



A Tutorial on Diagnostic Benefit and Radiation Risk in Videofluoroscopic Swallowing Studies

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Abstract

The videofluoroscopic swallowing study (VFSS) is a key tool in assessing swallowing function. As with any diagnostic procedure, the probable benefits of the study must be weighed against possible risks. The probable benefit of VFSS is an accurate assessment of swallowing function, enabling patient management decisions potentially leading to improved patient health status and quality of life. A possible (though highly unlikely) risk in VFSS is carcinogenesis, arising from the use of ionizing radiation. Clinicians performing videofluoroscopic swallowing studies should be familiar with both sides of the risk benefit equation in order to determine whether the study is medically justified. The intent of this article is to provide the necessary background for conversations about benefit and risk in videofluoroscopic swallowing studies.

Keywords Dysphagia · Deglutition Disorders · Videofluoroscopic Swallowing Studies · Radiation Dose · Pulse Rate · Frame Rate

Introduction

Any diagnostic procedure involves a decision regarding benefit versus risk. For any given procedure, the question must be asked, does the probable benefit obtained from the procedure outweigh the possible detriment? If the answer is yes, then the procedure is justified. The videofluoroscopic swallowing study (VFSS), also known as the Modified Barium Swallow Study (MBSS), is considered the most accurate instrumental assessment of swallowing physiology [1]. An effective VFSS provides the clinician with the clearest possible information about the presence, nature, and

severity of swallowing impairment [2–5]. This information provides significant potential benefit, in that it can be used to inform treatment and management decisions, creating the best chances for improved patient health status and quality of life. However, the benefits of the VFSS must be weighed against the risk, and it is the clinician's responsibility to ensure that benefit exceeds risk for a given procedure. In particular, the risks associated with radiation exposure must be carefully considered. In order to fulfill their responsibilities properly, the clinician must ensure that they are educated on both sides of the benefit versus risk equation.

Medical imaging using ionizing radiation imposes a trade-off scenario between image quality and radiation dose. In general, the quality of a radiographic image decreases as the amount of radiation used (i.e., dose) is decreased. So, any reductions in the amount of radiation used with the intent of sparing patient dose must be carefully balanced against loss of image quality and thus of diagnostic efficacy. This is true for single shot X-Ray images (such as a chest X-Ray or an X-Ray of a joint to look for fractures) but the situation is compounded in the context of dynamic studies like VFSS, where the procedure involves the collection of multiple images per second over an extended timeframe. Here, the risk side of the equation must consider not only the dose for each individual image but also the number of images obtained; both of these considerations have implications for

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diagnostic accuracy. Clinicians must work with colleagues from the radiology or diagnostic imaging department to establish VFSS protocols that use an optimal level of radiation—one that provides images of sufficient quality to be diagnostic, but not more than that. The goal of optimization is thus to identify and use the minimum amount of radiation required to achieve the diagnostic objective. This objective is summarized in the acronym ALARA (“as low as reasonably achievable”).

The ALARA principle was initially intended for use in radiation protection of occupationally exposed workers and the general public, for whom the target radiation exposure is zero [6]. It was later applied to patients, but with a slightly different intent. The goal of ALARA for patients is still to minimize radiation dose, but only if diagnostic objectives are not compromised [7]. This last statement is critical—the ALARA concept as applied to patient exposures is currently being revisited and reviewed, based on our current understanding of radiation biology [8, 9]. While the debate over the continued value of ALARA has not yet been resolved, there is a key message to take away from the discussion: dose reduction at the expense of diagnostic efficacy is not warranted.

In parallel with minimizing risk, we need to ensure that the VFSS exam is providing benefit. If radiation dose is reduced to the point where image quality is compromised, or if the number of images captured falls below the frequency required to detect critical events in swallowing, diagnostic accuracy may be lost, resulting in reduced benefit to the patient, perhaps even significantly reduced benefit. We then have to ask, was the reduction in patient risk worth the loss of useful diagnostic information? *The answer is likely no.* In the worst-case scenario, the study has no diagnostic utility. This may mean that incorrect dysphagia management decisions are made, placing the patient at risk. Alternatively, there may be a need to repeat the examination, leading to increased radiation exposure. In these scenarios, not only does the original VFSS have no diagnostic value, but the radiation exposure was completely unjustified. While reducing patient and staff radiation exposure are laudable goals, we must be careful that diagnostic objectives are not compromised in the pursuit of dose reduction.

Objective and Structure of the Article

Diagnostic medical imaging using X-Rays is a trade-off scenario. At the macro level, the trade-off is between how much benefit the patient is likely to receive from imaging versus how much risk they take on from exposure to ionizing radiation. At the micro level, the trade-off is between image quality and dose.

In order to make evidence-based decisions about risk versus benefit in VFSS, we need to understand the key factors involved in these trade-off scenarios. The objective of this article is to provide clinicians with the necessary background to inform discussions regarding the risk and benefit of VFSS. The article is intended primarily for practicing clinicians overseeing VFSSs, or for those preparing for that role. The article is structured in a question and answer format, with appropriate background material and references embedded in the answer portions.

Section “[Ionizing Radiation and Dose](#)” will provide a general overview of ionizing radiation and radiation dose relevant to medical X-Ray imaging. Section “[Image Quality](#)” will outline image quality for both static (single images) and dynamic (sequences of images, or video) X-Ray studies. Section “[Fluoroscopy and Fluoroscopic Systems](#)” will cover fluoroscopy systems, how system settings affect dose and image quality, and how dose is reported for a fluoroscopic exam. Section “[Radiation Protection Principles and Practice](#)” describes basic radiation protection principles and practice. Maximizing diagnostic benefit in VFSS is discussed in section “[How can we Maximize Diagnostic Benefit in VFSS?](#)” and minimizing risk for both patients and staff in VFSS is discussed in section “[How do we Minimize Patient and Clinician Risk in Videofluoroscopic Swallowing Studies?](#)”. Some final thoughts on evaluating the risk/benefit ratio along with conclusions on recommended best practices for VFSS are presented in section “[Conclusions on Best Practices for Balancing Risk and Benefit in VFSS](#)”.

Ionizing Radiation and Dose

Assessing benefit and risk in medical X-Ray imaging requires the clinician to have a basic understanding of ionizing radiation, how it interacts with matter, and how it contributes to both radiation dose and image quality.

What is Ionizing Radiation?

Radiation is energy that is emitted by a source and travels through space (vacuum) at the speed of light. It can penetrate a variety of materials, with the depth to which it penetrates being determined by the nature of the radiation as well as the composition of the materials. Radiation has both an electric field and a magnetic field associated with it, and has wave-like properties, so that radiation is often characterized as electromagnetic waves. Radiation can also be described as particles—small packets of energy. The ability to characterize radiation as waves or particles, or both, leads to a seeming paradox called wave-particle duality.

There is a range, or spectrum, of types of radiation. This spectrum includes light (infrared, visible, ultraviolet), radio

waves (AM, FM, and others), microwaves, and X-Rays. The different types of radiation are characterized by three quantities that are mathematically related—wavelength, frequency, and energy. Because radiation travels at c , the speed of light, if you know of one of these quantities, you can easily calculate the others. We generally describe light in terms of wavelength, radio waves in terms of frequency, and X-Rays in terms of energy. All three descriptions are equivalent though.

X-Rays are a form of high-energy radiation that can penetrate human tissue. X-Rays, and their use in medical imaging, were discovered by Wilhelm Röntgen in 1895 [10]. Within months, they were being used on different continents for medical imaging, illustrating the rapid uptake of this revolutionary technology [11].

X-Ray energies are characterized using units called electron-volts (eV). One electron-volt is the energy acquired by a single electron (e^-) accelerated from rest by a potential difference of one volt (V) in vacuum. The energy range of X-Rays is generally taken to be from roughly 100 eV up to millions of eV, or mega-electron-volts (MeV). In diagnostic imaging, the range of X-Ray energies used is in the tens to hundreds of thousands of electron-volts, typically from 20,000 eV, or 20 kilo-electron-volts (keV), up to 150,000 eV, or 150 keV.

Ionizing radiation is radiation that has sufficient energy to remove an electron from its orbit in an atom or molecule, thus *ionizing* that atom or molecule or giving it a net negative electric charge. The threshold for ionization varies with materials, but a generally accepted threshold is 10 eV. X-Rays are thus considered to be ionizing across their entire energy range.

