis to be more accurate than the ERC-recommended landmark-methods. We analysed the anatomical positions of NPA qualitatively and correlated insertion depths with NM and NT distances to compare the accuracy of these landmark-methods.

Methods

Setting & patients

We performed a prospective, single-centre, observational study from March to September 2020. The manuscript was prepared according to the STROBE guidelines for observational studies.[9]

Inclusion criteria were children up to 12 years requiring deep sedation for MRI that was indicated for the diagnosis, exclusion or control of neurological diseases or cranial abnormalities. *Exclusion criteria* were contraindications for the insertion of a NPA such as bleeding disorder, nasal or airway abnormalities, and risk of aspiration.

Procedures

As per our standards, patients received deep sedation with induction doses of propofol and esketamine, followed by a continuous propofol-infusion.[10] After induction of sedation, we measured the distances of all three landmark-methods with a tape measure at the patients faces:

- NT-10_{face} was defined as NT_{face} minus 10 mm according to the recently proposed evidence.[8]
- NM_{face} was defined as from middle of the nostril to the angle of the ipsilateral mandible.[4]
- NT_{face} was defined as middle of the nostril to the ipsilateral tragus of the ear.[6]

To maintain upper airway patency, a lubricated NPA (Rüsch Nasopharyngeal Airway™, Teleflex Medical, Kamunting, Perak, Malaysia) was inserted into the widest appearing nostril to the depth of the mark NT-10_{face} set by the anaesthesiologist. Diameter-sizing was based on the age-related formula 'age/4 + 4 [mm ID]'.[4] Lateral foam pads fixed the head in neutral position within the head cage for MRI. MRI was performed in T1-3D-MPRAGE (Magnetization Prepared Rapid Acquisition with Gradient Echoes) and sagittal T2-weighted TSE sequences. No additional sequences were required for study purposes.

We documented biometric data (sex, age, height, weight), medical diagnosis, and reason for MRI exam. We recorded routine vital signs (heart rate, respiratory rate, SpO_2, $etCO_2$) by hand at baseline, after induction before NPA placement, after NPA placement, and in 5-min-intervals until the end of the procedure. Specific observations, abnormalities regarding airway and breathing, and any adverse event were captured.

Measurements

Two board-certified neuroradiologists measured the distances on MRI independently while being blinded for NPA length and insertion depth. The mean of the two measurements was used. In case of relevant discrepancy of the mean to the NPA-length, a control measurement was performed by the team. The following distances were measured on sagittal T1 weighted images using the proprietary measurement tool of General Electric PACS® (version 6.0, General Electric, Boston, Massachusetts, USA):

(a) length of NPA (NPA_{MRI}),
(b) nostril to distal end of the soft palate (NP_{MRI}),
(c) end of soft palate to epiglottis (PE_{MRI}),
(d) epiglottis to vocal cord level (EV_{MRI}),

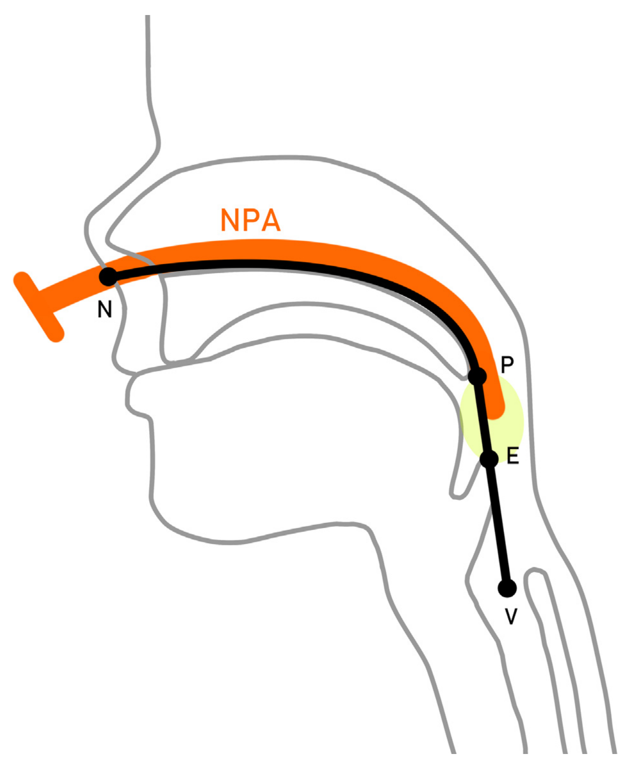

Fig. 1 – Schematic figure of measurements. NPA (orange) denotes the nasopharyngeal airway adjunct, N the nostril, P the distal end of the soft palate, E the epiglottis and V the level of the vocal cords. Green circle shows area of acceptable placement.

