Clinical Radiology 74 (2019) 736.e9–736.e12

Contents lists available at ScienceDirect

Clinical Radiology

journal homepage: www.clinicalradiologyonline.net

Trade-off between pulse rate and radiation dose during modified barium swallow examination: what is the reality?

S.J. Galgano [a,*], D. Gauntt [a], M.R. Boyd [b], D. Trahan [b], B.E. Jackson [a], R.E. Koehler [a], C.L. Canon [a], M.M. McNamara [a], J.G. Zarzour [a]

[a] *University of Alabama at Birmingham, Department of Radiology, Birmingham, AL, USA*
[b] *University of Alabama at Birmingham Medical Center, Birmingham, AL, USA*

ARTICLE INFORMATION

Article history:
Received 6 February 2019
Accepted 31 May 2019

AIM: To evaluate the effect of modification of dose mode and frame rate on patient radiation dose during modified barium swallow (MBS) examinations.

MATERIALS AND METHODS: A retrospective review was undertaken of consecutive MBS examinations performed over 6 months in the inpatient setting. Patients were divided into two cohorts: pre-implementation of the MBS Impairment Profile (MBSImP; low rate, normal dose) and post-implementation (high rate, low dose). Prior to implementation, pulse rate and dose testing were performed on multiple phantoms.

RESULTS: Four hundred and forty-nine patients were included in the pre-implementation cohort and 378 in the post-implementation cohort. Phantom dose testing demonstrated no significant difference in dose on either phantom between low rate/normal dose and high rate/low dose modes. Prior to MBS standardisation, the mean radiation dose was 5.86 (±4.35) mGy. Following standardisation, the mean radiation dose was 4.72 (±3.77) mGy (p<0.0001). The mean fluoroscopy time for MBS prior to standardisation was 83.8 (±44.4) seconds and the mean fluoroscopy time for MBS after standardisation was 82.3 (±39.8) seconds (p=0.62). The dose rate for MBS prior to standardisation was 4.35 (±2.42) and the dose rate for MBS after standardisation was 3.55 (±2.41) mGy/s (p<0.0001).

CONCLUSION: Adjustments made to lower the dose mode and the increase in fluoroscopy frame rate decreased the patient radiation dose and did not increase fluoroscopy time.

Introduction

The modified barium swallow examination (MBS) or video swallowing study is a commonly utilised fluoroscopic procedure in the United States for assessment of oropharyngeal swallowing dysfunction.[1] The MBS is performed in conjunction with a speech language pathologist and radiologist, and requires close collaboration. Although the MBS is essential for diagnosis of swallowing dysfunction, it does expose the patient to low levels of ionising radiation, but the radiation dose to the patient must be considered. One factor affecting the radiation dose to the patient is the frame rate. Although it is possible to lower the frame rate for radiation dose savings, the diagnostic accuracy of the MBS should not be compromised. Evidence has

* Guarantor and correspondent: S. J. Galgano, University of Alabama at Birmingham, Department of Radiology, Birmingham, AL, USA. Tel.: +1 (205) 996 2802.

E-mail address: samuelgalgano@uabmc.edu (S.J. Galgano).

https://doi.org/10.1016/j.crad.2019.05.030

shown that as the frame rate decreases, the ability to detect dynamic abnormalities in real-time becomes limited.[2] This is of particular interest in the fluoroscopic evaluation of the pharynx, as the oropharyngeal swallow lasts approximately 1 second and rapid real-time dynamic assessment of swallowing function allows for detection of subtle and transient abnormalities that could potentially be missed with a lower frame rate.[2]

Due to variations in technique and interpretation of the MBS examination, the MBS Impairment Profile (MBSImP) was developed. The MBSImp is a standardised MBS protocol and interpretation template to assess 17 critical components of swallowing and provides an objective profile of swallowing dysfunction (Electronic Supplementary Material Appendix S1).[3] The MBSImP has been validated and demonstrates high levels of inter-reader reliability and clinical practicality, allowing an effective way to communicate the MBS study results in a standardised way.[3] Prior research has demonstrated that although the MBSImP did increase thoroughness of the evaluation at the time of MBS, it did not unnecessarily increase radiation exposure time.[4]

In response to the growing literature about both standardising the MBS and increasing the frame rate, the effect of frame rate and dose level on the fluoroscopic machine utilising a phantom was investigated. Simultaneously, the speech language pathologist underwent a 6-month MBSImP training period. Following the phantom study and MBSImP training, changes were implemented and then the effect on radiation dose and fluoroscopy time was measured.