Instead of thinking about X-Rays in terms of waves, it is often convenient for explanation and visualization purposes to picture them as particles. Each X-Ray is considered as a tiny packet of energy, a *photon*. This description allows us to visualize interactions between X-Ray photons and other atomic and subatomic entities, such as atoms and electrons, using visual analogies such as billiard balls colliding and scattering. These analogies are not accurate representations of the underlying actual physics, but are convenient for descriptive purposes.

How Do X-Rays Interact with Matter?

X-Ray photons can either pass through matter without interacting or undergo some interaction within. There are two main types of interactions, absorption and scattering. Absorption means that the photon encounters an atom or molecule and is completely absorbed. Scattering means that the photon encounters an atom or molecule and is redirected on a new path, similar to billiard balls colliding and going in new directions. Both types of interactions result in

energy being deposited. This deposited energy may result in biological damage. Readers interested in learning about specific damage mechanisms arising in diagnostic X-Ray imaging should consult Hall and Giaccia, *Radiobiology for the Radiologist*, 8th Edition [12].

In medical X-Ray imaging, a controlled beam of X-Ray photons is generated by an X-Ray tube and directed at a detector. The photons travel through tissue, i.e., the patient, with some photons passing through undisturbed, and the remainder being absorbed or scattered. The removal of X-Ray photons from the beam by absorption or scattering is called *attenuation*. Photons that pass through the patient, along with photons scattered in the direction of the detector, are collected by the detector and form an image.

Human tissue is highly attenuating. This means that only a small fraction of the X-Ray beam that travels toward the patient actually reaches the detector where the X-Ray image is created. A usual rule of thumb is that roughly 99% of X-Ray photons are scattered or absorbed, with only 1% reaching the detector.

What is the Significance of Scatter?

Patient dose is the result of energy deposition within the patient due to scattering and absorption. Some scattered X-Rays escape the patient. Scattered X-Rays that reach clinical staff are the source of staff dose. Because staff receive no diagnostic benefit from this radiation, the goal is to reduce staff dose to as close to zero as possible.

X-Ray photons scatter in all directions. Just as the X-Ray tube is the source of the X-Ray beam, the area over which the X-Ray photons enter the patient can roughly be considered as the source of scatter, as shown in Fig. 1.

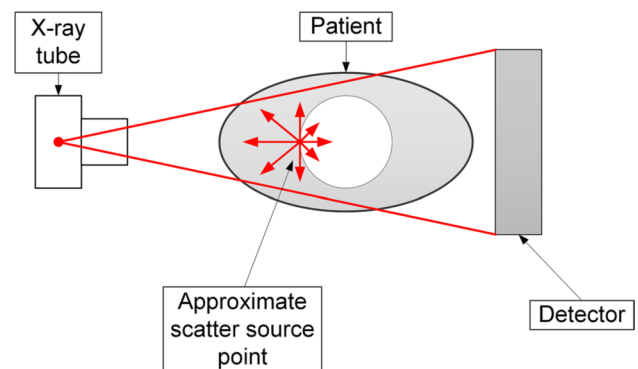


Fig. 1 The point where the central axis of the X-ray beam enters the patient can, very approximately, be treated as the source of scattered X-rays

What are the Risks Associated with Ionizing Radiation?

There are two categories of risks associated with ionizing radiation: deterministic and stochastic. Deterministic means that a phenomenon has a clear cause and effect relationship—if A occurs, then the result will be B. Stochastic means that a phenomenon is essentially random—if A occurs, then B may or may not occur, with some probability C.

Deterministic effects of ionizing radiation include skin effects such as temporary or lasting redness (erythema), hair loss (epilation), or cataracts [13]. Deterministic effects of ionizing radiation have a threshold dose. Below this threshold, the effect is highly unlikely to occur. Above this threshold, the effect is very likely to occur. The specific value of the threshold for a given effect and exposure will vary from person to person, depending on genetics and other factors. Relevant threshold values are discussed in the following section.

Stochastic effects of ionizing radiation include the possibility of cancer induction (carcinogenesis) or heritable genetic impacts [14]. The risk of cancer is the primary concern, as there has been no demonstrated evidence of heritable effects in humans [15]. The cancer risk for a given individual arising from a given X-Ray exam cannot be estimated reliably. We can, however, come up with a generic estimate of lifetime cancer risk from a given exposure using effective dose. The connection between stochastic risk and radiation dose is discussed in the following section.

What is Radiation Dose?

As X-Ray photons pass through matter, some fraction of the photons will interact with the matter, either being absorbed or scattered. Absorption and scattering events both deposit energy in the matter. The amount of energy deposited by X-Ray photons in a given volume of matter, per unit mass of that matter, is known as *absorbed dose*, which can be quantified in Joules per kilogram (J/kg). The Gray (Gy) is a specific unit used when reporting absorbed dose: one Gray is equal to one Joule of energy deposited in one kilogram of matter. If we consider the absorbed dose in a given tissue or organ, we may speak of *organ dose*. This is typically an average value of absorbed dose over the whole organ, but when we speak of dose to the skin, we are more often interested in the maximum value, the *peak skin dose*.

One Joule is not a large amount of energy. A 60 Watt (W) lightbulb uses 60 Joules of energy every second. One Joule is also about how much energy is required to lift an apple from the floor to a tabletop. One Joule distributed uniformly throughout one kilogram of tissue results in an absorbed dose of one Gray, which is a tremendous amount of dose.

In diagnostic X-Ray imaging, we typically speak of doses to various organs, including the skin, in terms of milliGray (mGy), or thousandths of a Gray.

The most common usage of absorbed dose in clinical practice is to estimate the likelihood of deterministic effects, such as skin injury. The threshold for the mildest deterministic effects, such as transient erythema, or temporary skin redness, is between 2 and 3 Gray peak skin dose [13]. This threshold is far, far above the skin dose levels encountered in VFSS, in which peak skin dose levels would be on the order of a few milliGray [16]. Therefore, we will not consider deterministic effects further in this review.

Estimating the absorbed dose for each organ and tissue exposed during an X-Ray procedure is very challenging. Going on to estimate the resulting stochastic risks arising from the absorbed doses for a specific patient is almost impossible, as there are a host of individual contributing factors, such as genetic sensitivity to radiation, lifestyle factors, etc., to consider. In order to assess and compare stochastic risk from radiation dose in diagnostic imaging, we instead use a quantity called *effective dose*.

Effective dose is a calculated quantity that attempts to characterize the overall stochastic risk arising from a given X-Ray procedure. The effective dose calculation accounts for the type of radiation used and the differing sensitivities of the various organs and tissues exposed [14, 17]. Effective dose is only defined for a theoretical reference patient model, which contains anatomy from both genders. It is not appropriate to use effective dose when talking about the radiation exposure of a specific individual [17, 18]. It is, however, very convenient when comparing different types of X-Ray exams, as it provides a single number indicative of relative risk.

The units of effective dose are Sieverts (Sv), with patient effective dose for most X-Ray imaging exams falling in the range from 0.1 to 10 milliSieverts (mSv) [19]. The lifetime risk of cancer from a single exposure for an adult is, very approximately, 5% per Sievert of effective dose [14]. The uncertainties on this estimate are very large, and it should never be applied to an individual [17, 18]. It can, however, give an indication of relative risk for various types of X-Ray exams and procedures.

What is the Effect of Cumulative Radiation Exposure?

Based on our current understanding of radiation biology at diagnostic dose levels, the risk of carcinogenesis for each X-Ray exam is additive and independent [14]. In fact, cellular repair will occur in between exams, and there is no increase in sensitivity with accumulated radiation dose [20]. This means that there is no limit at which cumulative radiation dose reaches a level beyond which further exams are not

allowed due to increased risk [20]. A patient who has had 10 identical CT scans is at a higher risk (although still exceedingly small) than if they only had one, but the amount of risk is the same for each exam. If an 11th exam was requested and is medically justified, the previous 10 CT scans should not factor into the decision making as far as radiation risk is concerned. The previous scans would only be relevant if they could provide the required diagnostic information without performing an 11th scan. Although the above reasoning applies equally to adults and children, we are more conscious of childhood radiation exposure due to both the greater radiosensitivity and longer expected future lifespan of children relative to adults.

What is the Difference Between Dose and Dose Rate?

Dose generally refers to patient or staff dose and is usually taken to indicate the cumulative radiation dose to which the patient or staff member was exposed over the course of an exam, or over some defined measurement period. In a fluoroscopic examination, the rate at which dose is accumulated will vary with time, depending on how the system radiation output varies in response to parameter adjustments, patient movement, and so on. The instantaneous rate of dose accumulation is called the *dose rate*, and is measured in dose per unit time, typically milliGray per second (mGy/s) or milliGray per minute (mGy/m). The dose rate reported by the system is not the same as the rate at which dose is accumulated by the patient – this will be discussed in a subsequent section.

