

Technical Aspects of a Videofluoroscopic Swallowing Study

Aspects techniques de l'étude vidéofluoroscopique de la déglutition

KEY WORDS

DYSPHAGIA

DEGLUTITION

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FLUOROSCOPY

Melanie Peladeau-Pigeon
Catriona M. Steele

Abstract

Dysphagia management has become a core area of practice for Speech-Language Pathologists (S-LPs). Videofluoroscopy is a readily available tool used to determine swallowing safety and efficiency as characterized by airway protection, penetration or aspiration and excess oral or pharyngeal residue. Performing a swallowing study successfully requires proper balance of many features. While many of the technical aspects are controlled by the radiology staff, it is important for the conducting S-LP to have a basic understanding of the technical aspects that can impact the quality and integrity of the video.

This article describes the types of fluoroscope available, factors influencing the image contrast, the creation of a contrast impregnated fluid, imaging techniques (pulsed versus continuous), imaging resolution (spatial and temporal) and safety considerations. This article hopes to clarify concepts to avoid future misuse of fluoroscopic imaging terminology as applied to a swallowing study. In addition, this article hopes to provide the foundations for S-LPs to be able to communicate effectively with the radiology staff, as the optimal videofluoroscopic exam can only be successfully obtained when both parties work together as a team.

Abrégé

La gestion de la dysphagie est devenue l'un des domaines centraux de la pratique en orthophonie. La vidéofluoroscopie est un outil facilement disponible utilisé pour déterminer la sécurité et l'efficacité de la déglutition, caractérisée par la protection, la pénétration ou l'aspiration des voies respiratoires, et un excédent de résidu buccal ou pharyngé. Pour réussir une étude de la déglutition, il faut un juste équilibre entre divers éléments. Si une bonne part des aspects techniques sont contrôlés par le personnel de radiologie, il est important pour l'orthophoniste en charge d'avoir une compréhension de base des aspects techniques pouvant avoir un impact sur la qualité et l'intégrité de la vidéo.

Cet article décrit les types de fluoroscopes disponibles, les facteurs qui influencent le contraste de l'image, la création d'un fluide imprégné de substances à contrastes, les techniques d'imagerie (pulsée par opposition à continue), la résolution de l'imagerie (spatiale et temporelle) et les considérations de sûreté. Cet article vise à clarifier les concepts de façon à éviter une mauvaise utilisation de la terminologie de l'imagerie fluoroscopique telle qu'appliquée à l'étude de la déglutition. En plus, il couvre les notions qui permettront aux orthophonistes de communiquer efficacement avec le personnel de radiologie, parce qu'un examen vidéofluoroscopique optimal ne peut être réussi que lorsque les deux parties travaillent en équipe.

Melanie Peladeau-Pigeon,
M.H.Sc.

Toronto Rehabilitation
Institute
University Health Network
Toronto, ON
Canada

Catriona M. Steele, Ph.D.

Toronto Rehabilitation
Institute
University Health Network
University of Toronto
Toronto, ON
Canada

Introduction

Swallowing is not only a basic function essential for maintaining proper nutrition and hydration but also a function important for quality of life given the central role that eating and drinking play in all varieties of human social activity. The term dysphagia refers to swallowing impairment. Impairments or abnormalities in swallowing physiology have both functional and social participation consequences. Dysphagia management has become a core area of practice for Speech-Language Pathologists (S-LPs) in Canada as demonstrated by the inclusion of dysphagia in the Canadian Association of Speech-Language Pathologists and Audiologists (CASLPA) national certification examination in 1999 (CASLPA, 2007) and re-iterated in the *Position Paper on Dysphagia in Adults* by CASLPA (2007). The importance of swallowing management in the scope of practice for S-LPs is also reflected in policies and guidelines provided by the provincial colleges/associations such as the College of Audiologists and S-LPs of Ontario (CASLPO) (2007), the Alberta College of S-LPs and Audiologists (ACSLPA) (2009) and the Manitoba Speech and Hearing Association (MSHA) (2009).

In clinical practice, the evaluation of swallowing focuses primarily on determining whether two areas of dysfunction exist: a) impaired airway protection leading to penetration or aspiration of material into the respiratory system; and b) impaired swallowing efficiency resulting in prolonged transit times and/or oral or pharyngeal residue (Clavé et al., 2008). A key component of dysphagia competency is the ability to perform and interpret videofluoroscopic swallowing examinations (VFSS), which may be used to confirm the presence/absence and severity of these areas of dysfunction, to identify abnormalities in swallowing physiology and to probe candidacy for specific forms of intervention (CASLPO, 2007). In an early and seminal article on videofluoroscopy practice, Drs. Bronwyn Jones and Martin Donner wrote: “examination of the patient with dysphagia depends on two major factors: a) meticulous attention to the examination itself; and b) an in-depth knowledge of normal and abnormal anatomy and physiology of swallowing” (Jones and Donner, 1989, p.162). The purpose of this tutorial article is to address the first of these two factors by reviewing technical aspects of fluoroscopy and the VFSS procedure. We believe that it is critical that S-LPs understand how technical considerations can influence the quality of data and information acquired during the VFSS assessment.

