Application and Verification of Quantitative Objective Videofluoroscopic Swallowing Measures in a Pediatric Population with Dysphagia

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Objective To investigate the feasibility of obtaining and utilizing objective measures of timing and displacement from videofluoroscopy performed in pediatrics.

Study design Children (n = 121; mean age 38 months, range 9 days-21 years, SD 4 years) referred for videofluoroscopy were recruited. All underwent a standardized protocol including a mid-feed 20-second loop recorded at 25 frames per second. Videos were analyzed using objective digital measures of timing and displacement. Radiation dose was recorded.

Results Quantitative measures were obtained in all children. Maximum opening of the pharyngoesophageal segment and timing measures were correlated with increasing age. Values were congruent with validated adult data. Mean radiation time was 1.58 minutes (range 0.15-3.47, SD 0.66), and mean radiation dose was 30.16 cGycm^2 (range 6.5-85 SD 15.17). Radiation dose ($P = .21$) and radiation time ($P = .72$) were not significantly different using the increased frame rate compared with an age-matched cohort (n =100) prior to protocol change.

Conclusions Objective quantitative measures of swallowing measurements can be obtained successfully from pediatric videofluoroscopy performed at high frame rates, without increasing radiation dose. Measures are biologically consistent, reproducible, demonstrate internal cross-correlation, and mirror adult data. These measures have potential to support targeted management and objective monitoring of change by pediatric feeding teams in the future. *(J Pediatr 2016;178:200-5).*

Swallowing is a developmental phenomenon that evolves through the first 3-5 years of life.[1] Although the changes in the anatomy of the pediatric oropharynx are well documented, the physiological progression from neonatal to mature swallowing is not.[2-6] Diagnosis of swallowing disorders is increasingly common in the pediatric population, in both children with medical conditions and those who are otherwise developmentally normal.[7,8] Consequently, there has been a rise in instrumental assessments required to investigate these swallowing problems. Even though the videofluoroscopic study of swallowing (VFS) remains the gold standard in identifying abnormalities that cause dysphagia and airway compromise, interpretation remains largely subjective. In addition, as radiation exposure is required, normative data cannot be obtained because of ethical restrictions. Considerable work has been completed validating objective measures in the adult population.[9-18] Adult objective measures have been validated against gold standard tests such as manometry[12,14] and have been shown to significantly correlate with disease progression,[15] symptoms of dysphagia, such as incidence of aspiration,[9,16] residue,[18] and its respiratory consequences.[17]

Given that VFS expose children to ionizing radiation, responsibility lies with the clinician to obtain the maximum amount of information from studies possible. Simply using the study as a binary aspiration test undervalues VFS and fails to extract valuable available data, such as identifying physiological variables that may influence management of the swallowing disorder. This includes the timely movement of the bolus and structures required for safe, efficient swallowing. Few studies have addressed such measures in the pediatric population. The aims of this exploratory study were to examine the feasibility of objective measures of timing and displacement in children undergoing VFS, examine the objective measures across the age range of a pediatric caseload, and compare this data to established adult measures. In addition, the study aimed to compare radiation dose before and after an increased frame rate protocol as higher frame rates are associated with improved diagnostic accuracy.[19]

Methods

All children consecutively referred for VFS at the participating Children's Hospital over a 12-month period were included in this study. Children were referred

AEcl	First approximation of arytenoids and epiglottis to close laryngeal vestibule
BP1	First entrance of head of bolus into pharyngoesophageal segment
VFS	Videofluoroscopic study of swallowing
PES	Pharyngoesophageal segment
PCR	Pharyngeal constriction ratio
PAS	Penetration-aspiration scale

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by their primary treating physician for a VFS following concerns regarding swallowing. Information regarding patient diagnosis, demographics, presence of a tracheostomy, history of pneumonia, and requirement of supplemental oxygen was collected from the hospital clinical databases by the primary researcher. The child's usual eating status (eg, oral vs enteral) was recorded. The children presented with a wide range of underlying problems but for the purpose of this study were categorized into unifying groups: neurologic (acquired and congenital), structural (congenital abnormalities of the structures involved in swallowing), respiratory, cardiac, other, or nil diagnosis. Ethical approval was obtained from The University of Auckland Human Participants Ethics Committee (011722).

Children were excluded from the cohort if thin fluids were not provided during the procedure owing to refusal or not requiring assessment with this consistency. Those who did not have the calibration ring placed, secondary to human error or refusal, were excluded from the displacement measures only.