Materials and methods

Equipment

Both MBS examinations and phantom studies were performed on a Philips Eleva EasyDiagnost general radiography and fluoroscopy unit.

Patients

The study was an institutional review board-approved, Health Insurance Portability and Accountability Act-compliant retrospective review of fluoroscopic dose and study length of 449 consecutive patients who had an inpatient MBS examination prior to standardisation (between September 2014 and February 2015) and 378 consecutive patients who had an MBS examination in the same inpatient setting after standardisation (between September 2015 and February 2016). Patient demographic data are summarised in Table 1.

Table 1
Patient demographics.

Pre-intervention		Post-intervention	
Gender			
F	196	F	167
M	253	M	211
Race			
Asian	2	Asian	2
Black/AA	130	Black/AA	107
Decline	6	Decline	3
Hispanic/Latino	4	Hispanic/Latino	6
Multiple	8	Multiple	15
Other	0	Other	2
White	299	White	243
Weight (kg)[a]			
Mean	79.1	Mean	81.3
Median	76.2	Median	76.7
Range	39.8–368.5	Range	32.7–240
SD	28.1	SD	27.8

[a] $p=0.26$.

Phantom testing

Estimated dose to a phantom was performed to establish how the changes in pulse rate and technique would affect patient radiation dose. Two uniform phantoms constructed of polymethylmethacrylate (PMMA) sheets were tested with a variety of dose settings and pulse rates; the phantoms differed only in their thickness (10 cm and 17.5 cm). Measurements were acquired at continuous (30 frames/s), fast (15 frames/s), medium (7.5 frames/s), and slow (3.75 frames/s) frame rates. Measurements were also acquired at low, normal, and high-dose modes. All measurements were done at the largest field of view (30 cm).

Fluoroscope setting changes

Prior to the study intervention, there was no standardisation of the technique for inpatient MBS examinations. Different operators (including residents, fellows, and attending physicians) were independently responsible for the pulse rate and dose setting during MBS examinations. The most commonly used MBS technique prior to standardisation was to use the fluoroscopic lowest pulse rate (3.75 frames/s) and normal dose. Following standardisation, the pulse rate was uniformly increased to 15 frames/s and the default settings on the fluoroscope was changed to low dose.

Speech language pathologist training

The purposes of the MBS and MBSImP approach in adults are to: (1) identify and distinguish type and severity of physiological swallowing impairment; (2) provide *surrogate* information regarding sensorimotor mechanisms that contribute to swallowing impairment (e.g., weakness, sensation, etc. that cannot be directly testing but inferred based on evidence); (3) determine the presence, cause, and patient response to airway invasion (penetration/aspiration); and (4) assess the response and adaptations of the mechanism(s) to interventions that identify treatment targets and guide the clinician's plan of care.[3]

Prior to adopting the MBSImP protocol, there was no set procedure for conducting the studies. There was wide variability in the barium consistencies, amount of bolus presentations, and number of bolus trials. On implementation, speech pathologists within the inpatient, acute, and outpatient venues were required to complete the MBSImP continuing educational programme within a 6-month period. This involved at least 26 hours of watching MBS examinations and rating them according to the 17 critical components. To be MBSImP certified, they had to pass a test with 80% reliability rating these 17 critical components across 10 MBS. Portions of the training also involved collaboration with the Radiology Department for further education and understanding of the different pulse rates, and also for consistency in protocol adherence during procedures.

Statistical analysis

An independent sample *t*-test was performed to examine the difference between the mean radiation dose and fluoroscopic time in the two separate populations both before and after MBS standardisation.

Results

Phantom testing

The results are displayed in Table 2. Prior to the MBS standardisation, the normal dose and slow frame rate were employed (44% and 55% of continuous rate, normal dose mode in the 4 inch and 7 inch phantoms, respectively). Following standardisation, the low dose and high frame rate were used (estimated to be 46% and 48% of continuous rate, normal dose mode in the 4 and 7 inch phantoms, respectively). Thus, standardisation was expected to decrease the dose rate by up to approximately 15%.