The VFSS Assessment

Fluoroscopy is a medical imaging technique that enables the visualization of the motion of internal fluids and anatomical structures. When used to examine

oropharyngeal swallowing physiology and bolus flow through the upper aerodigestive tract, this procedure is commonly referred to as a VFSS or Modified Barium Swallow (MBS). Other names for the procedure may reflect particular protocol decisions (e.g., the “cookie swallow”, which is a term used by Logemann (1993), reflecting the inclusion of a Lorna Doone cookie in their protocol) or health insurance billing codes (e.g., “palatopharyngeal analysis”). The assessment typically begins in the lateral (sagittal) plane; however an anterior-posterior (A-P) view may also be included at the end of the procedure (CASLPO, 2007; Martin-Harris et al., 2008). The lateral plane is ideal for detecting invasion of material into the airway (penetration-aspiration) as the view clearly differentiates the airway from the esophagus, and allows visualization of the entry of material into the supraglottic space and larynx (Martin-Harris & Jones, 2008). The A-P view provides information regarding symmetry of structures, function and bolus flow, and is particularly useful when further exploration of bolus flow through the cervical esophagus is desired (Martin-Harris & Jones, 2008).

The following is a list of the different types of information that can be gathered from a VFSS to inform and justify clinical management decisions:

- Assessment:
 - Determine the presence, nature and severity of swallowing impairment;
 - Assess the various components of swallowing physiology and detect abnormalities;
 - Evaluate swallowing efficiency and safety (Martin-Harris & Jones, 2008; Martin-Harris, Logemann, McMahon, Schleicher & Sandidge, 2000):
 - ◇ Efficiency of bolus preparation in the oral cavity;
 - ◇ Efficiency of transport from the oral cavity, to the pharyngeal cavity and into the esophagus;
 - ◇ Safety of airway protection;
 - Determine the presence of and response to penetration or aspiration;
 - Analyze the timing of swallowing events;
 - Determine the impact of fatigue on swallowing physiology.
- Management Plan:
 - Evaluate changes in swallowing efficiency and safety as a function of food/fluid consistency;

- Evaluate the effects of rehabilitation techniques such as postural changes, sensory enhancement and behavioural manoeuvres on swallowing function (Logemann, 1997).

As part of the VFSS exam, a dynamic movie of swallowing is recorded; in addition to providing the opportunity for careful review by the clinician, this movie can be used for patient education or for the communication of findings to other health care practitioners (Kelchner, 2004).

In order to competently perform and interpret a VFSS, health practitioners should have a clear understanding of physiological features and abnormalities (Jones & Donner, 1989). The optimal VFSS examination aims to capture an accurate representation of swallowing physiology; this is best achieved through interdisciplinary collaboration between radiology staff and S-LPs. In turn, successful interpretation of the VFSS depends on the number and quality of the images obtained, the observer's skills (education, experience, and confidence), and on human visual perception and the ability to recognize patterns (Rauch, 2008). In the sections that follow, we review a number of technical features of fluoroscopy as applied in the VFSS. Topics covered include: equipment type, image contrast, contrast agents, imaging modes, imaging resolution and safety considerations. We believe that an understanding of all of these issues by S-LPs is important for ensuring successful performance of quality VFSS examinations, as illustrated schematically in Figure 1.

Figure 1: Technical aspects influencing the successful acquisition of a videofluoroscopic swallowing exam



Fluoroscopy Equipment Type: Flat panel detectors and Image Intensifier Systems

Fluoroscopy is an imaging modality used to acquire a continuous series of x-ray images, which can be viewed in real time, allowing an appreciation of dynamic physiology. There are two major types of fluoroscopy system: flat-panel detectors (FPD) and image intensifier systems. The type of system used impacts the resulting image and its resolution, which will be discussed in a subsequent section. The easiest method of differentiating the two systems is to look at the image display. For an image intensifier, the corners of the display are typically cut off and straight lines such as that of a mesh are slightly curved, as in a 2-dimensional depiction of the world as a globe. Unfortunately, this system produces image distortions which can impact quantitative analyses performed on the series of images (Cerveri, Forlani, Borghese, & Ferrigno, 2002). In an FPD system, the grid shows up with no distortion; all lines in the mesh are perpendicular and the image produced uses the full screen size. Fluoroscopy images of a mesh grid produced by each type of system can be found in an article by Nickoloff (2011). The type of fluoroscopy system used can also determine the type of video capture system that is suitable to use for post VFSS analysis: an image intensifier typically yields an analog signal while an FPD generates a digital signal. Fluoroscopy systems used in swallowing studies are typically image intensifiers.

Image Contrast and Brightness

The fluoroscopy image sequence has a characteristic contrast or range of grayscale values. The contrast is obtained due to the various tissue compositions present, each holding their own characteristic densities. Overall contrast can be altered by the fluoroscope operator by changing the energy properties of the x-ray photons that are emitted. Automatic brightness control (ABC) is a feature that is often used by the technologist to help maintain the overall image brightness at a constant level and ensure adequate contrast of anatomical features on the image.

Contrast Agents: Barium Radio-opacity, Concentration, Density and Recipes

The contrast or opacity of the bolus that is being observed can be further enhanced using contrast agents. Barium is the most common active ingredient for oral or gastrointestinal contrast due to its high density, which shows up as a radiopaque substance on the fluoroscopic image. Radio-opacity refers to the ability of a substance or object to obstruct the passage of energy such as x-rays. On a traditional x-ray image, radiopaque material such as bone or barium, has greater attenuation and is represented by the lighter end of the grayscale spectrum (i.e., white). However, in fluoroscopy, the resulting representation is a reverse

pattern: barium impregnated fluids, bones and attenuating materials such as metal will typically appear as darker objects.