How Do We Assess Radiation Risk to Patients and Staff

In order to compare patient risk for procedures such as VFSS to other X-Ray exams, we can use effective dose, as estimated for our hypothetical reference patient. There are published tables of effective dose values for common X-Ray exams [19] but unfortunately VFSS has not yet been included. Typical effective dose values for VFSS are given in section “[How do we minimize patient and clinician risk in videofluoroscopic swallowing studies?](#)”.

We can also compare effective dose from a given exam to annual background radiation dose. This arises from cosmic and terrestrial radiation sources, and everyone is exposed to such radiation. Levels vary worldwide, with a global average of 2.4 mSv per year [21].

We can compare radiation dose for an individual exam to average values for a facility using cumulative air kerma or dose-area product. These terms are discussed further in the section on fluoroscopy. These values are not indicative of specific individual risk but may be helpful for identifying

and labeling any outliers relative to normal trends, such as particularly difficult cases.

Staff occupational dose from scattered radiation is assessed using a personal dosimeter. Dosimeter readings are typically collected quarterly and represent cumulative effective dose for the wearing period. Ideally, staff occupational dose will be close to zero. Further details on dosimeters are given in the section on radiation protection.

Occupationally exposed staff have legislated exposure limits, with the limit in the United States being 50 mSv per year [22]. There are no legislated limits on patient radiation exposure, so long as all such exposure is medically justified.

Image Quality

The diagnostic benefit obtained from an X-Ray imaging exam is determined by the quality of the images acquired. The most important determinant of image quality is whether the clinician can see what they need to see to make an accurate diagnosis. This holds for both single, static images, as well as sequences of images, such as those acquired using fluoroscopy.

In order to assess image quality in a more objective, quantifiable way, we use a number of quality metrics. In assessing single images, whether standalone images or individual images in a sequence, three interrelated metrics are used: contrast, noise, and spatial resolution. When assessing image sequences and how well motion is represented, we add another: temporal resolution. In this section, we will briefly define all of these metrics, considering both static and dynamic image quality holistically. The significance and application of these metrics in VFSS will be discussed in depth in section “[How can we maximize diagnostic benefit in VFSS?](#)”.

What Does an X-Ray Image Represent?

A digital X-Ray image is a composite of small squares or rectangles, called picture elements, or *pixels*. Each pixel is assigned a gray level, from a range of shades of gray between black and white. The gray level assigned to a given pixel reflects how many X-Ray photons reached the detector at that location. In film-based X-Ray imaging, the film was darker at points where more X-Rays were detected, and lighter where there were fewer. Bone, which resulted in greater attenuation, thus, appeared lighter, while soft tissue appeared darker and air was black. Digital X-Ray systems generally follow this convention. However, the image gray-scale can be inverted, so that air appears white and bone or barium appears dark—this is common in VFSS. A simplified illustration of a pixelated image with varying gray levels is shown in Fig. 2.

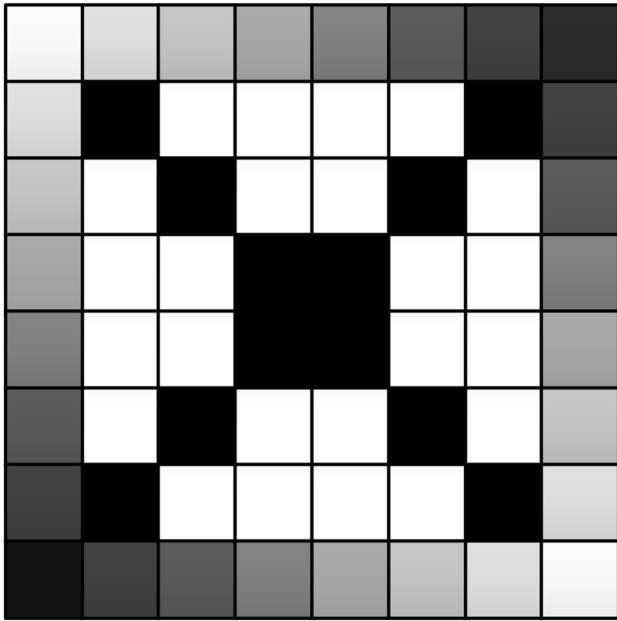


Fig. 2 Simplified 8×8 representation of a pixelated grayscale image, showing varying gray levels

What is Contrast?

Contrast refers to the ability to distinguish an object against a uniform background, or to distinguish individual structures. Contrast in X-Ray imaging arises from differences in attenuation properties between different tissues and is a function of their chemical composition as well as the energy of the X-Ray photons interacting with them. Substances with higher density and larger atomic number produce greater attenuation. The difference in attenuation between strong attenuators such as bone (or other dense materials), and weaker attenuators such as soft tissue, creates contrast between them. As noted above, contrast appears as a difference in pixel gray levels, so that bone appears dark and soft tissue appears lighter (using the inverted grayscale typical in VFSS).

How Does Barium Enhance Contrast?

Pure barium has a density of 3.5 g per cubic centimeter (g/cm^3) and an atomic number of 56. Soft tissue has a density of roughly $1.0 \text{ g}/\text{cm}^3$ and an effective atomic number of roughly 7. Barium is highly attenuating relative to soft tissue, so that X-Ray images display strong contrast between the two. The energy of the radiation beam, adjusted using the tube voltage (to be discussed later), is usually tailored

to maximize this contrast in barium studies. Readers should note that use of the word “density” above is not referring to the concentration of barium in a suspension, but rather to the physical density of the element barium.

What is Noise?

Image noise appears as pixel-to-pixel variations in gray level in areas that should be uniform. A noisy image has a distinct grainy or salt and pepper appearance. Noise makes it difficult to see small, low-contrast structures. Image noise is directly related to the amount of radiation used to form the image, and thus to dose. The more radiation used to form a given image, the less noisy the image will be. It is thus important to recognize whether an image, or image sequence, is too noisy to be diagnostically useful. If so, it may be appropriate to use more radiation in order to meet diagnostic objectives. The ideal is to use just enough radiation that the image is diagnostic, and no more.

When we speak about how much radiation is used to form an image, we mean the number of X-Ray photons that reach the detector to form an image. A larger number of photons reaching the detector means less image noise. Given that roughly 1% of the photons entering the patient actually reach the detector, an increase in the number of photons forming an image means an increase in the number of photons with which the patient is irradiated, and thus an increase in patient dose. This is the crux of the image quality and dose trade-off – we want just enough photons to reach the detector for the resultant image to be diagnostic, and no more, as this represents the optimal balance between dose and image quality, risk and benefit.

What is Spatial Resolution?

Spatial resolution refers to the ability to resolve small or closely spaced objects. Spatial resolution is primarily determined by the characteristics of the detector used in the fluoroscopy system. Magnification modes, which will be discussed later, allow for improved visualization of small and closely spaced objects in fluoroscopic images.

The ideal fluoroscopic image, or image sequence, is one where contrast and spatial resolution are adequate to discriminate structures of interest, without being compromised by noise to the point of being nondiagnostic.

What is Temporal Resolution?

Temporal resolution describes how well an image sequence represents motion. Poor temporal resolution means that motion is poorly represented. This could manifest in several ways. Moving structures may be blurred in individual images, resulting in an image sequence that is also blurred,

compromising visibility of structures of interest. The interval between images may be such that motion that should be smooth and continuous appears choppy and disjointed during image sequence playback. Finally, gaps between images may result in key elements of a motion sequence being missed. Adequate temporal resolution is critical for assessment of swallowing function [23].

The specific significance of image quality measures in VFSS, and how adequate image quality is best achieved, is discussed in section “[How can we maximize diagnostic benefit in VFSS?](#)”.

Fluoroscopy and Fluoroscopic Systems

In order to obtain an accurate diagnostic VFSS, with an appropriate radiation dose for the patient and minimum radiation dose to staff, the clinician should be familiar with the basic architecture and operation of the fluoroscopy system in use. A block diagram showing the essential components of a fluoroscopy system is shown in Fig. 3.

What Types of Fluoroscopy Systems are Used for VFSS?

Fluoroscopy systems come in several different configurations, with each configuration appropriate for different types of exams and procedures. In general, one can find examples of each configuration in use for VFSS. The determining factor for use of a given configuration for VFSS is whether the system can be oriented with the X-Ray tube and detector in a horizontal plane so that the patient can be seated and upright.