(e) nostril to ipsilateral angle of the mandible (NM_{MRI}),
(f) nostril to ipsilateral tragus (NT_{MRI}).

The distance of nostril to epiglottis was calculated by the sum of b) and c) (NE_{MRI}). Fig. 1 illustrates the used landmarks schematically.

Our **primary outcome**, the rate of correctly placed NPA, required a specific definition. As other investigators have defined, the tip of a NPA must lie distal of the soft palate and proximal of the epiglottis.[3] Stoneham defined the ideal position for the tip to be 10 mm above the epiglottis.[2] But this static point is likely to depend on body proportions and does not allow tube movement.[8,11] Thus, we defined an optimal target corridor relative to the distance between soft palate and epiglottis (PE_{MRI}), starting at 25% of the distance of PE_{MRI} and ending at 75%. NPA beyond the optimal target corridor but still between soft palate and epiglottis (from 0% to 100%) were defined as acceptably placed. Outside of this distance, it was defined as inserted either too proximal or too distal.

Our **secondary outcome** was the qualitative position of the NPA, e.g., if the distal end would be flexed or the shape modified such that it would obstruct the lumen thus hindering the NPA to be effective. Safety endpoints that could be associated with NPA insertion were the rate of respiratory adverse events: decrease of $SpO_2 < 95\%$,[12] incidence of laryngospasm, bronchospasm, apnoea, regurgitation, and other adverse events (AE) such as nose bleeding/injuries, and vomiting. Furthermore, we evaluated the probability of being in the optimal and acceptable target corridors for the objective measurements of NT-10_{face}, NM_{face} and NT_{face} and compared the three estimation-formulas with each another. Additionally, we tested the influence of sex, age, height, and weight on optimal NPA insertion depth and compared the proportions of NM_{MRI} to NM_{face} and of NT_{MRI} to NT_{face}.

Ethics

Approval for this prospective, single-centre, observational study was granted by the local Institutional Review Board of the University Medical Centre Goettingen (No. 23/02/20). The study was registered in the German Clinical Trials Register (DRKS-ID: DRKS00021007) on 03/06/2020. We obtained written informed consent from parents or legal guardians before enrolment.

Statistics

With a sample size of 90 patients, a two-sided 95%-confidence interval for the primary outcome would extend by 0.103 points from the observed proportion, assuming the true proportion is 0.5. Assumptions on the true proportion are based on Johnson et al.[8] For secondary comparisons between methods, a significant difference can be shown with 80% power, if the true difference in proportions is at least 0.2. To account for a dropout rate of 10%, a total recruitment of 100 patients was targeted. Calculations were performed in nQuery 8 (Statsols, Cork, Ireland) and R version 3.6.1 (The R Foundation for Statistical Computing, Vienna, Austria).

Proportions of optimally and acceptably placed NPA were calculated using Wald-Type intervals with logit-transformation. Comparisons between methods were conducted using a Z-Test, accounting for possible correlations within subjects. Influence of sex, age, height, and weight, on optimal and acceptably placed NPA, was examined using univariate logistic regressions. Exploratory analyses for calculated optimal rules were conducted using linear models and adjusted R-squared were reported descriptively. Data were analysed using R version 4.0.2.

Results

We enrolled 124 children from 4 months to 11 years and 11 months of age. After exclusion of 32 children (see Fig. 2 for reasons), we analysed 92 children (of which 42 female) with a mean age (standard deviation, SD) of 51.9 (37.2) months, a mean weight of 17.1 (7.8) kg and a mean height of 101.8 (22.4) cm.

Primary outcome

Method NT-10_{face} achieved optimally placed nasopharyngeal airways in 34 children (37.0% [95%-CI 27.7–47.2%]). 71 NPA (77.2%) were still acceptably placed between the distal end of the soft palate and proximal to the epiglottis. Eight NPA (8.7%) were placed too proximal and 13 (14.1%) of NPA too distal. Fig. 3 shows the distribution of the NPA tips, while Fig. 4A illustrates an optimally placed NPA.