Barium impregnated fluids or foods are used so that the clinician can track the movement of stimuli from the oral cavity to the upper esophagus. Caution must be used when choosing both the test fluid and the barium product. The addition of barium, liquid or powder, will affect the density and viscosity of the test fluid. In the United States, Varibar™ is a commercially available line of low concentration (40% w/v) barium products that are produced in different consistencies (e.g., thin, nectar-thick, honey-thick) and were developed specifically for use in oropharyngeal swallowing examinations. Given that Varibar™ products are not currently available for clinical use in Canada, it is common practice to mix or dilute other gastrointestinal imaging preparations for use in the examination of the oropharynx. Clinicians should be aware that mixing barium preparations in ways that differ from the manufacturer's labeled instructions constitutes an "off-label" use of the product. Essentially, this means that the product is being used for reasons that have not yet received approval from Health Canada. Off-label uses include varying dosage and using different routes of administration than those indicated on the product label. The manufacturer and supplier are not allowed to advertise the product for off-label use. In addition, federal authorities such as Health Canada do not regulate off-label use (CMPA, 2012). Regulation of off-label use may be addressed under either provincial jurisdictions or by professional regulatory bodies or colleges. Regardless of whether product use falls under intended or off-label use, attention should always be paid to manufacturer instructions regarding the shelf-life and expiry dates of products once opened. It is recommended that S-LPs consult with colleagues in the radiology department to understand shelf-life restrictions of barium, once opened, and that a log be maintained for bottle open dates. Alternatively, the open date or the expiry date can be labeled on the bottle directly.

Recipes can help to ensure that standard preparations of the stimuli are used across examinations. Ideally, standardized recipes would be used across institutions; however, none exist at the current time. When mixing barium into concentrations other than those described on the manufacturer's label, two pieces of information are required to determine the appropriate amounts of powder (or solution) to mix with given volumes of water (or other test stimuli): a) the concentration; and b) the density of the original product. There is often confusion between the terms "concentration" and "density" when describing barium mixtures. The term "concentration" refers to the amount of one compound in reference to another compound, expressed in a weight to volume ratio (w/v), volume to

volume ratio (v/v) or weight to weight ratio (w/w). For example, the Polibar Liquid Plus label says that it is a 105% w/v solution (E-Z-EM Canada Inc., 2012). This means that there are 105g of barium sulfate in 100mL of the Polibar Liquid Plus solution. The concentration is also listed as 58% w/w meaning that there are 58g of barium sulfate in 100g of the Polibar Liquid Plus solution. The concentration of a barium preparation relates directly to its opacity, or visibility on an x-ray image; higher concentrations will appear more radio-opaque (darker) on the image. Higher concentrations of barium are also intended to coat the mucosal walls of the gastrointestinal tract, to allow double-contrast examinations in which the outline of an anatomical space or cavity can be appreciated as well as the outline of a fluid flowing through that space. Clinicians need to be aware that higher concentrations of barium may leave a coating in the oropharynx that could be mistakenly interpreted as being residue (Steele, Molfenter, Péladeau-Pigeon and Stokely, 2013).

By contrast, the term "density" refers to the mass per unit volume of a material. For example, water has a density of approximately 1g/mL at 20 °C. This simply means that a measured volume of 1mL weighs 1g. The temperature of the material is typically noted when reporting density; given that density is a physical property that varies with temperature. Density is also pressure dependent (a fact that is sometimes omitted). The densities of barium solutions are often not listed on the product label. However, density is a material property that can be easily measured in a lab setting.

When preparing barium for use in VFSS, the goal is to produce a product with a concentration that is adequately opaque to be visible on the radiographic image, but not so concentrated that significant mucosal coating occurs. The Varibar™ product line in the USA is manufactured to have a 40% w/v concentration. However, a recent article by Fink and Ross (2009) argued that even this low-concentration solution is not like a "true thin liquid" and proposed further dilution of thin liquid Varibar™ in 50% ratio with water to yield a concentration of approximately 20-22% w/v. Sample calculations for preparing a 22% w/v barium solution using a commercially available barium preparation (Liquid Polibar) are shown in the Appendix of this article.

Imaging Modes: Continuous versus Pulsed Fluoroscopy

There are three modes of operation in fluoroscopy: continuous, high dose, and pulsed. In VFSS, continuous and pulsed modes are commonly used. Continuous fluoroscopy generates a steady current. Images are generated at a rate of 30 images per second. Therefore, each image is exposed or acquired over a timeframe of 33 milliseconds. Pulsed fluoroscopy delivers short or pulsed bursts of current. The image exposure time can vary between 3 and 10

milliseconds and the pulse rate can be set at 30, 15 or 7.5 pulses per second. Pulsed fluoroscopy offers the advantage of eliminating motion blur caused by long acquisition or exposure times (Schueler, 2000). In addition, the pulsed mode can theoretically help to reduce radiation exposure. For example, an equivalent total examination time of 5 seconds would involve 5000 milliseconds of exposure under continuous fluoroscopy conditions, but this could be reduced to 1500 milliseconds of exposure using a pulse rate of 30 pulses per second and 10 millisecond duration bursts.

Continuous and pulsed fluoroscopy yield different image quality. If the same tube current is used in videos pulsed at 30 and 15 pulses per second, there will be a noticeable deterioration in image quality at the lower pulse rate due to human visual field perception. When viewing a video, which is essentially a series of images, the “eye integrates the noise content of all images presented within a period of approximately 0.2 seconds” (Van Lysel, 2000). Therefore, when fewer images are displayed, as in the example of 15 pulses per second, the observer perceives an increase in noise even if the image quality and resolution has remained constant. The reader is directed to a presentation by Rauch (2008) for examples of videofluoroscopic images obtained using pulsed versus continuous fluoroscopy modes. It should be noted that fluoroscopy pulse rate is not the same thing as video frame rate. Controversies regarding pulse and video frame rate will be discussed below.