Patient radiation dose

Prior to MBS standardisation, the mean radiation dose was 5.86 (±4.35) mGy. Following standardisation, the mean radiation dose was 4.72 (±3.77) mGy ($p<0.0001$). The mean fluoroscopy time for MBS prior to standardisation was 83.8 (±44.4) seconds and the mean fluoroscopy time for MBS after standardisation was 82.3 (±39.8) seconds ($p=0.62$). The dose rate for MBS prior to standardisation was 4.35 (±2.42) mGy/s and the dose rate for MBS after standardisation was 3.55 (±2.41) mGy/s ($p<0.0001$). Overall, there was a decrease in dose during MBS of approximately 18.4% following standardisation of MBS and change in fluoroscopic technique. Results are summarised in Table 3.

Table 2
Fluoroscopic dose to the phantoms displayed as percentage of the maximum dose (e.g. continuous fluoroscopy and high dose mode = 100%).

		Pulse mode			
		Continuous	Fast	Medium	Slow
4 inch PMMA					
Dose mode	High	N/A	83%	79%	52%
	Normal	100%	70%	58%	44%
	Low	65%	46%	39%	29%
Frames per second		30	15	7.5	3.75
7 inch PMMA					
Dose mode	High	N/A	91%	74%	49%
	Normal	100%	69%	59%	55%
	Low	65%	48%	38%	29%
Frames per second		30	15	7.5	3.75

Discussion

Evidence shows that judgement of swallowing impairment and treatment recommendations are positively affected by MBS standardisation and increasing the frame rate.[2,4] In response to the growing evidence, the aim was to standardise the MBS at Birmingham Medical Center. After MBSImP training, increasing frame rate, and lowering the dose rate on the fluoroscope, a decrease in dose to the patient and no significant increase in the fluoroscopy time were observed. Radiation exposure to patients is an increasing focus given the increasing utilisation of radiological studies for the diagnosis and treatment of patients. A key concept in diagnostic imaging is the ALARA ("as low as reasonably achievable") principle, which strives to maintain the lowest possible radiation dose during an imaging study while maintaining diagnostic quality.[5] The radiation dose to the patient during an MBS is relatively low, estimated to be between 0.2–0.85 mSv.[6] Despite the low average radiation dose in these studies, it is still prudent to keep the dose ALARA, particularly in paediatric patients who are known to be more radiosensitive, and the radiation field often contains two of the most radiosensitive organs in the body (the lens and the thyroid gland).[7] In addition, an important consideration is that many patients may undergo more than one MBS.

Radiation dose during fluoroscopy is a complex topic that depends on several technical factors, including fluoroscopic dose level settings and the fluoroscopic pulse rate. Various technical factors influencing patient dose during MBS examinations have been studied and increasing frame rate has been shown to increase dose to the patient.[8,9] Although frame rate used during fluoroscopy is a major determinant of radiation dose, modulations in dose are also possible through the adjustment of the dose mode. Most fluoroscopic units have low, medium, and high dose modes. The low dose mode is half of the medium dose and the high dose mode is often twice the medium dose.[10] The medium dose mode is most often set as the default and is the most commonly used dose mode in other areas of fluoroscopy. Thus, it would be expected that the radiation dose would decrease by a factor of two when changing from the medium setting to the low setting with the drawback of increased image noise. The fluoroscopic pulse rate allows for dose savings by emitting X-ray beams as a series of short pulses rather than a continuous beam. Pulse rate settings typically include 30 frames/s (continuous fluoroscopy), 15 frames/s, 7.5 frames/s, and 3 frames/s. A dose reduction of 50% would be expected for a reduction from 30 to 15 frames/s due to half the amount of X-rays being emitted; however, manufacturer setting frequently encode increases

Table 3
Fluoroscopic dose, fluoroscopy time, and fluoroscopic dose rate of patients undergoing inpatient modified barium swallow (MBS) before and after standardisation of the MBS and change in MBS fluoroscopy technique.

	Before (low rate/normal dose)	After (high rate/low dose)	*p*-Value
Mean radiation dose (mGy)	5.86 (±4.35)	4.72 (±3.77)	<0.0001
Mean fluoroscopic time (s)	83.8 (±44.4)	82.3 (±39.8)	0.62
Dose rate (mGy/s)	4.35 (±2.42)	3.55 (±2.41)	<0.0001

in milliamperes to reduce image noise. Thus, a reduction from 30 to 15 frames/s actually results in dose savings of approximately 25%.[10] Thus, if the tube current is set too high to achieve improved image quality at lower frame rates, the dose advantage of pulsed fluoroscopy may be eliminated.