The most significant aspects of fluoroscopy system architecture that the clinician needs to be aware of are *the location of the X-Ray tube and detector*. *Under-table systems* have the X-Ray tube positioned under the patient table, surrounded by lead shielding, with the detector suspended above the table,

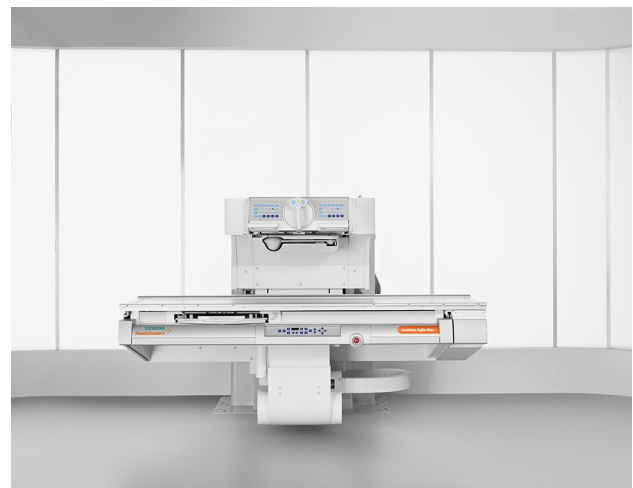


Fig. 4 Fluoroscopy system with an under-table X-Ray tube. © 2018 Siemens Healthcare GmbH. All Rights Reserved. Product photo provided courtesy of Siemens Healthcare GmbH

as shown in Fig. 4. *Over-table systems* reverse this arrangement, with the detector located immediately under the table and the X-Ray tube suspended above, as shown in Fig. 5. Under-table and over-table systems suitable for VFSS allow the bed to rotate from the standard horizontal position to a vertical position, so that the X-Ray tube and detector can be positioned at head height for a seated patient.

In a *C-arm* system, the X-Ray tube and detector are positioned at the ends of a C-shaped arm, which can be raised, lowered, and rotated as needed. Figure 6 shows a *stationary C-arm*, which has a floor or ceiling mount and an integrated patient table. Figure 7 shows a *mobile C-arm* with a wheeled mount that can be positioned as desired. Either type of C-arm system can be used for VFSS. Research from other imaging disciplines suggests that C-arms are associated with lower radiation exposure than fixed systems with tables [24, 25].

The locations of the X-Ray tube and detector are not always immediately visually obvious. Some fluoroscopy

Fig. 3 Simplified block diagram of a fluoroscopy system, showing key components

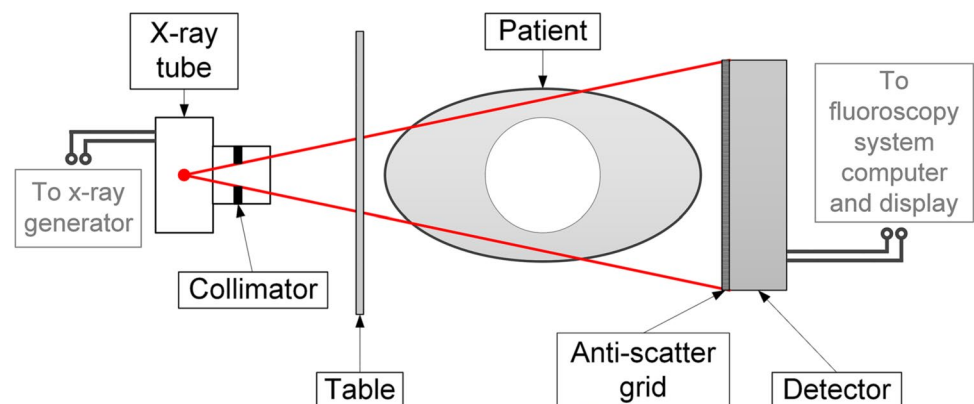


Fig. 5 Fluoroscopy system with an over-table X-Ray tube. © 2018 Siemens Healthcare GmbH. All Rights Reserved. Product photo provided courtesy of Siemens Healthcare GmbH

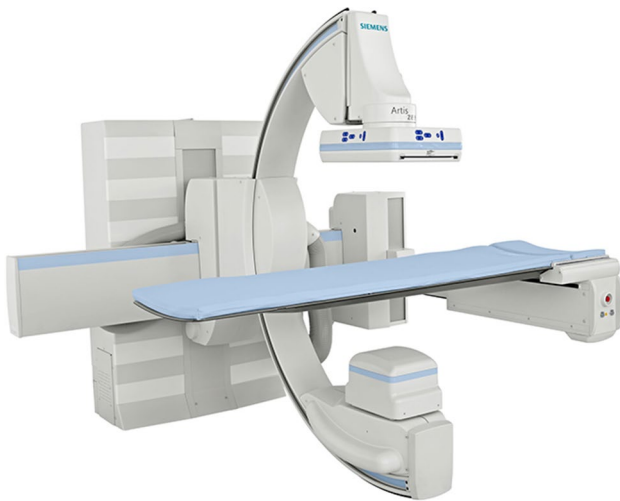


Fig. 6 Stationary C-arm fluoroscopy system with integrated table. © 2018 Siemens Healthcare GmbH. All Rights Reserved. Product photo provided courtesy of Siemens Healthcare GmbH

Fig. 7 Mobile C-arm fluoroscopy system. © 2018 Siemens Healthcare GmbH. All Rights Reserved. Product photo provided courtesy of Siemens Healthcare GmbH



systems are designed with a piece of equipment called an image intensifier, which is part of the detector. Image intensifiers typically have cylindrical housings and may be mistaken for the X-Ray tube. If in doubt, clinicians should ask radiology staff to clearly identify the location of both tube and detector.

Knowledge of where the X-Ray tube and detector are located will inform two key aspects of patient and staff radiation protection—where the patient should be positioned and where the clinician should stand. These aspects will be discussed in subsequent sections. The key takeaway about system configurations is: *know where the tube and detector are!*

What are Image Intensifiers and Flat Panel Detectors?

The two detector technologies in current use in fluoroscopy are image intensifiers and flat panel detectors. Image intensifiers are the older technology and first gained prominence in

the 1950's [26]. An image intensifier (II) converts a pattern of X-Rays into a visible light image, which is then captured by a camera. Over time, camera technology has evolved, but fluoroscopy systems using image intensifiers are still in use. A flat panel detector (FPD) is an integrated system that does not require a camera but performs the same function – converting a pattern of X-Rays into a visible light image that can be captured. Both types of detectors produce digital images that can be stored and manipulated on a computer and transmitted over a computer network. Although the technologies used in image intensifiers and flat panel detectors are quite different, their functional use is essentially the same. Relevant operational differences between systems using image intensifiers and flat panel detectors are discussed in subsequent sections. In cases where the distinction is irrelevant, we will simply refer to the detector.

What are the Key Operating Parameters of the Fluoroscopy System?

The essential function of the fluoroscopy system controls is to allow the user to adjust the quantity, energy, and lateral extent of photons in the X-Ray beam, along with the image acquisition parameters of the detector. The goal of adjusting the controls for a given exam is to get enough photons to the detector to form a diagnostically useful image. For a given image, there will be an optimal number of photons reaching the detector that represents the best trade-off between image quality and dose.

In the following sections, we will define and discuss the following controllable parameters of fluoroscopic systems:

- Frame rate,
- Pulse rate,
- Acquisition modes,
- Dose modes,
- Magnification,
- Collimation
- Anti-scatter grid,
- Tube potential (kVp), tube current (mA) and filtration.

We will also discuss the radiation dose metrics commonly used in fluoroscopy, and how they are displayed and recorded, the significance of fluoroscopy time and the five-minute buzzer, and the impact of inserting metallic objects into the X-Ray beam. Finally, we will briefly touch on how fluoroscopic image sequences are captured and recorded for viewing as video. The specific significance of these operating parameters and associated issues in VFSS will be discussed in sections “[How can we maximize diagnostic benefit in VFSS?](#)” and “[How do we minimize patient and clinician risk in videofluoroscopic swallowing studies?](#)”

What is the Frame Rate?

A *frame* is a single, unique image in a sequence of images. Capturing and viewing a time sequence of frames allows us to visualize motion, as in a movie. The acquisition of a single frame is similar to capturing a single image using a still camera, whether the still camera is analog and uses film or digital and uses a digital image sensor. The frame, just like a still image, will be acquired over a certain finite period of time, which could be called the exposure time or frame integration time. This would be analogous to the time during which the shutter is open in a still camera. The number of distinct, unique frames captured or displayed per second is called the *frame rate*, which may be specified in units of frames per second (fps) or, equivalently, in Hertz (Hz).