Image Resolution: Spatial and Temporal Resolution

While image quality is partly an intrinsic property of the imaging system, it is also dependent on the visual perception of the observer (Rauch, 2008). Spatial and temporal resolutions are two key features that contribute to intrinsic image quality. Spatial resolution describes the level of detail that is captured in an image and temporal resolution refers to the number of images displayed over a given time period.

Spatial Resolution

Spatial resolution refers to “the ability to see small detail” (Bushberg, Seibert, Leidholdt, & Boone, 2012). A system with higher spatial resolution is able to detect the presence of smaller objects or details. The lower limit of spatial resolution is “the size of the smallest possible object that the system can resolve” (Bushberg et al., 2012). There are two spatial dimensions and thus two resolutions of interest; vertical and horizontal.

Vertical spatial resolution is determined by the number of horizontal lines contained in the image. This is also called the number of raster lines or scan lines. The CASLPO Practice Standards and Guidelines for Dysphagia indicate that the VFSS video should contain a minimum of 400

raster lines (CASLPO, 2007). It should be noted that limits to image resolution may be influenced both by monitor used to display the live fluoroscopic images and/or by the equipment used to capture these images in a recording. Spatial resolution can also be influenced by the Field of View (FOV) or magnification for an image intensifier fluoroscopy system. For a given number of raster lines, a smaller FOV would have a higher vertical resolution than that of a larger FOV. However, in an FPD system, the maximum spatial resolution is inherent to the system. Horizontal spatial resolution refers to the number of vertical lines contained in an image and is proportional to bandwidth. While vertical and horizontal resolutions can differ, they are typically designed to be equal (Van Lysel, 2000). The number of raster lines and the bandwidth of the system can be found in the user manual or by contacting the manufacturer. The radiology staff may also be able to provide this information.

Temporal Resolution

Temporal resolution is a factor of fluoroscopy pulse rate during the VFSS exam (image registration rate), but will also vary depending on frame rate of the system used to capture or record the video (video recording frame rate). These are two very different and distinct features; one related to the fluoroscopy equipment and the other to the video recording device. Historically, the terminology of 30 frames per second has been confusing and prone to misinterpretation because it has been used to describe both the fluoroscopy image registration rate and video recording frame rates. Image registration rates for pulsed fluoroscopy are typically described by reporting the pulse rate. For continuous fluoroscopy, however, there is no pulse rate information that can be reported; in the dysphagia literature the image registration rate of continuous fluoroscopy has often been reported 30 frames per second. This is not to be confused with the frame rate of the video recording.

The standard video recording system in North America has a video frame rate of 30 *frames per second*; in Europe, Australia, Japan and South America, standard video frame rates are slightly lower at 25 frames per second. These frame rates correspond to the upper temporal resolution achievable for a video recording and are independent of the fluoroscopy system. What is important to realize is the fact that temporal resolution of any given VFSS recording will be determined by the lowest resolution of either the fluoroscopy equipment or the recording settings. For example, if a VFSS is performed using a pulse rate of 15 *pulses per second* (yielding 15 images per second) and a recorded at a video frame rate of 30 *frames per second*, the temporal resolution will in fact be 15 *frames per second*. In this situation, each image from the fluoroscopy will be displayed twice (or over 2 successive video frames) in the video recording.

While the CASLPO Guidelines (2007) recommend recording VFSS at 30 frames per second, no recommendations are in terms of the imaging mode (i.e., continuous or pulsed fluoroscopy) or image registration rates (i.e., minimum pulse rate). Clinicians need to be aware that trade-offs in temporal resolution occur when reducing radiation exposure through pulsed fluoroscopy at rates below 30 pulses per second. Using 30 images per second, Cohen (2009) demonstrated that the depth and severity of transient penetration-aspiration was apparent on only a single frame in 70% of children (age range of 1 month to 3 years 9 months); consequently, if image registration rates lower than 30 pulses per second had been used in this study, the severity of penetration-aspiration would have been underestimated. Similar conclusions are reported by Bonilha, Blair and colleagues (2013), who contrived to present 30-image-per-second VFSS recordings in full resolution and half resolution (i.e., 15 images per second) for interpretation by trained S-LPs. They demonstrated that the lower resolution was insufficient to capture swallowing events: differences were observed in numerous MBSImp™© measurements as well as in Penetration-Aspiration Scale (PAS) Scores. In a related study (Bonilha, Humphries et al., 2013), the authors also showed that the availability of 30 images per second leads to a more efficient VFSS examination, thereby limiting radiation exposure; procedures yielding only 15 images per second may require a larger number of swallowing tasks in order to adequately capture swallowing impairment.

Video Capture Considerations

As previously mentioned, CASLPO Practice Standard and Guidelines require S-LPs to record the videofluoroscopic exam for post-VFSS analysis (CASLPO, 2007). A wide array of commercially available hardware and software combinations exist for video capture. This section does not seek to provide an extensive review of available products but rather to explain the basic principles behind these video capture methods. In determining the best video capture method, both the radiology staff and information management systems should be consulted. Digital video capture systems will specify minimum requirements for computer processor speed, RAM, graphics cards and the computer monitor, due to the fact that digital video conversion requires a lot of processing power. When high quality video recordings are viewed on computers with inadequate processing power, this can result in poor video viewing conditions, such as periodic freezing and an inability to view all recorded frames.

If the VFSS is recorded to a computer, there is a one major component present: a digital video converter, which is used to transfer the video signal from the fluoroscope to a computer system. Converters typically come with preferred software, which can be used to capture the video.

