Reliability and Construct Validity of the Penetration-Aspiration Scale for Quantifying Pediatric Outcomes after Interarytenoid Augmentation

Elizabeth H. Wick, MD1, Kaalan Johnson, MD2,3, Kim Demarre, MS, CCC-SLP4, Amy Faherty, MS, CCC-SLP4, Sanjay Parikh, MD2,3, and David L. Horn, MD2,3

Abstract

Objective. To assess the reliability and construct validity of the Penetration-Aspiration Scale in children.

Study Design. This was a retrospective cohort study of pre- and postoperative video modified barium swallow studies from children who underwent interarytenoid injection augmentation for unexplained persistent pharyngeal dysphagia. Two pediatric speech and language pathologists reviewed each study twice in a blinded and randomized fashion.

Setting. Tertiary academic pediatric hospital.

Subjects and Methods. Thirty children were identified with adequate pre- and postoperative modified barium swallow studies within 4 weeks of intervention. Children were separated into clinical outcome groups based on ability to advance to thinner diet consistencies postoperatively. Construct validity was assessed with a mixed linear model to test the hypothesis that only the clinically improved group would receive better Penetration-Aspiration Scale scores after surgery. Reliability was assessed by calculating chance-corrected agreement between raters (interrater) and raters’ repeat evaluations (intrarater).

Results. Inter- and intrarater reliabilities (Cohen’s κ) were both excellent. Results of the mixed model revealed a significant interaction between outcome group and pre- and postoperative time interval. As hypothesized, this involved a significant improvement in Penetration-Aspiration Scale scores only in the improved group.

Conclusions. These findings suggest that the Penetration-Aspiration Scale is a reliable and valid measure of clinical response to interarytenoid injection augmentation in children.

Keywords

Penetration-Aspiration Scale, construct validity, persistent pharyngeal dysphagia, interarytenoid injection augmentation, modified barium swallow, pediatric outcomes

Pneumonia remains a predominant cause of death in children <5 years old. Recurrent pneumonia, defined as ≥2 episodes in a year or 3 in a lifetime, is a leading cause of pediatric hospitalization. Pharyngeal and esophageal disorders increase a child’s risk of recurrent pneumonia by impairing airway-protective mechanisms during feeding. Accurately identifying these unsafe feeding mechanisms is therefore essential to timely implementation of interventions that may be lifesaving or reduce morbidity.

The modified barium swallow (MBS), synonymous with the videofluoroscopic swallow study, has become the most widely utilized instrumental assessment of swallowing function in children. MBS allows dynamic visualization of all swallowing phases, accurate detection of aspiration with patient response, and simulation of individualized feeding requirements. Patients are presented with different feeding consistencies and modifications while being assessed radiographically to detect penetration or aspiration events. The Penetration-Aspiration Scale (PAS) is a standardized method of quantifying MBS performance. It was originally validated in adults by Rosenbek et al and has since become the most frequently used objective grading

1Department of Otolaryngology, Barnes-Jewish Hospital–Washington University in St Louis, St Louis, Missouri, USA
2Department of Otolaryngology, University of Washington Medical Center, Seattle, Washington, USA
3Department of Pediatric Otolaryngology, Seattle Children’s Hospital, Seattle, Washington, USA
4Department of Speech and Language Pathology, Seattle Children’s Hospital, Seattle, Washington, USA

This article was presented at the American Society of Pediatric Otolaryngology Meeting; May 2016; Austin, Texas.

Corresponding Author:
David L. Horn, MD, Department of Pediatric Otolaryngology, Seattle Children’s Hospital, 4800 Sand Point Way NE, Seattle, WA 98105, USA. Email: David.horn@seattlechildrens.org
tool for swallowing disorders in clinical and scientific use in adults.\textsuperscript{7,10,11} Despite the similar demand for a quantifiable measure of swallowing function in children, there remains little available data on the reliability or validity of the PAS in children.\textsuperscript{5,12}