Before the transition to digital technology, which began in the late 1970's [27], fluoroscopic images were captured using analog video cameras very similar to those used for broadcast television (TV). An image intensifier converted X-Ray patterns into visible light images, which were then captured by the video camera. Television broadcast standards based on available technology used a frame rate of 30 fps in North America (25 fps in Europe) for both capture and display of images, and this also became the de facto standard frame rate in fluoroscopy [28].

With the introduction of digital imaging technology, analog video cameras were replaced with digital systems, starting with charge-coupled devices (CCD's) [26]. Flat panel detectors began to appear in the early 2000's [29]. As camera and detector technology evolved, a range of fluoroscopic frame rates became available. Initially, the most common frame rates in fluoroscopy In North America were 30, 15, and 7.5 fps (25, 12.5 and 6 fps in Europe). The flat panel detectors used in modern fluoroscopy systems allow for tremendous variability in frame rate, from as few as 1 fps up to 30 or more fps.

We apply the term frame rate to both the capture and display of image sequences. While the rate at which fluoroscopic images are captured has evolved from the original 30 fps to the currently available wide range, the default frame rate for video playback is still 30 fps, the same as the original broadcast TV standard.

What is the X-Ray Pulse Rate?

Early fluoroscopy systems used continuous fluoroscopy. We can think of the X-Ray beam as having ON and OFF states, with continuous fluoroscopy meaning that the beam is always ON. We can similarly think of the fluoroscopy system detector as having ON and OFF states, where ON corresponds to the exposure time for a given frame, and OFF corresponds to any pause between frames. Continuous

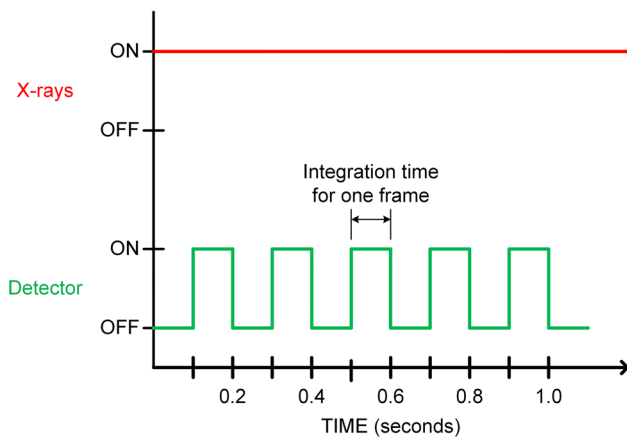


Fig. 8 Continuous fluoroscopy (X-Ray beam on continuously) with a hypothetical detector frame rate of 5 frames per second, showing integration time for a single frame

fluoroscopy with a hypothetical detector frame rate of 5 fps is shown graphically in Fig. 8.

As fluoroscopic technology evolved, several issues with the frame rate became apparent. First, that if the motion being observed was not rapid, a lower frame rate might still be diagnostically sufficient [30]. Following from this, if a lower frame rate was used, the X-Ray beam only needed to be ON intermittently, during the exposure time of each frame, thus reducing patient and staff dose [30]. This is illustrated in Fig. 9, where continuous fluoroscopy with a hypothetical frame rate of 5 fps shows the resulting unnecessary patient dose. Further, it was found that, depending on the type of motion being imaged, the length of the exposure time for each frame, along with the length of the pause between frames, strongly influenced temporal resolution, or

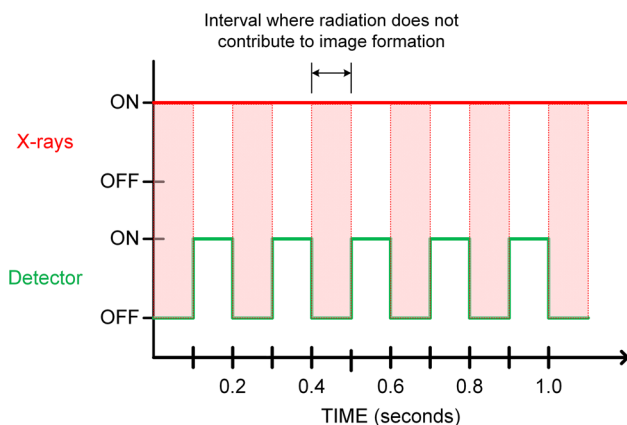


Fig. 9 Continuous fluoroscopy (X-Ray beam on continuously) with a hypothetical detector frame rate of 5 frames per second, illustrating radiation that does not contribute to image formation, thus creating unnecessary patient dose

how smoothly and accurately such motion would appear in the fluoroscopic image sequence [31].

Improvements in X-Ray tubes and generators were made, such that the X-Ray beam could be rapidly and reliably cycled on and off, in synchronization with the image capture cycle of the detector. This synchronization ensured that only radiation that was contributing to image formation was used, reducing patient dose. By fine-tuning the frame exposure time and interval between frames, and synchronizing the radiation beam with this timing, image capture for different types of motion could also be optimized. The interval over which the X-Ray beam is ON is a *pulse*, and the number of X-Ray pulses emitted per second is the X-Ray pulse rate, specified in pulses per second (pps), or equivalently in Hertz (Hz). A pulse rate of 5 pps and a corresponding frame rate of 5 fps are shown in Fig. 10.

Are the X-Ray Pulse Rate and the Frame Rate Always the Same?

During a fluoroscopic exam, a sequence of individual images (frames) will be captured by the fluoroscopy system detector, whether it uses an image intensifier or a flat panel detector. If pulsed fluoroscopy is being used, then selecting a specific X-Ray pulse rate (e.g., 30 pps) should result in a matching frame rate (e.g., 30 fps) of images captured by the detector. If continuous fluoroscopy is being used, then the frame rate may either be selectable or have some default value.

Most fluoroscopy systems provide options for image processing, to enhance visibility of image features and reduce noise. One form of image processing used to reduce image noise is called temporal averaging. In temporal averaging, two or more consecutive images are averaged together, resulting in a composite image with less noise than the individual original images. This averaging process results in a processed image sequence with fewer unique images

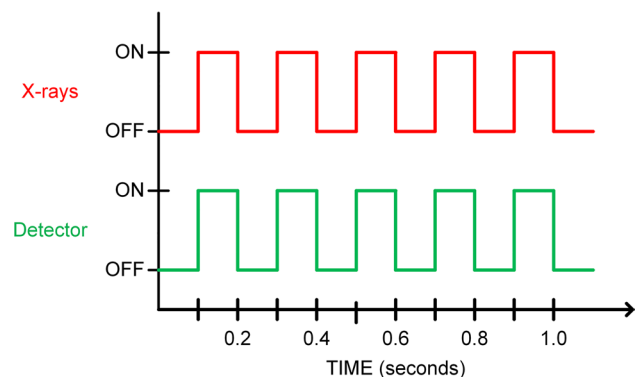


Fig. 10 Pulsed fluoroscopy at 5 pulses per second and a detector frame rate of 5 frames per second, showing radiation pulses synchronized with detector frame integration periods

than in the original sequence, however. For example, say that the fluoroscopy system detector acquires images for 1 s at 30 fps, resulting in 30 distinct frames. Temporal averaging is applied, with pairs of consecutive frames being averaged together, creating a new sequence with only 15 distinct frames. Because the image playback standard is typically 30 fps, it is likely that the output image sequence after image processing will still contain 30 frames, but 15 of those frames will be duplicates. This new sequence has less noise than the sequence originally captured, but now has only half of the temporal resolution of the original sequence and could be said to have an effective frame rate, in terms of unique images captured per second, of only 15 fps, even though 30 frames are displayed per second during review. Temporal averaging over 6 frames of such a sequence is illustrated in Fig. 11.

In modern fluoroscopy practice, a sequence of acquired fluoroscopic images is often called a fluoroscopic loop, or *fluoro loop* [32]. A fluoro loop can be stored on the fluoroscopy system hard drive and reviewed on the fluoroscopy system display. The fluoro loop will include the effects of any image processing that has been applied. The true frame rate of the fluoro loop thus may or may not match the selected X-Ray pulse rate, depending on whether processing such as temporal averaging has been applied. It should be noted that fluoro loops are generally limited to a maximum number of frames, with images at the start of the loop being deleted to make room for new images if the limit is exceeded.