Depending on the software, a number of different digital file formats can be selected. The choice of format and settings will impact the quality of the video recording. Compression software may also be available to restrict file size to reduce burden to the hospital servers, data storage, and transmission rates (Hirshfeld, et al., 2004). While the details of video settings and compression codes are not covered in this article, it is important for S-LPs to be aware that choices in compression may influence video quality for post VFSS analysis. Each video compression tool differs in the method or algorithm it uses to reduce the file size; additional details regarding these methods can be found with a simple internet search. If compression is required in a hospital in order to limit file size for storage, S-LPs may want to explore optimal choices by preparing different versions of a set of VFSS and comparing observations and feedback regarding image quality across clinicians.

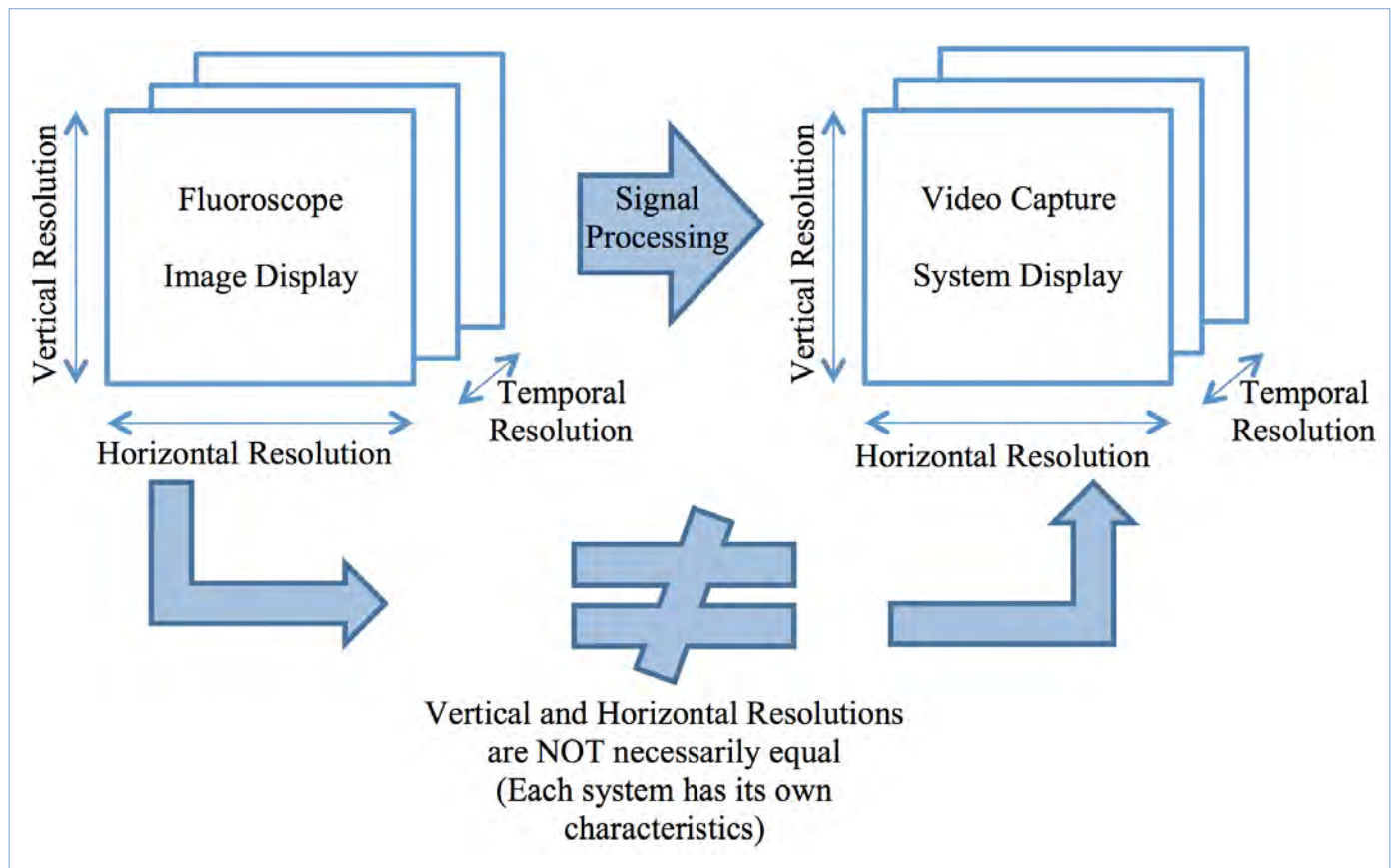
A downscanner (scan converter) may be required to reduce the data rate of the video stream between the fluoroscope and the recording system. Scan conversion is a video processing tool that changes the horizontal frequency or bandwidth (refer to Spatial Resolution Section for definition) to reduce the video data rate. This conversion creates compatibility with conventional video equipment and recording devices. In North America, the National Television System Committee (NTSC) defines the standard. However, video streaming rate and data format standards vary across countries (e.g., PAL, SECAM, NTSC). Depending on whether the fluoroscopy system used is analog or digital, and whether the video capture method is digital (e.g., computer) or analog (e.g., VHS tape), analog-to-digital or digital-to-analog converters may be required. Some fluoroscopic units already integrate this type of conversion prior to video display on the monitor (Schueler, 2000).

Figure 2 provides a schematic summary of all of the previously discussed issues with respect to fluoroscope and image resolution considerations for VFSS.