Validation in children is important because dissimilarities between adult and pediatric MBS protocols can affect study reliability and reproducibility. Pediatric protocols are more individualized to patient performance to reduce study duration and radiation exposure and to optimize study efficacy.\textsuperscript{5} This individualization increases study variability among patients, time points, and institutions. Children also show higher rates of silent aspiration and greater variation between sequential swallows on MBS.\textsuperscript{6} Lastly, a significant portion of the children with unexplained persistent pharyngeal dysphagia (PPD) present with various anatomic abnormalities that may be less evident and more challenging to diagnose on MBS.\textsuperscript{13-16}

An example is a type 1 laryngeal cleft (LC-1), defined as a supraglottic cleft that does not extend past the level of the true vocal folds.\textsuperscript{17,18} It is the most common anatomic cause of PPD in children.\textsuperscript{14,18,19} Treatment options include interarytenoid suture repair or interarytenoid injection augmentation (IAIA).\textsuperscript{13,20} The latter has also shown promise in diagnosing and treating milder variants of the classic LC-1, variably described as low interarytenoid height or deep interarytenoid notch, that may not be evident on diagnostic endoscopy.\textsuperscript{21,22} Controversy exists about why these patients improve after IAIA without an evident anatomic abnormality on endoscopy. This may suggest a functional deficit in interarytenoid muscular physiology or maturation (ie, interarytenoid insufficiency). Alternatively, IAIA may create an intrinsic advantage by providing additional bulk in the interarytenoid region during closure of the laryngeal valve with swallowing (an interarytenoid superfunction).

The concepts of interarytenoid insufficiency and superfunction are based on data indicating that a similar proportion of children with unexplained PPD improve after IAIA, regardless of the presence or absence of an LC-1.\textsuperscript{13} These improvements may be permanent or temporary. Patients with a temporary response may require repeat IAIA, interarytenoid suture augmentation, or ongoing dietary modifications after the effects of augmentation fade.\textsuperscript{13,14} No consensus exists on the treatment of these patients without a true LC-1 because little is understood about normal interarytenoid maturation and the role that interarytenoid bulk plays in overall swallowing performance.

Distinguishing unsafe feeding from the range of normal swallowing maturation is an important step in developing individualized evidence-based management protocols for these children with unexplained PPD. This requires a reliable, validated assessment tool to objectively measure swallowing performance. Previous studies in this area have relied on qualitative measures of swallowing function.\textsuperscript{14,23,24} This study aims to test the reliability and construct validity of the PAS in children by calculating inter- and intrarater agreement and comparing overall PAS performance between 2 clinical outcomes groups before and after IAIA.

### Methods

The institutional review board at Seattle Children’s Hospital approved this study. Participants were identified retrospectively from a prospective longitudinal registry containing all children who underwent IAIA for PPD between 2011 and 2015. Patients were included if they had undergone at least 1 preoperative video MBS evaluation and a repeat postoperative video MBS evaluation within 4 weeks of their procedure. Patients were excluded from all testing if their video MBS had been performed elsewhere. Patients were excluded from construct validity testing if thin liquids had not been introduced during both pre- and postoperative MBS studies. This was done to increase uniformity in the comparison of PAS scores across heterogeneous MBS protocols.

Patients’ electronic medical records were then reviewed for patient demographics such as sex, age at initial presentation and time of surgery, and follow-up duration. Patient risk factors were also identified, including the presence of pulmonary comorbidities (ie, recurrent pneumonia or reactive airway disease); neurologic and developmental comorbidities, including preterm delivery (defined as <30 weeks); and gastroesophageal reflux disease. Records were finally reviewed for outcome measures, including specific diet modifications trialed during each MBS study, patient and clinician reports regarding successful diet advancement, and the need for revision or repeat procedures.

### Preoperative Evaluation and Procedure

The management protocol used in this study was previously described by the authors (D.H., K.D., and S.P.)\textsuperscript{13} and established prior to enrolling the first patient. Patients all underwent a comprehensive history and physical examination. Parents were offered microlaryngoscopy and bronchoscopy.
with IAIA if no obvious laryngopharyngeal anomalies or other causes for aspiration were identified on clinical evaluation.