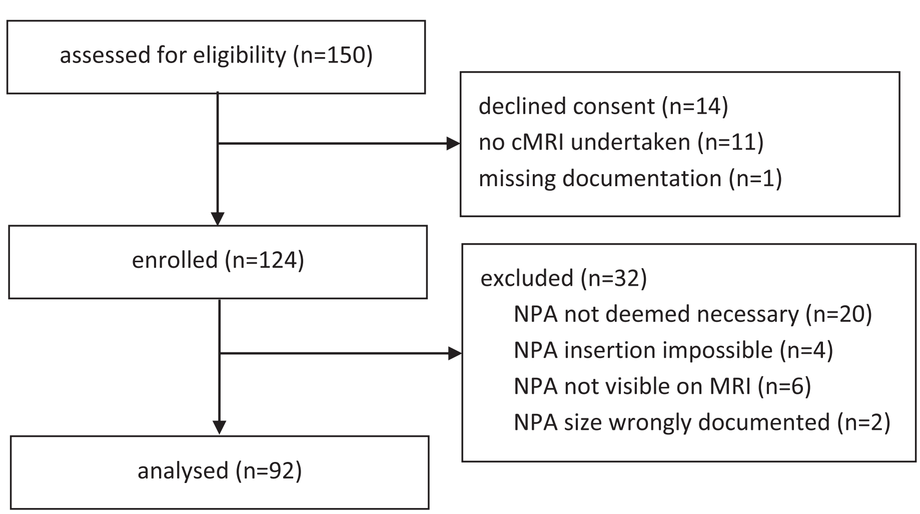

Fig. 2 – Flow diagram of enrolment.

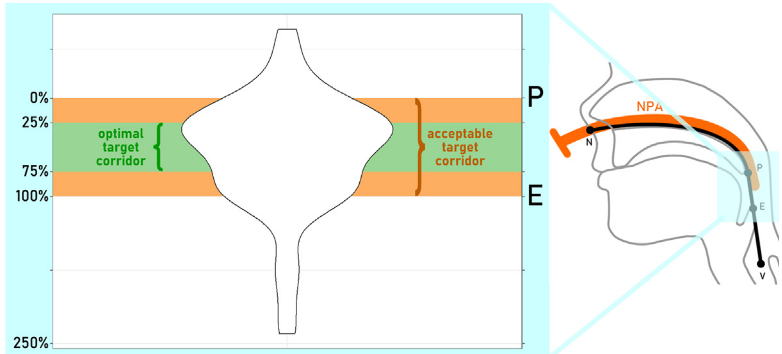

Fig. 3 – Violin plot of insertion depth relative to the distance between points P and E, with estimation-formula NT-10$_{face}$. P denotes the distal end of the soft palate and E the epiglottis. Green colour shows the optimal target corridor (25–75% between P and E), orange the acceptable target corridor between P (0%) and E (100%).

Secondary outcomes

Three NPA tips (3.3%) protruded into the pharyngeal back wall, hindering airflow through the lumen despite the tip being in the optimal target corridor in two of these patients (see Fig. 4B as an example). Two NPA tips (2.2%) were placed paralaryngeally in the sinus piriformis (see Fig. 4C). None of these five patients suffered from AE.

In eleven children (11.9%), the SpO_2 decreased below 95% after induction of sedation before NPA insertion. The steepest decrease was 11% down to 85%, while the mean (SD) change was −1.2% (−2.3%). After placement of NPA, the mean (SD) increase of SpO_2 was 1.7% (2.3%). One child was still below 95% SpO_2 (coming from 87% to 93%), which was suspected to suffer from a short apnoea after induction. We did not observe laryngospasm, bronchospasm, regurgitation, or other AE such as nose bleeding, injury, or vomiting.

Based on objective MRI measurements, NT-10$_{face}$ had a probability of 40.2% [95%-CI 30.7–50.5%] being in the optimal target corridor and 67.4% [57.2–76.2%] in the acceptable position. 5.4% would be too proximal and 27.2% too distal. If the NPA had been inserted according to NM_{face}, the probability of being in the optimal target corridor was 38.0% [28.7–48.3%], for an acceptable position of 58.7% [48.4–68.3%], and for NT_{face} 13.0% [7.6–21.6%] and 28.3% [20.0–38.3%], respectively. NM_{face} would have led to 17.4% of NPA being too proximal and to 23.9% being too distal. For NT_{face}, no NPA would be too proximal but 71.7% too distal (see Fig. 5). NT_{face} showed statistically significant lower proportions of being in the optimal target corridor vs. NM_{face} ($p < 0.001$) and NT-10$_{face}$ ($p < 0.001$), while NM_{face} did not significantly differ from NT-10$_{face}$ ($p = 0.37$).