Safety and Radiation Exposure

Optimal methods should be used to ensure that the patient's exposure to radiation is kept to a minimum. Radiation dose is measured in millisieverts (mSv) and is present in everyday activities such as flying in a plane (0.005 mSv per hour) or smoking cigarettes (0.18 mSv per half pack) as well as during medical tests such as a chest x-ray (0.02 mSv) or a CT scan (10 mSv) (Green, 2011). On average, Canadians are exposed to approximately 2-4 mSv of background radiation per year (Health Canada, 2011). In a workplace, including work with x-ray equipment, the radiation exposure limit is 50 mSv in a single year and 100 mSv over 5 years, according to the Canadian Nuclear Safety Commission (Health Canada, 2011).

Figure 2: Illustration of fluoroscope and video capture image features



In a VFSS, radiation dose is typically controlled by the x-ray technician or radiologist. However, it is important for S-LPs to have some basic understanding of the factors influencing the radiation dose as it can affect the health of both themselves and their patients. The radiation dose is a factor of:

- Equipment used (design)
- Equipment set-up (equipment parameters)
- Equipment maintenance
- Proper utilization of the equipment
- Knowledge and skill of the radiologist or radiology technician
- Use of personal protective equipment
- Position or proximity to the equipment or radiation source

The voltage chosen by the radiology staff impacts both the dose and the image contrast. Increasing the voltage, in kV, reduces skin exposure to the beam because higher values

have increased penetration. However, increased voltage can compromise the image contrast.

For patient radiation exposure, two factors that can in part be controlled by the S-LPs are the magnification and the imaging time. The magnification mode or Field of View (FOV) impacts the radiation exposure of the patient. While the energy released remains the same, the absorbed dose to the region of tissue does change. For a 2 fold magnification, the dose increases fourfold (IAEA, 2012). The second factor is the imaging time, which has a large impact on the overall radiation exposure. The shortest videofluoroscopic times should be used while ensuring adequate information is obtained for the clinical analysis. This is consistent with the radiological principle ALARA, "as low as reasonably achievable".

The major source of occupational radiation exposure during this procedure is due to scattered radiation (McLean, Smart, Collins, & Varas, 2006). S-LPs can help to reduce their own radiation exposure by using personal protective equipment (PPE), increasing their distance from the radiation source, and limiting the exposure time. A position 6 feet away from the patient in any direction is considered to be a zero exposure location.

The type of PPE used in a typical VFSS includes a lead apron and a thyroid guard. Eye protection and lead gloves may also be available. It is not recommended to use lead gloves when administering stimuli to a patient as a radiopaque substance in the FOV will cause fluctuations in image contrast and radiation due to the use of the automatic brightness control (ABC) (briefly mentioned in the image contrast section) (Kelchner, 2004). There exists a delicate balance between radiation dose and image quality. It is imperative that the S-LP works with the radiology staff to minimize radiation exposure while ensuring that an adequate video is recorded for the swallowing assessment.

Radiation exposure follows the inverse square law, therefore, increasing the distance by a factor of two results in a fourfold decrease in radiation exposure. It is recommended that the S-LP stand as far from the patient and the source of radiation as feasible. Exposure time is directly related to the radiation

exposure. Therefore, a reduction in time by half results in half the radiation to both the patient and the attending S-LP. Once again, the shortest video fluoroscopic times should be used while ensuring adequate information is obtained for the clinical analysis.

Ionizing radiation exposure can be monitored using dosimeters. One dosimeter should be placed outside the lead apron in the neck area. A second dosimeter is recommended and should be placed under the apron (ASHA, 2004). Safety and monitoring device requirements are specific to a hospital and policies should be reviewed prior to the VFSS. The approximate radiation dose to an S-LP during a typical VFSS exam is summarized in Table 1. The median levels of radiation exposure associated with a VFSS in patient populations have been quantified by researchers and the exposures summarized in Table 2.

Table 1: Staff (S-LP) ionizing radiation exposure during a VFSS

Study	Length of Time Measured	System Used	Location of Measurement	Exposure
McLean et al (2006)	Average per procedure with an average procedure time varying from 3.0 to 3.6 min	Unknown for all sites	Outside thyroid shield	Site 1- 17 µGy Site 2 - 3.2 µGy Site 3- Below detection limit of 6µGy
			Under S-LP lead apron at waist level	All 3 sites - Below detection limit of 6µGy
Crawley et al (2004)	Total for 21 exams over 6 months with a mean screening time of 3.7 min (range: 2.5-4.3 min)	Siemens Uroskop C2	Under S-LP lead apron	Below detection limit of 0.3mSv
			Finger on right hand of right handed operators	0.9mSv
			Forehead of operators	0.5mSv

Table 2: Patient ionizing radiation exposure during a VFSS

Study	System Used	Sample Size (# of Patients)	Mean Equipment Parameters	Mean DAP (Gy cm ²)	Mean Effective Radiation Dose (mSv)	Mean Length of Exam (s)
Zammit-Maempel, Chapple, & Leslie (2007)	Siemens Sireskop 5-45	230	77kVp	1.6 (0.05-10)	0.20 (0.01-1.4)	181 (18-564)
Moro & Cazzani (2006)	Prestige VH by GE	22	78.4kV 0.7mA	2.3 (1-5.4)	0.4 (0.17-0.92)	155 (84-306)
Crawley, Savage, & Oakley (2004)	Siemens Uroskop C2	21	N/A	3.5 (3.1-5.2)	(Median 0.85) (0.76-1.3)	220 (150-258)
Wright, Boyd, & Workman (1998)	Siemens Siregraph 2	23	65.4kV	4 (0.28-9.74)	0.4 (0.027-1.1)	286 (32-497)

Radiology staff members have a wealth of knowledge about radiation and mitigation strategies for both staff and patients. Dialogue between the S-LPs and radiology staff is highly encouraged in order to minimize the radiation risk to everyone present and to obtain the highest quality VFSS data acquisition.