VFS Procedure

The VFS were completed in the radiology suite on a Siemens Sireskop radiographic unit (Siemens, Munich, Germany). To increase the reliability and validity of the study, a standardized protocol, including increased screening rate, was introduced for completion of all VFS. Lateral views were obtained, with anteroposterior assessment completed if asymmetry was questioned. The objective measures were calculated from a period of continuous screening at 25 frames per second (f/s). Given the speed at which oropharyngeal swallowing occurs, it is imperative that the screening rate is high to accurately visualize the timing and coordination of rapidly occurring events. Although 30 frames/second (f/s) is identified as optimal in the literature, above 15 f/s is considered satisfactory.[19] Frame rates were restricted to 25 f/s in this study because of mechanical limitations of the facility's radiographic unit. All loops were recorded on DVD for playback and frame-by-frame analysis. The radiation time and dose were logged. Varibar barium sulfate contrast (40% w/v) (E-Z-EM Canada Inc, Quebec, Canada) was used in 50:50 to create a thin fluids as well as premixed Varibar nectar and honey barium. Neonates and infants who received all, or the majority, of their nutrition by liquid (breastmilk or formula) were screened continuously during "midfeed sucking." Young children who no longer relied on a bottle, but had not established open-cup-drinking skills, were assessed with sequential swallowing from a sipper cup or bottle. This was referred to as "midfeed drinking." Assessment midway through the feed was captured to ensure the participants had established their feeding pattern. Children who received the majority of their nutrition through solids and had established cup-drinking skills were assessed with a range of bolus sizes by an open cup (5 mL, 10 mL, 20 ml, 100 mL by means of a straw). The volume remaining in the cup following each swallow was measured to determine the ingested size of the bolus. Maximum penetration-aspiration scale (PAS) scores were recorded for all children. This 8-point scale (where 1 = no penetration/aspiration and 8 = aspiration below the level of the cords with no attempt to clear) considers scores 6 and above as an aspiration event.[20]

Radiation

Radiation dose and radiation time were compared with an age- and sex-matched cohort of 100 children who had received a VFS prior to initiation of the standardized protocol and increased frame rate. Prior to implementation of the new protocol, VFS at this facility were completed at 12.5 f/s, and the procedure was not standardized nor bolus sizes measured.

Objective Measures

Objective pharyngeal measures obtained were based on extensive work completed in adults by Leonard and Kendall.[10] All objective measures (**Table I**; available at www.jpeds.com) in this study were obtained during the period of continuous screening (25 f/s) on the largest bolus ingested with pre- and postswallow comparisons. Midfeed sequential swallows where the airway did not open prior to the next swallow were not chosen. Quintic Biomechanics Video Analysis software (Quintic Consultancy Ltd, Birmingham, United Kingdom) was used to analyze the timing of the bolus trajectory during the swallow. Quintic superimposes a timer onto the recording and allows for slow motion and frame-by-frame analysis of the swallow. Each measure was calculated to the 100th of a second. For displacement measures to be calculated, calibration is required with a 1.65 cm radiopaque ring placed midline on the child's chin in the viewing frame. Universal Desktop Ruler (AVPSoft, http://www.avp.soft) "line and area" tools were used to measure displacement and area. Following completion of the study, the inter-rater reliability second marker used "Swallowtail" for all measures (BellDev Medical, Arlington Heights, Illinois). This new software application allows frame-by-frame viewing and includes integrated tools designed for timing and displacement measurement based on the Leonard and Kendall[10] measures.

Data Analyses

Data were entered into SPSS Statistics v 20 (SPSS Inc, Chicago, Illinois) for analysis. Descriptive statistics were calculated to describe the swallowing characteristics and demographics of the cohort. Log transformations were completed as required to ensure that the data met assumptions for normal distribution or equalize variances. Pearson product-moment correlation coefficients were used to analyze relationships between each objective measure (total pharyngeal transit time, airway closure duration, pharyngoesophageal segment [PES] opening duration, PES maximum opening, pharyngeal constriction ratio [PCR], first entrance of head of bolus into pharyngoesophageal segment-first approximation of arytenoids and epiglottis to close laryngeal vestibule [BP1-AEcl]) and between all objective measures with age and PAS. Differences in radiation pre- and postprotocol change were tested using independent *t* tests (t). Relationships with <.05 probability level were considered significant. To provide interrater reliability of measures, 20% of the cohort were measured by a second researcher and agreement was analyzed using intraclass correlation