How Does Image Recording for Offline Review Affect the Frame Rate?

In addition to being saved on the hard drive of the fluoroscopy system itself, a fluoro loop may also be stored externally for subsequent offline review. This ensures that the

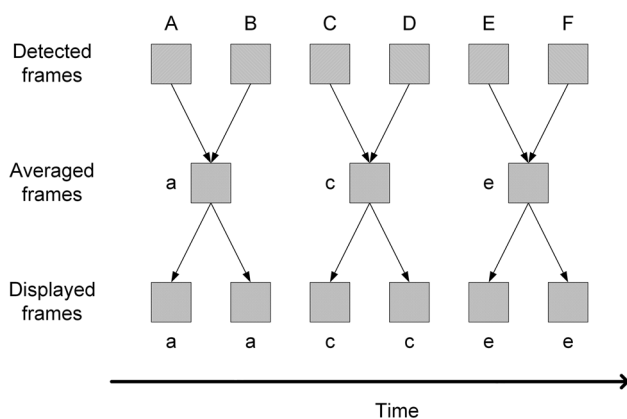


Fig. 11 Temporal averaging, showing 6 detected frames, and pairs of detected frames averaged to create 3 averaged frames. Averaged frames are duplicated to maintain expected display frame rate

entire study is captured even if loop limits are exceeded. The fluoroscopic images can be recorded to external media, such as to DVD using a DVD writer, or to an external workstation incorporating video capture hardware and software. The complete fluoroscopy exam, or portions of it, could also be sent to a local review station, a hospital server, or to a Picture Archiving and Communications System (PACS) network, for storage and review.

Ideally, the image quality of a fluoroscopic sequence reviewed offline should be exactly the same as that shown on the fluoroscopy system display, with no loss of quality occurring during the processes of recording, storage, transmission, or playback. In reality, it is possible for image degradation to occur in each of these processes. For example, recording the fluoroscopic image sequence in a commercial video format such as MPEG on a DVD might result in downsampling (loss of resolution), compression (which may affect resolution and contrast), or frame rate changes. If local PACS administration has imposed limits on the length of studies that may be archived on the PACS system, there may also be a loss of frames when studies are sent to PACS.

The clinician should thus be aware of potential quality losses in the image recording and playback chain that may influence or even compromise diagnostic benefit, as this may affect risk/benefit decisions. This topic is discussed further in section [How can we maximize diagnostic benefit in VFSS?](#)

Does Halving the X-Ray Pulse Rate Also Halve the Dose Rate?

The answer to this question is: it depends. Perceived noise may increase with lower pulse rates, so with some systems, the amount of radiation used per pulse (and thus per image) is increased to compensate. Halving the pulse rate thus leads to a dose reduction of roughly 30% [33, 34]. The actual amount of dose reduction with a decrease in pulse rate will vary from system to system, however [34]. The true degree of dose reduction with a decrease in pulse rate can be determined from equipment specifications provided by the vendor, or by testing by a medical physicist.

What are Acquisition Modes?

In the early days of fluoroscopy, the visible light images produced by the image intensifier were captured by a TV camera, and displayed in real time on a TV monitor – essentially, closed-circuit X-Ray TV [35]. Initially, the images from the TV camera were not recorded in any way. In order to create a recording that could be played back at a later time, a movie camera was used to capture images from the image intensifier on film. This led to the use of the term “cine”

for such recordings. Still film images were also acquired, with direct X-Ray film images (radiographs) not using the image intensifier being called “spot films” and still film images of the image intensifier output referred to as “photo-spot films” [35]. In order to have adequate image quality, cine sequences, along with spot and photospot films, were acquired with much larger amounts of radiation than standard live fluoroscopic images displayed on the TV monitor. This meant that acquiring cine, spot, and photospot films resulted in increased patient dose.

The transition to digital detector technology meant that fluoroscopic images could be recorded and stored without the use of a film camera. Direct digital capture of these images also did not require the elevated dose levels necessitated by film systems. Thus, standard fluoroscopic image sequences, or fluoro loops, can be captured and stored on the fluoroscopy system hard drive for viewing, transmission, or archiving.

Other image capture modes aside from fluoro loops are available with modern digital fluoroscopy systems. The terms cine and spot have persisted in the form of digital cine or digital spot. Digital cine is a higher dose, higher quality mode of capturing an image sequence relative to standard fluoroscopy, while a digital spot is a digital radiograph, again acquired with a much higher dose than a single fluoroscopic frame in order to provide higher image quality.

Digital cine is typically referred to as “acquisition”, to differentiate it from recording of standard fluoroscopic image sequences or fluoro loops. Guidance documents on best practices in fluoroscopy, such as those published by the American College of Radiology [36] use this terminology. Acquisition modes are not typically used in VFSS. Given the much higher dose levels associated with them, up to 10 times greater [34], their use is discouraged unless clinically necessary. Clinicians should be clear when asking for fluoroscopic frame rates of 30 fps that they are not requesting high-dose acquisition or digital cine modes, but rather standard fluoroscopy (a fluoro loop), although at a higher pulse and frame rate than is used in some other exams.

What are Fluoroscopic Dose Modes and How Should They be Used?

A typical fluoroscopic system will have three or more dose modes. The selection of dose mode governs the number of X-Ray photons emitted per second and should thus more accurately be thought of as dose rate modes. The names and specific behaviors of the different dose modes will vary from vendor to vendor and system to system. A typical arrangement, however, is to have Low, Normal, and High modes.

The Normal dose mode is the default mode and is expected to produce images of diagnostic quality with

reasonable patient dose. The Low dose mode typically gives a dose rate half that of Normal mode and would be suitable for situations in which noisier images can be tolerated, with significant reduction in patient dose. The High dose mode would typically give a dose rate double that of Normal mode and would be used where higher quality images with less noise are required, at the expense of significantly increased patient dose [37].

Individual vendors and systems may have different labels for the various dose modes than those used above. The clinician should consult with radiology staff to understand the available options. The takeaway message regarding dose modes is to use the lowest dose rate mode which provides sufficiently good (i.e., sufficiently low noise) images for diagnostic purposes, and to limit the use of higher dose rate modes to those situations when they are absolutely required.

Clinicians should also be aware that changing the dose mode may trigger a change in fluoroscopic pulse rate. The technical specifications for the specific fluoroscopy system in use should be reviewed to understand its operating characteristics.

What are Magnification Modes and How Should They be Used?

Magnification in fluoroscopy means reducing the size of the field of view (FOV) – that is, the area being imaged – in order to better visualize small structures. A fluoroscopy system will typically have three or more magnification modes, associated with progressively smaller fields of view. As the field of view becomes smaller, the level of magnification increases with a corresponding improvement in the ability to resolve fine detail.

There is, however, a price to be paid for the use of increasing levels of magnification, and that price is increased dose. The mechanism for this dose increase varies between image intensifier (II) systems and flat panel detector (FPD) systems. In II systems, the relationship between FOV size and dose rate roughly follows an inverse square relationship, so that halving the size of the field of view results in the dose rate increasing by a factor of four [26]. The actual increase in dose rate with increasing magnification will vary from system to system, however. In FPD systems, the increase in dose rate with increasing magnification (smaller FOV) is not as large as in II systems, but still represents a significant increase relative to the normal or unmagnified FOV [26]. Use of magnification should thus be restricted to when it is clinically required.

Changing the magnification mode may also trigger a change in fluoroscopic pulse rate. Again, reviewing the technical specifications for the specific fluoroscopy system in use allows the clinician to understand how the system functions as different options are selected.

What is Collimation and How Should it be Adjusted?

Collimation is the process of limiting the lateral extent of the X-Ray beam, using adjustable lead shutters (the collimator) at the front of the X-Ray tube. Ideally, the irradiated area should be as small as possible while meeting diagnostic objectives. General advice on sparing dose is thus to limit the size of the beam to only cover the anatomy of interest. The specific application of collimation in VFSS is discussed in sections [What do we need to see for a good VFSS?](#) and [How important is it that I narrowly collimate?](#).

What is an Anti-Scatter Grid?

An anti-scatter grid is a mechanical structure positioned between the patient and the detector, designed to absorb scattered photons, while allowing unscattered photons through. The benefit of using an anti-scatter grid is improved image contrast, as too high a proportion of scattered photons reaching the detector reduces contrast. Unfortunately, anti-scatter grids, while effective, are not perfect – desirable unscattered photons are absorbed, while undesirable scattered photons pass through. Using an anti-scatter grid has consequences for radiation dose, as the radiation output must be increased to compensate for absorption of unscattered photons when using a grid relative to when it is not used.