Conclusion

This article described the types of fluoroscope available, factors influencing the image contrast, the creation of a contrast impregnated fluid, imaging techniques (pulsed versus continuous), imaging resolution (spatial and temporal), and safety considerations. The optimal videofluoroscopy features can only be successfully obtained when both S-LPs and radiology staff work together as a team. This article aimed to describe fundamental fluoroscopy features as applied to the VFSS for S-LPs to effectively communicate with the radiology staff. In addition, clarification of fluoroscopic imaging terminology was provided with the hopes of avoiding future terminology misuse in publications relating to videofluoroscopic studies.

References

- ACSLPA. (2009). *Guideline: Swallowing (dysphagia) and feeding*. Retrieved from http://www.acslpa.ab.ca/public/data/documents/Dyshagia_-_single-sided_-_Final.pdf?oE6CA8F4-6866-4150-8A7D17E228FF660D
- ASHA. (2004). *Guidelines for speech-language pathologists performing videofluoroscopic swallowing studies*. Retrieved from <http://www.asha.org/policy/GL2004-00050.htm>
- Bonilha, H. S., Blair, J., Carnes, B., Huda, W., Humphries, K., McGrattan, K., . . . Martin-Harris, B. (2013). Preliminary investigation of the effect of pulse rate on judgments of swallowing impairment and treatment recommendations. *Dysphagia*. Online first. doi: 10.1007/s00455-013-9463-z
- Bonilha, H. S., Humphries, K., Blair, J., Hill, E. G., McGrattan, K., Carnes, B., . . . Martin-Harris, B. (2013). Radiation exposure time during MBSS: Influence of swallowing impairment severity, medical diagnosis, clinician experience, and standardized protocol use. *Dysphagia*, 28(1), 77-85.
- Bushberg, J. T., Seibert, J. A., Leidholdt, E. M., & Boone, J. M. (2012). *The Essential Physics of Medical Imaging*. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins.
- CASLPA. (2007). CASLPA Position paper on dysphagia in adults. Retrieved from http://www.caslpa.ca/PDF/position%20papers/English_Dysphagia_June%202007.pdf
- CASLPO. (2007). Practice Standards and Guidelines for Dysphagia Intervention by Speech-Language Pathologist. Retrieved Oct 26, 2012, from http://www.caslpo.com/portals/o/ppg/dysphagia_psg.pdf

- Cerveri, P., Forlani, C., Borghese, N.A., & Ferrigno, G. (2002). Distortion correction for x-ray image intensifiers: Local unwarping polynomials and RBF neural networks. *Medical Physics*, 29(8), 1759-1771.
- Clave, P., Arreola, V., Romea, M., Medina, L., Palomera, E., & Serra-Prat, M. (2008). Accuracy of the volume-viscosity swallow test for clinical screening of oropharyngeal dysphagia and aspiration. *Clinical Nutrition*, 27(6), 806-815.
- CMPA. (2012). *Risk management when using drugs or medical devices off-label*. Retrieved from http://www.cmpa-acpm.ca/cmpapdo4/docs/resource_files/perspective/2012/03/pdf/com_p1203_15-e.pdf
- Cohen, M. (2009). Can we use pulsed fluoroscopy to decrease the radiation dose during video fluoroscopy feeding studies in children. *Clinical Radiology*, 64, 70-73.
- Crawley, M., Savage, P., & Oakley, F. (2004). Patient and operator dose during fluoroscopic examination of swallow mechanism. *British Journal of Radiology*, 77, 654-656.
- E-Z-EM Canada Inc. (2012). Liquid Polibar Plus Barium Sulfate [Product Label]. Canada
- Fink, T. A., & Ross, J. B. (2009). Are we testing a true thin liquid? *Dysphagia*, 24(3), 285-289.
- Green, H. (2011, Jun 23). *Radiation exposure and air travel – Should we worry?* Retrieved from <http://www.farecompare.com/travel-advice/radiation-exposure-and-air-travel-should-we-worry/>
- Health Canada. (2011, Nov 2). *Occupational exposure to radiation*. Retrieved from <http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/expos-eng.php>
- Hirshfeld, J.W. Jr., Balter, S., Brinker, J. A., Kern, M. J., Klein, L. W., Lindsay, B. D., Tommaso, C. L., Tracy, C. M., Wagner, L. K., Creager, M. A., Elnicki, M., Hirshfeld, J.W. Jr., Lorell, B. H., Rodgers, G. P., Tracy, C. M., Weitz, H. H. (2004). ACCF/AHA/HRS/SCAI clinical competence statement on physician knowledge to optimize patient safety and image quality in fluoroscopically guided invasive cardiovascular procedures. A report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence and Training. *Journal of the American College of Cardiology*, 44(11), 2259-2282.
- IAEA. (2012). *Fluoroscopy*. Retrieved from https://rpop.iaea.org/rpop/rpop/content/informationfor/healthprofessionals/1_radiology/fluoroscopy.htm
- Jones, B., & Donner, M. W. (1989). How I do it: Examination of the patient with dysphagia. *Dysphagia*, 4(3), 162-172.
- Kelchner, L.N. (2004). Radiation safety during the videofluoroscopic swallowing study: The adult exam. *Perspectives on Swallowing and Swallowing Disorders (Dysphagia)*, 13(3), 24-28.
- Logemann, J.A. (1993). *Manual for the videofluorographic study of swallowing: Second edition*. Austin, TX: Pro-Ed, Inc.
- Logemann, J. (1997). Role of the modified barium swallow in management of patients with dysphagia. *Otolaryngology- Head and Neck Surgery*, 116(3), 335-338.
- Martin-Harris, B., Brodsky, M. B., Michel, Y., Castell, D. O., Schleicher, M., Sandidge, J., ... Blair, J. (2008). MBS measurement tool for swallow impairment--MBSimp: Establishing a standard. *Dysphagia*, 23(4), 392-405.
- Martin-Harris, B., & Jones, B. (2008). The videofluorographic swallowing study. *Physical Medicine and Rehabilitation Clinics of North America*, 19(4), 769-785.
- McLean, D.M., Smart, R., Collins, L., & Varas, J. (2006). Thyroid dose measurements for staff involved in modified barium swallow exams. *Health Physics*, 90(1), 38-41.
- MSHA. (2009). *Guidelines for provision of dysphagia services (for adults)*. Retrieved from <http://www.msha.ca/documents/1-GuidelineforProvisionofDysphagiaServicesforAdults.pdf>
- Moro, L., & Cazzani, C. (2006). Dynamic swallowing study and radiation dose to patients. *La Radiologia Medica*, 111, 123-129.
- Nickoloff, E. L. (2011). AAPM/RSNA physics tutorial for residents: Physics of flat-panel fluoroscopy systems. *Radiographics*, 31, 591-602.
- Rauch, P. (2008). *Fluoroscopic imaging equipment considerations for optimization of performance and dose* [PowerPoint slides]. Retrieved from <http://www.aapm.org/meetings/amos2/pdf/35-9917-69462-287.pdf>
- Royal College of Speech and Language Therapists (2012) *Videofluoroscopic evaluation of oropharyngeal swallowing disorders (VFS): The role of speech and language therapists*. Retrieved from http://www.rcslt.org/news/docs/rcslt_vfs_position_paper_consult (Not referenced in the text)
- Schueler, B. (2000). The AAPM/RSNA physics tutorial for residents: General overview of fluoroscopic imaging. *Radiographics*, 20(4), 1115-1126.
- Steele, C. M., Molfenter, S. M., Péladeau-Pigeon, M., & Stokely, S. (2013). Letter to the Editor: Challenges in preparing contrast media for videofluoroscopy. *Dysphagia*. [Epub ahead of print]
- Van Lysel, M. (2000). The AAPM/RSNA physics tutorial for residents: Fluoroscopy: Optical coupling and the video system. *Radiographics*, 20(6), 1769-1786.
- Wright, R., Boyd, C., & Workman, A. (1998). Radiation doses to patients during pharyngeal videofluoroscopy. *Dysphagia*, 13, 113-115.
- Zammit-Maempel, I., Chapple, C., & Leslies, P. (2007). Radiation dose in videofluoroscopic swallow studies. *Dysphagia*, 22(1), 13-15.