Microlaryngoscopy, bronchoscopy, and IAIA were performed with a technique similar to that of Cohen et al as described by Horn et al. Interarytenoid competency was systematically assessed in all patients by using laryngeal distending forceps, palpating the interarytenoid notch, and photodocumenting its depth relative to the true and false vocal folds. IAIA was performed if an LC-1 was diagnosed or if no other cause for PPD could be identified. Patients with more significant laryngeal clefts received alternative treatment, as medically indicated, and were excluded from this study.

Follow-up and Outcome Groups
All participants in this study received a postoperative video MBS within 4 weeks, at a mean 16 days after their procedure. Each patient’s doctor and speech and language pathologist (SLP) determined together whether patients were safe to advance their diet based on MBS performance and surrounding comorbidities. Diet advancement, for the purposes of this study, was defined as successful transition to thinner feeding consistencies (honey-thick liquids to nectar-thick liquids, nectar-thick to thin liquids, etc). Diet advancement was considered successful if (1) diet changes were implemented at home and there were no (2) feeding symptoms (ie, choking or coughing) or (3) respiratory complications reported by the parents. Clinical outcome groups were separated into clinically improved and unimproved groups based on successful diet advancement.

MBS Protocol
MBS studies at our institution are initiated by presenting patients with their recommended home diet or a thinner consistency after interviewing the family. At postoperative MBS studies, patients are progressively trialed on thinner feeding consistencies at the discretion of their SLP, who may omit consistencies if aspiration or patient intolerance is observed or if performance was clearly advanced beyond several thicker consistencies.

Video MBS Processing
One author performed all the video editing using QuickTime Pro software. Editing was done to separate video excerpts according to diet modifications (ie, consistencies), remove extraneous footage, and deidentify text. A video key was made to code each excerpt according to patient, diet modification, and timing (ie, pre- vs postoperative). Videos were stored as AVI files (audio video interleave) on a password-protected database in accordance with the Institutional Review Board–approved study protocol. The video key was saved similarly in a separate file. The editing author was not involved in rating swallow performance, and raters did not have access to the video key. The number of swallows for each feeding consistency varied according to SLP discretion.

Reliability Testing
Thirty patients met inclusion criteria for use in rater reliability testing. This resulted in 60 pre- and postoperative video MBS studies, including a total of 1039 swallows. Two experienced pediatric SLPs independently assigned a PAS score to each swallow. They were both blinded to the patient, timing of study relative to the procedure, and feeding consistency for each swallow. Each rater scored videos in a different randomized order. After a minimum of 8 weeks, raters repeated their evaluations in a different randomized order, each assigning another PAS score to each swallow.

Interrater reliability was assessed by comparing scores between raters. Intrarater reliability was assessed by comparing each rater’s scores from different rounds of evaluation. Pearson correlation coefficients (r) were used to calculate inter- and intrarater association. An r value > 0.80 was considered excellent. All reported r values were statistically significant (P < .05). Inter- and intrarater reliability were also calculated using Cohen’s kappa (κ) coefficient to measure chance-corrected rater agreement, and the intraclass correlation coefficient (ICC; [3,1]) to specify a fixed number of raters. The intraclass reliability of each score on the 8-point scale was assessed with weighted intraclass kappa coefficients as initially described by Bloch and Kraemer to account for differences in clinical importance between scores. Levels of agreement for inter- and intrarater reliability (Cohen’s kappa) and intraclass reliability were considered good, excellent, and outstanding if kappa values were greater than 0.60, 0.75, and 0.80, respectively.

Construct Validity
Construct validity was assessed per the hypothesis that patients in the improved outcome group, with clinical improvement after IAIA, would have a greater decrease in their PAS score than patients in the unimproved group. The worst performance (ie, highest PAS score) across all swallows of thin liquids during each study was recorded as the overall PAS score for that study. This was done to simulate clinical practice, where management decisions are based on a patient’s worst performance during a study. Assessment was limited to swallows of thin liquids to improve uniformity and avoid averaging PAS scores across feeding consistencies.