Anti-scatter grids are generally used by default, and the grid may or may not be removable. When imaging small patients, such as young children, there is much less scatter than with larger patients. In such cases, it may be possible to remove the grid without compromising the diagnostic quality of the study. Removing the grid results in a significant dose reduction. The pros and cons of removing the grid for a small patient should be carefully discussed with radiology staff. Aspects of anti-scatter grid usage relevant to VFSS are discussed in section [How do we minimize patient and clinician risk in videofluoroscopic swallowing studies?](#).

What About Tube Voltage, Tube Current, and Filtration?

An X-Ray tube produces useful X-Ray photons by accelerating electrons in an applied electric field. The potential difference or applied voltage creating this field is generally in the tens of thousands of volts (V) and is thus expressed in kilovolts (kV). This applied voltage is called the *tube voltage*, and it determines the range of X-Ray photon energies present in the X-Ray beam. The number of X-Ray photons emitted per second by the X-Ray tube is controlled by another parameter, the *tube current*, which is expressed in milliAmperes (mA), or thousandths of an Ampere (A), the standard unit of electrical current.

The tube voltage and tube current together determine the number and energy of photons in the X-Ray beam. X-Ray photons with higher energies are more penetrating and are thus more likely to pass through the patient without interacting and reach the detector. Selecting an appropriate tube voltage in kV and tube current in mA so that sufficient photons reach the detector is thus critical to obtain a diagnostically useful image.

The selection of the most appropriate tube voltage, kV, and tube current, mA, for a given exposure scenario is generally determined automatically. Fluoroscopy systems come with pre-programmed kV and mA progressions, called trajectories, that automatically govern the kV and mA used in response to the object being imaged. As more attenuation is introduced into the X-Ray beam, the kV and mA will be increased to compensate, so that the number of photons reaching the detector is sufficient to maintain diagnostic image quality. Thus, a larger patient will result in higher kV and mA levels than a small patient, so that bariatric patients will require much higher levels than cachectic patients.

Each imaging protocol programmed in the system will have an associated trajectory, and protocols will be identified by anatomy and/or study type. The instantaneous values of tube current and tube voltage are governed by the kV-mA trajectory in use for a given protocol. Changes in tube voltage and tube current occur in response to changes in the attenuation properties of the object being imaged. The control system implementing these changes in kV and mA is called automatic brightness control or automatic dose rate control [34]. The system attempts to maintain a given level of image quality by adjusting the kV and mA dynamically in response to changes in how much the X-Ray beam is being attenuated.

The energy of the X-Ray photons in the beam is also controlled by inserting or removing aluminum or copper filters. Changes in filtration are also generally governed by the system's automatic brightness control or automatic dose rate control and are typically not user selectable.

The clinician is thus not responsible for selecting kV and mA values manually. However, particularly when commencing VFSS with a new piece of equipment, the clinician in consultation with the X-Ray technologist, vendor service engineer, biomedical engineer, or medical physicist, should ensure that an appropriate protocol for VFSS has been specified.

What are Air Kerma (AK) and Dose-Area Product (DAP)?

Kerma stands for kinetic energy released in matter, and air kerma (AK) is essentially radiation dose, energy deposited per unit mass, in air. Because we are unable to directly measure patient dose during a procedure, we instead use a

proxy – a measurement or estimate of radiation output from the X-Ray tube. One form of this proxy measurement is air kerma. The amount of radiation dose in air, or air kerma, is measured or estimated at a specific point along the central axis of the X-Ray beam. During live fluoroscopy, when the foot pedal is depressed, the air kerma rate at this reference point may be displayed on the system console, in units of milliGray per second (mGy/s) or milliGray per minute (mGy/min). A running total of cumulative air kerma may also be displayed in units of milliGray (mGy). When the pedal is released, the cumulative air kerma in milliGray up to that point in the exam will be shown, and when the exam is completed, a total cumulative value will be displayed and logged.

Air kerma is thus a measure of system radiation output and not of dose to a given patient. We can, however, make crude estimates of patient dose for a given exam, using the cumulative air kerma value along with other X-Ray beam parameters. We generally use the terms air kerma and dose interchangeably, as an indication of system radiation output.

A second radiation output metric is also in common usage in fluoroscopy. This is the dose-area product (DAP). As its name suggests, it is the product of dose in air (air kerma) at a given point, multiplied by the cross-sectional area of the radiation beam at this point. The units of dose-area product are thus dose multiplied by area and would have the form milliGray-meter² (mGy-m²) or similar. The units of dose may be Gray (Gy), milliGray (mGy), or microGray (μGy, or millionths of a Gray), while the units of area may be in meters squared (m²) or centimeters squared (cm²). The dose-area product possesses some useful mathematical properties. However, in order to use it to estimate patient dose, one must know both the dose-area product and the radiation field size. In high-dose fluoroscopy environments, such as interventional cardiology, where fluoroscopy time may exceed an hour in complex cases, it has generally been concluded that air kerma is a better predictor of patient dose than dose-area product [38]. In VFSS, where deterministic effects are not a concern, either metric can be used as a rough indicator of relative radiation output, and thus relative patient dose. Kerma-area product (KAP) is an equivalent term to DAP.

Similar to air kerma, dose-area product may be reported during live fluoro as an instantaneous rate, in mGy-m²/s, or as a running total in mGy-m². When the pedal is released and at the end of the exam, total cumulative values in mGy-m² will be shown, with the total for the exam logged. Some systems will display both air kerma and dose-area product, while others will only show one metric.

How are the Dose Metrics Displayed at the Console Useful?

The values of various parameters are shown on the system console during and after a fluoroscopic examination. When the foot pedal is depressed and live fluoroscopy is occurring (radiation is being emitted), the system should show instantaneous values for kV, mA, dose rate (AK rate or DAP rate), and possibly a running total of cumulative dose (cumulative AK or cumulative DAP). When the pedal is released, cumulative dose should be displayed, and when the exam is completed, the cumulative dose in the form of total AK or DAP for the entire procedure should be logged with the patient record.

While cumulative AK or DAP are not directly indicative of patient dose for a given procedure, they provide a useful means of benchmarking practice. Maintaining a log of cumulative dose values across a range of patients over time will allow for basic analysis and trending. For example, if an institution adopts a standardized protocol, one result might be more efficient studies. This should be reflected in a comparison of average cumulative dose values for representative sample groups of patients before and after protocol adoption. Similarly, unusually high or low cumulative doses for individual patients would show up as outliers and may be worthy of investigation. For example, a particularly difficult patient scenario might lead to an unusually high value, even though the increased dose is completely justified.

What About Fluoroscopy Time?

All fluoroscopy systems should display a running total of fluoroscopy time, or the amount of time that radiation is being emitted (pedal is down). This can be a useful benchmark for trending and comparing the average length of time for a complete VFSS. Fluoroscopy time does not generally correlate well with patient dose, however [39, 40].

What is the Significance of the Five-Minute Buzzer?

All fluoroscopy systems will have an audible tone that sounds after a predetermined period of cumulative fluoroscopy, typically five minutes. The requirement for such a timer is mentioned in early U.S. guidance [41] and regulatory documents [42]. There is no special radiobiological risk associated with five minutes of fluoroscopy. The sounding of the five-minute buzzer should thus not be taken as an indication to terminate an exam prematurely. So long as continued fluoroscopy is medically justified – the benefit to the patient outweighs the risk – the buzzer should not be a factor in decision making. It may provide a useful prompt, however, to pause and evaluate whether continuation of the exam is in fact providing diagnostic benefit.

What Happens When Metallic Objects are in the X-Ray Beam?

Metal, having a high density and large atomic number relative to tissue, is highly attenuating, particularly lead. This is why lead is used as shielding. Introducing a metal object in the field of view of the fluoroscopy system will drive the system to use much higher tube voltage and tube current than when only soft tissue and bone are present. This will dramatically increase the dose rate, and thus the rate of accumulation of patient dose, over the period when the metal is present [43]. Metal is also a very good scatterer, and metal in the beam will result in increased levels of scattered radiation [44]. It is thus in the best interests of both patient and staff to keep metal out of the X-Ray beam as much as possible.

Radiation Protection Principles and Practice

The key principles of radiation protection are justification, optimization, and limitation. All medical imaging using ionizing radiation should be clinically justified, in that the expected benefit outweighs the possible risk. All X-Ray imaging protocols should be optimized, so that diagnostic objectives are met while using the minimum necessary radiation. Staff exposure is to be limited as much as possible and should never exceed regulated limits. Note that there is no regulated limit to patient exposure, so long as all exposures are medically justified.