Univariate logistic regression analysis revealed no influence of sex, but significant influences of age, height, and weight on the probability of reaching the optimal region for NT_{face} and NT-10$_{face}$ (see Fig. 6). Especially in younger, and thus smaller and lighter children, NT_{face} and NT-10$_{face}$ performed poorly. Proportions of optimally classified insertion depths for NM_{face}, on the other hand, were not significantly influenced by these factors, but generally lower (see Table S1).

The two-dimensional measured distances on MRI were shorter than the three-dimensional distances at the faces, with 97.2% (SD 9.0%) of NM_{MRI} to NM_{face}, and 89.6% (SD 5.9%) of NT_{MRI} to NT_{face}.

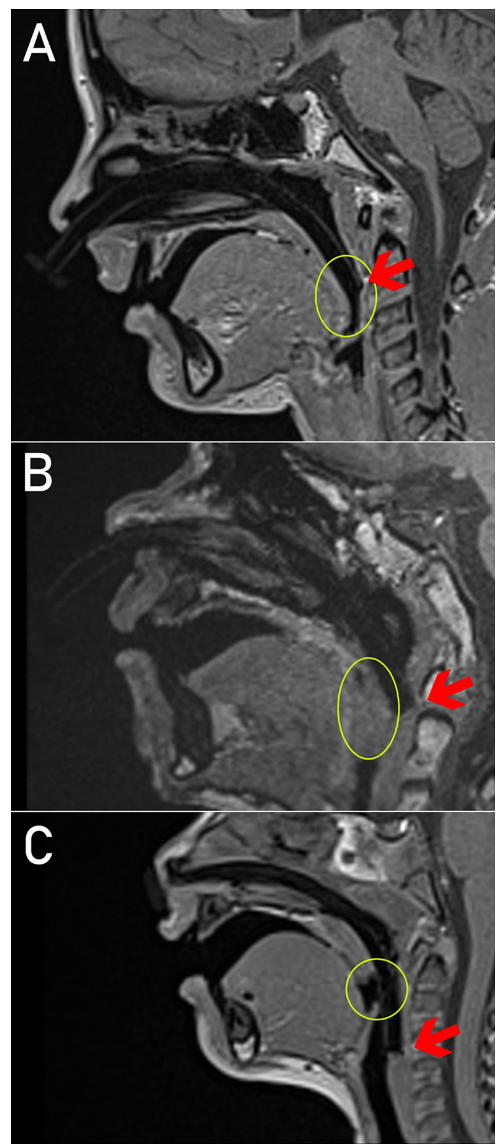

Fig. 4 – MRIs with red arrows denoting the tip of the NPA. A: 11-year-old boy with an optimally placed NPA. B: 7-year-old girl with the NPA protruding into the pharyngeal back wall. C: 2-year-old girl with the NPA too distal and in the sinus piriformis. Green circle show areas of acceptable placements.

Discussion

In our study, we validated the landmark-method 'distance from nostril to tragus minus 10 mm' for the estimation of nasopharyngeal airway length sizing in children in clinical practice by means of real-life imaging of nasopharyngeal airway positions on MRI. This is in contrast with previous studies, which compared only distance measurements without a nasopharyngeal airway in place. The applied formula NT-10 resulted in an optimal placement in 37.0% of NPA. More than three-quarters of all NPA were still acceptably placed, being located distal to the soft palate and proximal to the epiglottis.