For each reviewer, a linear full factorial mixed model with a scaled identity covariance matrix was constructed with SPSS. For each model, there were 3 fixed effects (review number, clinical outcome group, and pre- and post-IAIA interval) and 1 random effect (patient). Clinical outcome group was a between-subjects variable. Repeated measures variables included the review number (each reviewer provided 2 PAS scores for each patient and interval) and pre- and post-IAIA intervals. Post hoc linear models were created per the results of these initial analyses. For all main effects and interactions, findings were considered statistically significant if P < .05. Pairwise comparisons were conducted where interactions were significant. Model fits were analyzed according to the conditional $R^2$ calculation.
described by Nakagawa and Schielzeth. This $R^2$ value represents the shared variance between observed and model-predicted PAS scores based on fixed and random effects.

**Results**

**Patient Demographics**

Thirty patients, 13 females and 17 males, met inclusion criteria for reliability testing of the PAS in children. Three of these children (all males) were later excluded for use in validity testing because they were not trialed on thin liquids during both of their MBS studies. The improved group tended to be older at treatment and have a longer time to surgery than the unimproved group (Table 2), but neither of these factors reached statistical significance ($P > .05$). The only significant difference between groups was the greater frequency of associated comorbidities in the unimproved group. Gastroesophageal reflux disease symptoms (66.7%), pulmonary comorbidities (66.7%), and neurodevelopmental risk factors (25.9%) were relatively common in this series.

**Reliability**

Reliability assessments were calculated according to the PAS scores presented in Tables 3 and 4. Intrarater reliability compared scores from different rounds of evaluations, resulting in an $r$ value of 0.93 and Cohen's $\kappa$ (95% CI, $P$ value) of 0.88 (0.87-0.90, $P = .01$). These values represent outstanding levels of agreement with thresholds for $r$ and $\kappa$ previously established.25,27 Intrarater reliability compared scores from different raters, with an $r$ of 0.83 and Cohen’s $\kappa$ of 0.76 (0.73-0.78, $P = .01$), representing excellent to outstanding reliability.

**Construct Validity**

Construct validity was assessed according to the hypothesis that children who are clinically improved after IAIA will experience a greater improvement (ie, decrease) in PAS score than children who are unimproved after treatment. There were 13 and 14 patients in the improved and unimproved groups, respectively (Table 2). Mixed linear models were constructed for each reviewer, and the estimated marginal means for both models are shown in Figure 1. Both models showed excellent fit to the data based on conditional
In both models, there was a significant effect of clinical outcome group, indicating that PAS scores were higher in the unimproved than the improved group: $F(1, 25.038) = 6.834$ ($P = .015$) and $F(1, 25) = 8.385$ ($P = .008$) for reviewers 1 and 2, respectively. Additionally, there was a significant effect of pre- and post-IAIA interval, indicating that PAS scores were significantly reduced after IAIA: $F(1, 72.347) = 26.475$ ($P < .0001$) and $F(1, 75) = 18.241$ ($P < .0001$) for reviewers 1 and 2, respectively. There was a significant interaction in each model between clinical outcome group and test interval: $F(1, 72.347) = 20.729$ ($P < .0001$) and $F(1, 75) = 11.289$ ($P = .001$) for reviewers 1 and 2, respectively. Post hoc pairwise comparisons for the improved outcome group showed a mean reduction in PAS score from pre- to post-IAIA interval of 3.154 (95% CI, 2.24-4.07, $P < .0001$) and 2.69 (95% CI, 1.68-3.71, $P < .0001$) for reviewers 1 and 2, respectively. In contrast, pairwise comparisons for the unimproved group were not significantly different from zero for either reviewer (both $P$ values $>.50$). In both models, the main effects and interactions involving the review number variable did not reach significance (all $P$ values $>.69$).

**Discussion**

The PAS showed excellent overall rater reliability and good construct validity in this cohort of children who underwent IAIA for PPD. Reliability was assessed by comparing scores between raters (intrarater) and among subsequent scores of the same rater (intrarater): $k = 0.89$ (95% CI, 0.87-0.90; $P = .01$). Construct validity was assessed per the assumptions that children who are able to safely advance their diet have superior swallowing function and this is reflected in their superior (ie, lower) PAS scores.