Authors' Note

Correspondence concerning this article should be addressed to Melanie Peladeau-Pigeon, M.H.Sc., Toronto Rehabilitation Institute, University Health Network, 550 University Avenue, Toronto, ON, M5G 2A2. Canada. Email: Melanie.Peladeau-Pigeon@uhn.ca

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Fluid barium mixture concentration and density calculations

The following are calculations for a total volume of 250mL with a desired barium concentration of 22% w/v (weight of barium to volume of total solution).

Given that Liquid Polibar contains 100% w/v or 56% w/w (E-Z-EM, 2012), as shown on the product label then the following calculations can be used:

Inputs:

- (1) Liquid Polibar Concentration = 100% w/v (100g Barium / 100mL Liquid Polibar Solution)
- (2) Liquid Polibar Concentration = 56% w/w (56g Barium / 100 g Liquid Polibar Solution)
- (3) Total Mixed Solution Volume = 250mL
- (4) Mixed Solution Concentration = 22% w/v (22g Barium / 100mL Mixed Solution)

Calculations:

(1) *Mass of Barium Desired (g)*

$$= \text{Total Mixed Solution Volume (mL)} * \text{Mixed Solution Concentration} \left(\frac{\text{g Barium}}{\text{mL Mixed Solution}} \right)$$

$$= 250\text{mL Mixed Solution} \left(\frac{22\text{g Barium}}{100\text{mL Mixed Solution}} \right)$$

$$= 55\text{g Barium}$$

(2) *Mass of Liquid Polibar Desired (g)*

$$= \frac{\text{Mass of Barium Desired (g)}}{\text{Liquid Polibar Concentration} \left(\frac{\text{g Barium}}{\text{g Liquid Polibar Solution}} \right)}$$

$$= \frac{55\text{g Barium}}{56\text{g Barium} / 100\text{g Liquid Polibar Solution}}$$

$$= \sim 98\text{g Liquid Polibar Solution}$$

NOTE: If a scale is not readily available, the mass of barium required can be converted to volume of Liquid Polibar solution:

Volume of Liquid Polibar Desired (mL)

$$= \frac{\text{Mass of Barium Desired (g)}}{\text{Liquid Polibar Concentration} \left(\frac{\text{g Barium}}{\text{mL Liquid Polibar Solution}} \right)}$$

$$= \frac{55\text{g Barium}}{100\text{g Barium} / 100\text{mL Liquid Polibar Solution}}$$

$$= 55\text{mL Liquid Polibar Solution}$$

- (3) Add the desired mass or volume of Liquid Polibar and fill the remainder of the desired 250mL with the fluid of interest (e.g., water)