Comparing the probability of objective distance measurements, we found both ERC recommended landmark-methods NM_{face} and NT_{face} to be inferior to NT-10_{face}. While NT_{face} clearly overestimated insertion depth - more than two thirds too distal - NM_{face} slightly underestimated it: about a tenth more NPA were too proximal. These findings are in accordance with Johnson et al. who predicted 45% of NPA tips in an ideal position with NT-10, arguing that an insertion according to NT would have many tips below the epiglottis.[8]

However, there are still considerable knowledge gaps for the optimal insertion depth in children. It is known that when the NPA is proximal to the soft palate, it does not separate the soft palate from the oropharynx resulting in no effect on the airway patency.[2,13,14] If the NPA tip is too distal, it may protrude into the larynx and trigger laryngeal reflexes or pass anterior the epiglottis into the vallecula or posterior into the proximal oesophagus leading to secondary airway obstruction.[2,13] In adults, Stoneham concluded that the NPA should lie 10 mm above the epiglottis, considering that head movements alter the relative position of the NPA.[2] Johnson et al. defined a further 5 mm above and below this static point in children to allow a zone of acceptability.[8] However, it remained unclear whether this static definition is applicable in children. Thus, we used a relative definition instead and kept the ratios that apply to adults. By differing between optimal and acceptable position of the NPA, this definition still takes possible movements into account. For example, it is known that head position influences the relationship between laryngeal structures and airway devices age-dependently.[11] Because of their smaller relation, one might expect the movements of NPA to be lower in children than in adults, where Stoneham described +5.7 mm during flexion and +1.3 mm during extension.[2]

Our finding of a relatively small distance between soft palate and epiglottis, particularly in children with age < 2y, height < 90 cm or weight < 11 kg (Tables S2–S4), underlines the need for a new definition of the ideal position of NPA tips in children. In nearly a quarter of all included patients, the distance between soft palate and epiglottis was less than 10 mm. This raises the question, whether it is even possible to place the tip exactly within the desired corridor using an external estimation method. Hence, the probability of reaching the optimal region was lower for young age, small height or low weight.

Another question is if and how NPA change their position after insertion. Our primary finding differed slightly from what we expected by objective distance measurements of NT-10_{face} on MRI. The rate of optimally placed NPA is a bit lower (37.0% vs. 40.2% expected), but the rate of acceptably placed NPA is higher (77.2% vs. 67.4%). One explanation for this difference can be movements of NPA after insertion. The rate of too distally placed NPA was expected to be 27.2%, but we observed only 14.1%, showing that some NPA tended to come slightly outside the nostril. In these cases, the NPA could have compressed the mucosa and the backwards movement could be the result of elastic recoil forces. Fixating the NPA, for example with a tape, could therefore be disadvantageous.

Despite 14.1% of NPA being too distal and some obvious malpositions, we observed few AE. These were not associated with incorrectly placed NPA. One explanation might be that upper airways were not severely obstructed, and a sufficient respiratory airflow