Studies examining the radiation dose reduction provided by pulsed fluoroscopy when compared to continuous fluoroscopy demonstrate a dose reduction of 22% for pulsed fluoroscopy at 15 frames/s and 49% for pulsed fluoroscopy at 7.5 frames/s.[11] Additionally, very little perceptual differences between the pulsed and continuous fluoroscopy were reported in the experimental simulated study[11]; however, significant perceptual differences during MBS have been reported with the use of lower fluoroscopic frame rates.[2,12] One retrospective study compared five 30 frames/s MBS studies to the same studies modified to simulate 15 frames/s examinations, and found that the lower frame rate significantly affected MBSImP scores.[2] Decreasing the frame rate specifically during MBS appears to be detrimental to the quality and interpretation of the study. In these studies, adjustments to both the dose mode and frame rate were not simultaneously performed to assess if the effects of both adjustments balance out the changes in radiation dose.

The literature reports a wide range of fluoroscopic times for MBS, ranging from 150 to 1,080 seconds.[4] Use of the MBSImP has been shown to increase fluoroscopy times, particularly in the presence of marked swallowing dysfunction or novice operator[4]; however, the MBSImP did not increase radiation exposure time in relation to reported exposure times in the published literature, with a mean exposure time of 2.9 minutes.[4]

There were several limitations of the present study, with the main limitation being its retrospective nature. Additionally, there was a heterogeneous population with a variety of swallowing difficulties in the inpatient setting. The variation in dose from one patient to another is likely larger than the overall change due to higher frame rate and low dose mode. Finally, many of the prior studies have compared slow frame rate mode to continuous fluoroscopy, not the 15 frames/s mode utilised in the present study. At Birmingham Medical Center, providers felt uneasy about immediately increasing the fluoroscopy rate from slow frame rate to continuous fluoroscopy mode due to concerns about patient dose. Thus, during the transition, 15 frames/s mode was used, but the future direction for Birmingham Medical Center includes increasing the frame rate to continuous.

In the present patient population, the adjustments made to lower the dose mode and the increase in fluoroscopy frame rate decreased the radiation dose. Standardisation of the MBS at Birmingham Medical Center has led to positive results from both the radiology and speech pathology points of view.

Conflict of interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crad.2019.05.030.

References

1. Martin-Harris B, Logemann JA, McMahon S, *et al.* Clinical utility of the modified barium swallow. *Dysphagia* 2000;**15**(3):136–41.
2. Bonilha HS, Blair J, Carnes B, *et al.* Preliminary investigation of the effect of pulse rate on judgments of swallowing impairment and treatment recommendations. *Dysphagia* 2013;**28**(4):528–38.
3. Martin-Harris B, Brodsky MB, Michel Y, *et al.* MBS measurement tool for swallow impairment—MBSImp: establishing a standard. *Dysphagia* 2008;**23**(4):392–405.
4. Bonilha HS, Humphries K, Blair J, *et al.* Radiation exposure time during MBSS: influence of swallowing impairment severity, medical diagnosis, clinician experience, and standardized protocol use. *Dysphagia* 2013;**28**(1):77–85.
5. Strauss KJ, Kaste SC. The ALARA (as low as reasonably achievable) concept in pediatric interventional and fluoroscopic imaging: striving to keep radiation doses as low as possible during fluoroscopy of pediatric patients—a white paper executive summary. *Radiology* 2006;**240**(3):621–2.
6. Mettler Jr FA, Huda W, Yoshizumi TT, *et al.* Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology* 2008;**248**(1):254–63.
7. National Research Council. *Health risks from exposure to low levels of ionizing radiation: BEIR VII phase 2*. Washington, DC: The National Academies Press; 2006.
8. Wright RE, Boyd CS, Workman A. Radiation doses to patients during pharyngeal videofluoroscopy. *Dysphagia* 1998;**13**(2):113–5.
9. Bonilha HS, Wilmskoetter J, Tipnis SV, *et al.* Effective dose per unit kerma–area product conversion factors in adults undergoing modified barium swallow studies. *Radiat Prot Dosim* 2017;**176**(3):269–77.
10. Mahesh M. Fluoroscopy: patient radiation exposure issues. *RadioGraphics* 2001;**21**(4):1033–45.
11. Aufrichtig R, Xue P, Thomas CW, *et al.* Perceptual comparison of pulsed and continuous fluoroscopy. *Med Phys* 1994;**21**(2):245–56.
12. Cohen MD. Can we use pulsed fluoroscopy to decrease the radiation dose during video fluoroscopic feeding studies in children? *Clin Radiol* 2009;**64**(1):70–3.