The study aimed to measure construct validity by calculating the effect of time interval (pre- and postoperative) and clinical outcome group on mean PAS scores with the expectation that the clinically improved outcome group

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**Table 3. Rater Reliability and Score Frequency of the Penetration-Aspiration Scale: Intrarater Reliability.**

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Cross-correlation and agreement (bold) of scores from subsequent evaluations by both raters; totaling 2078 scores per evaluation: Cohen's $k = 0.76$ (95% CI, 0.73-0.78; $P = .01$).

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**Table 4. Rater Reliability and Score Frequency of the Penetration-Aspiration Scale: Interrater Reliability.**

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Cross-correlation and agreement (bold) of scores between raters from both evaluations; totaling 2078 scores per rater: Cohen's $k = 0.76$ (95% CI, 0.73-0.78; $P = .01$)
would have better (ie, lower) overall scores and show a greater score improvement (ie, reduction) from pre- to postoperative study time points. Our data demonstrated good construct validity with a statistically significant interaction between outcome group and PAS score improvement. Post hoc analysis further attributed this interaction to the improved group by showing a statistically significant improvement only in the improved group.

Reliability of the PAS in children ranged from excellent (intrarater) to outstanding (intrarater). Individual PAS score (intraclass) reliabilities were outstanding for scale extremes of normal swallowing and silent aspiration (1 and 8, respectively) and excellent for shallow penetration with ejection (PAS = 2) in children. Intraclass reliability measures for the remaining PAS scores did not reach statistical significance because of inadequate score frequency, but aspiration scores of 6 and 7 trended toward outstanding and good, respectively. These score frequencies and results were similar to those reported by Rosenbek et al in adults. The main discrepancies included a slightly higher frequency of silent aspiration, corresponding to previous results in children, and a slightly higher level of reliability.

This difference in reliability may be attributable to the use of pediatric SLPs, instead of random judges, which may limit the generalizability of reliability results to institutions with pediatric SLPs. Despite this, the reliability of the PAS in children should still be estimated as good to excellent when used by general SLPs. Other limitations of this study stem from the heterogeneity of the study population. This study did not control for age or comorbidities, which tended to be higher and less frequent, respectively, in the improved group. Neither of these factors were significantly different between clinical groups, but the trend may suggest that the PAS may be less sensitive in younger children or children with comorbidities. Future research should control for these variables. To reduce heterogeneity, construct validity testing also included only PAS scores of trials on thin liquids. This may limit the generalizability of the construct validity results to trials of thin liquids. Despite these limitations, these study results are at least as favorable in children as those reported by Rosenbek et al prior to the wide acceptance and utilization of the PAS in adults.

**Conclusion**

The PAS demonstrates excellent reliability and good construct validity as a measure of pediatric outcomes after IAIA in children with PPD. This represents a promising research and clinical tool to objectively and reliably measure swallowing function in children. In the future, this may provide an opportunity to more accurately assess treatment response, compare outcomes across institutions, and evaluate natural progression of swallowing physiology.
Author Contributions
Elizabeth H. Wick, design, analysis and interpretation, manuscript drafting and review; approved final draft and is accountability for the accuracy and integrity of the data presented; Kaalan Johnson, conception, analysis, and interpretation, manuscript revision regarding the concepts of construct validity and statistical assessments; approved final draft and is accountability for the accuracy and integrity of the data presented; Kim Demarre, data acquisition and interpretation, manuscript review and editing regarding clinical interpretation of PAS scores; approved final draft and is accountability for the accuracy and integrity of the data presented; Amy Faherty, data acquisition, manuscript review and editing regarding details of MBS protocols and data acquisition; approved final draft and is accountability for the accuracy and integrity of the data presented; Sanjay Parikh, conception and design, manuscript review with edits regarding overall study importance and clinical relevance; approved final draft and is accountability for the accuracy and integrity of the data presented; David Horn, conception and design, analysis and interpretation, manuscript drafting and review; approved final draft and is accountability for the accuracy and integrity of the data presented.

Disclosures
Competing interests: None.
Sponsorships: None.
Funding source: National Institutes of Health funding: 5T32DC00-0018-33 (collection, analysis, and interpretation of data).

References