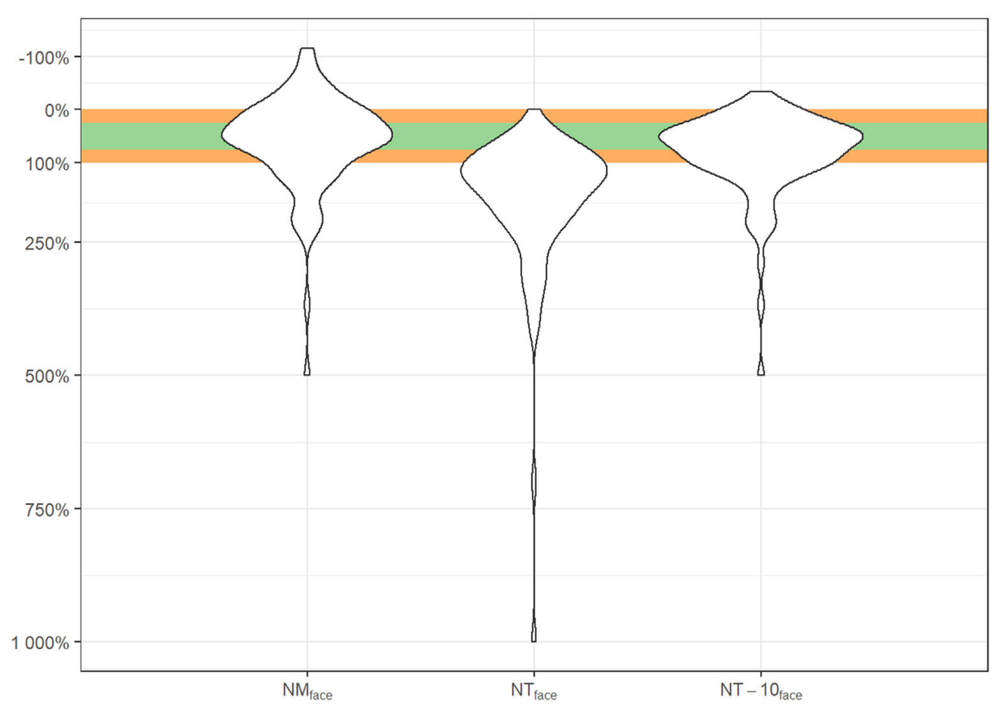

Fig. 5 – Violin plots of relative insertion depths, if the NPA had been inserted according to NM_{face}, NT_{face} and NT-10_{face} in theory (without any movements). Green colour shows the optimal target corridor (25–75% between P and E), orange the acceptable target corridor between P (0%) and E (100%).

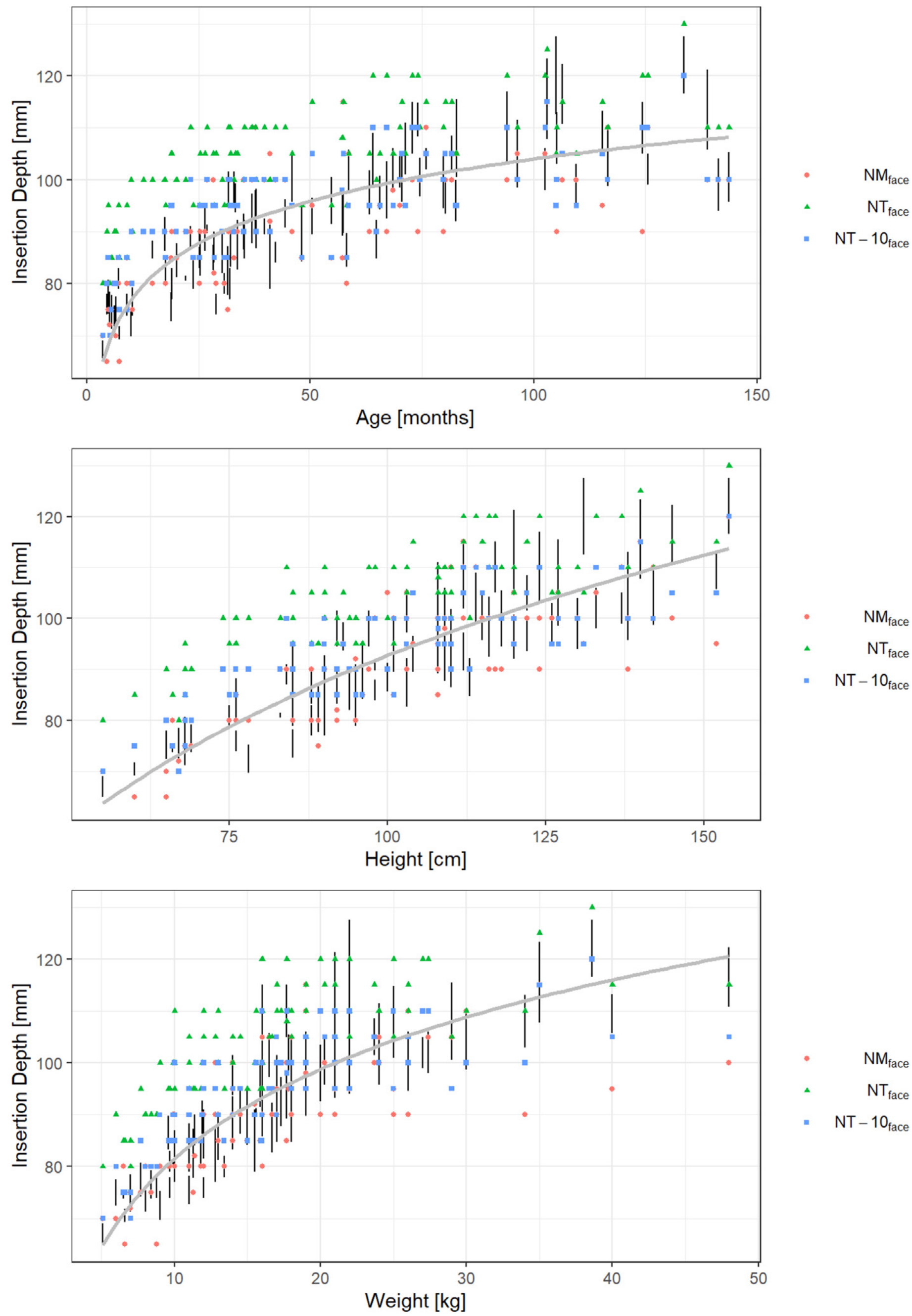

Fig. 6 – Log-linear regressions on insertion depth by age [months] (R^2 = 0.76), height [cm] (R^2 = 0.80) and weight [kg] (R^2 = 0.81).

could still occur. Respiratory AE assumed to be characteristic for a too distal NPA, such as paradoxical airway obstruction or triggering of reflexes that induce laryngospasm or vomiting,[13] did not occur. Possibly, a too distal position of the NPA tip is not regularly associated with complications. Together with the finding that NPA tend to come slightly outside the nostril, this might explain why the recommended method NT[5,6] has not been clinically identified as improper yet. Although the prevalence of such AE is unclear, it is known that a mechanical stimulus near the larynx can trigger airway reflexes and should thus be avoided.[14]

Our measured distances correlate well with the anatomic distances of Kim et al.[7] and the radiologic distances of Johnson et al.[8]. The partially large differences in their studies could be explained by a different approach in measuring the real-life (3-dimensional) vs. the radiological image (2-dimensional). For example, the distance NT was 10% less on MRI than on patients faces in our study. Therefore, we propose to base derivations for formulas on real-life conditions instead of two-dimensional images.

Kim et al. reported a multivariate formula for the best available prediction of insertion depth.[7] However, a formula based on biometric parameters always requires a calculation-step making it susceptible to errors, whereas landmark-methods are readily available and simple to apply, particularly for life-saving interventions in emergencies.[15] However, some estimation-formulas have been proven to be imprecise and lack evidence but are still commonly taught in paediatric critical care. These formulas, used for decades, might be too popular and widespread for new evidence to prevail. In search of a simple estimation-formula for NPA insertion depth, it remains unclear whether the NT-10_{face} rule is the final answer.

As a consequence of this discussion, in addition to estimate the insertion depth, it is crucial to check the adequate position and function of the NPA clinically, during and after insertion. Subject to the clinical setting, this can be supported by checking the presence of airflow and, if applicable, CO_2–, flow- or pressure detection via the NPA.

This study focused on landmark-methods recommended in paediatric life support guidelines, or a method derived from them, to estimate correct insertion depth. The current ERC-guideline recommendation NT_{face} would only lead to a small number of acceptably placed NPA, but a high number of NPA too distal. With more than three-quarters acceptable NPA placements and no adverse event in our study, we consider NT-10_{face} reasonable for clinical use.

Limitations

This study has several limitations. First, because of the observational nature of our study, we report an uneven number of age groups. This may limit the validity of the results, especially in older ages. Second, measurements on MRI scans underlie a certain inaccuracy due to the technical resolution power. Therefore, we excluded patients from analysis if the MRI measurement deviation exceeded 10% compared to the length of the NPA. The mean (SD) deviation was −3.9% (4.1%). Third, we evaluated positions of NPA mainly by images. We did not measure airflow through the NPA. Fourth, we did not investigate NPA placement in different positions of the head and did not standardize the head positioning precisely by means of measuring the exact angle.[16] Fifth, our study was not powered to evaluate the rate of adverse events.

Conclusions

None of the investigated landmark-methods can reliably predict NPA position and only serve as an approximation. Further research is necessary to investigate if an easily applicable formula achieves a higher rate of placement in the optimal target corridor. Until then, we suggest considering NT-10 as this estimation-formula seems the least inaccurate one. However, airway patency and the presence of a sufficient airstream through the lumen must be carefully evaluated during NPA insertion.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Marcus Nemeth: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Marielle Ernst:** Investigation, Writing – review & editing. **Thomas Asendorf:** Conceptualization, Methodology, Formal analysis, Data curation, Writing – review & editing, Visualization. **Juliane Richter:** Investigation, Data curation, Writing – review & editing. **Philipp von Gottberg:** Investigation, Writing – review & editing. **Ivo Florian Brandes:** Writing – review & editing, Supervision. **Clemens Miller:** Conceptualization, Methodology, Formal analysis, Data curation, Investigation, Writing – original draft, Writing – review & editing, Visualization.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resuscitation.2021.09.024.

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