Key radiation practices revolve around time, distance, and shielding. In order to minimize both patient and staff dose, the amount of time the radiation beam is on should be kept to the minimum necessary. As much as possible, staff should distance themselves from the X-Ray tube and the scatter source (the patient). Staff should use available shielding, including personal protective equipment and any other appropriate shielding that does not compromise clinical objectives.

Very useful guidance on best practices for minimizing both patient and staff dose in fluoroscopy is available from various organizations. Some useful examples include the “10 Pearls” posters, published by the IAEA [45, 46] and Appendix B of the ACR–AAPM Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures [36]. This guidance is often generic, however, and should be considered in the context of the objectives of a given procedure. For example, Appendix B of the ACR–AAPM Technical Standard states that “Behaviors that will reduce patient exposure include ... Use of a low fluoroscopic pulse rate...” [36]. This recommendation is intended to be applied only if it does not compromise diagnostic objectives, however.

Where Should the Patient be Positioned Relative to the X-Ray Tube and Detector?

The primary method for reducing patient skin dose is to increase the distance between the source of radiation (the X-Ray tube) and the point where radiation reaches the patient. The patient should be positioned as close to the detector—image intensifier or flat-panel detector—as possible without compromising the exam.

What Personal Protective Equipment is Available?

Standard personal protective equipment used by staff in fluoroscopic suites includes lead aprons, lead thyroid shields, and possibly lead gloves and glasses. Lead aprons and thyroid shields are very effective and will absorb roughly 95% of scattered radiation [47]. Lead gloves and glasses may also be available, their use is discussed subsequently. Mobile shields may be used when they do not impede necessary interactions with the patient. Finally, clinicians should ensure that their personal dosimeter(s) are worn at all times during fluoroscopic procedures, so that their personal exposure can be monitored. Additional aprons may be recommended for use by clinicians who are pregnant. Lead aprons should be inspected annually to ensure that they are free from holes and tears, per your local guidance and regulations.

Where Should I Wear my Dosimeter(s)?

Dosimeters may be worn in different locations on the body. General guidance for dosimeter use in fluoroscopy is to wear them in locations that will capture the dose received by the head (head badge) and the body (body badge). The head badge should be worn outside the lead apron or collar, close to the head or neck of the clinician. The body badge should be worn high on the torso under the lead apron. An additional badge may be recommended for use by clinicians who are pregnant.

In Addition to Personal Protective Equipment, How Should I Protect Myself From Scatter?

In addition to shielding, the key factors in minimizing staff exposure from scattered radiation are time and distance. In order to minimize the amount of time that the X-Ray beam is on, thus minimizing both patient and staff dose, the exam should be done as efficiently as possible. *This does not mean the exam should be rushed or terminated prematurely.* The objective is to meet diagnostic objectives, thus maximizing benefit, while also maintaining risk at an acceptable level.

Radiation intensity decreases in proportion to the square of the distance from the X-Ray source. The source of

scattered radiation is the patient, and the source point can roughly be taken as the center of the radiation beam where it enters the patient. If you are standing 1 m from this source point and take a step back so that you are now 2 m away, the amount of scattered radiation reaching you at 2 m distance will be $\frac{1}{4}$ of that you are exposed to at 1 m distance. Thus, doubling your distance reduces exposure by 75%, so take an additional step back when you can.

Given that the effective source of scatter is on the X-Ray tube side of the patient, you should stand on the side toward the detector, keeping the patient between you and the X-Ray beam. If a mobile shield is available, positioning this shield on the detector side of the patient and stepping behind it when possible will also dramatically reduce staff exposure.

What About Lead Gloves?

Lead gloves may be available, theoretically offering protection to the clinician's hands if they must be inserted into the X-Ray beam. Their use should be very carefully considered, however. Inserting metal into the X-Ray beam has consequences, as the automatic dose rate control will increase kV and mA in response to the presence of a highly attenuating object, thus increasing the X-Ray tube output dose rate. The degree of dose rate increase varies from system to system, but depending on the imaging mode in use, can be substantial [48]. This increase in dose rate means that lead gloves provide minimal dose reduction when hands enter the primary X-Ray beam and may in fact produce a false sense of security [49]. More significantly, the increase in dose rate may result in greatly increased patient dose [48].

Ideally, the clinician's hands should never enter the X-Ray beam. If it is absolutely necessary to do so to achieve clinical goals, the amount of time spent with hands in the beam should be minimized. We cannot offer a firm prescription on whether or not to use lead gloves, but the clinician should be aware that using them will increase patient dose, and that the benefit to staff is likely not significant.

What About Lead Glasses?

In 2011, the International Commission on Radiation Protection [50] released new recommended guidelines for occupational limits on radiation dose to the lens of the eye. The new recommended limit is 20 mSv per year [50]. A large number of studies have been conducted, mostly in interventional radiology and cardiology but also in other disciplines, to evaluate potential staff exposure. The general findings have been that interventional physicians who work close to the patient for the duration of the procedure may approach the new limit, but other staff who stand further away, such as nurses, in general will not (see, for example, Haga et al. 2017 [51]). It is recommended that clinicians who may approach

the occupational radiation dose limits to the lens of the eye wear lead glasses. It is important to note that radiation exposure to clinicians is significantly higher in interventional radiology and cardiology than that associated with VFSS.

What Role Does an Equipment Quality Assurance Program Play?

In order to maintain confidence that both diagnostic benefit and radiation risks are at acceptable levels, it is critical that X-Ray equipment receive testing and maintenance on a regular schedule. An effective quality assurance program for fluoroscopy systems includes regular evaluation of radiation output and image quality against vendor specifications, industry guidelines, and regulatory standards. Equipment should also receive regular preventive maintenance per the vendor's recommendations. Clinicians should ensure that equipment they use is being tested and maintained appropriately.

How can we Maximize Diagnostic Benefit in VFSS?

In the preceding sections, we have provided detailed information regarding radiation, fluoroscopy systems, the settings on those systems, and how these issues can impact image quality and dose (both to the patient and to the clinician). In this section we turn our attention to the application of these factors in obtaining an effective videofluoroscopic swallowing study. Here, optimal diagnostic accuracy requires quality images (which capture the anatomy of interest with adequate contrast and spatial resolution and minimal noise) and a dynamic sequence of images, captured and recorded with temporal resolution that is both adequate to detect brief events of clinical importance and that is properly synchronized with the image source, so that the order of events is not distorted.

What do we Need to See for a Good VFSS?

A comprehensive VFSS examination typically begins with a lateral view of the oropharynx. The field of view is generally described with boundaries of the lips anteriorly, the palate superiorly, the cervical spine posteriorly, and the cervical esophagus inferiorly [2]. Additionally, it is important to ensure that the patient is sitting at a 90-degree angle to the X-Ray tube to avoid image shadows arising from misalignment, for example of the right and left mandible. In order to optimize image quality and minimize unnecessary dose, collimation may be used. Because swallowing is a dynamic activity, and there may be significant motion of the head and upper body in the course of a swallow, the field of view

after applying collimation should be kept large enough to allow for such motion and cover the anatomical region(s) of interest throughout the swallow. The takeaway message is thus to collimate as much as possible, without losing visibility of the structures and anatomical region of interest, bearing in mind the specific requirements for obtaining a successful VFSS.

Although the bolus moves during swallowing, a static view that incorporates the entire oropharynx is preferable to chasing the bolus downwards with a moving field of view. This technique of a static view minimizes image blur due to motion artifacts. Importantly, this also allows clinicians to determine the upstream anatomy and physiology that may contribute or be related to impairments noted later in the swallow. When the examination continues on to examine upper esophageal anatomy and physiology, a static view that encompasses the oropharynx and a larger extent of the esophagus is the typical starting point, with the possibility of then moving the tube lower to provide a view of the lower esophagus. Similarly, when a posterior-anterior view is used, the procedure should capture the oropharynx superiorly and the cervical esophagus down as far as the aortic arch inferiorly.

In addition to seeing anatomical structures of interest, a key consideration in VFSS is ensuring that sufficient radio-paque contrast is used to provide good visualization of the bolus. Optimal barium concentration for oropharyngeal imaging is thought to be in the 20%-40% weight-to-volume (w/v) range [52, 53]. Weight to volume is a measurement of the number of grams of barium sulfate (BaSO_4) per 100 ml of liquid, usually expressed as a %, such that a suspension containing 40 g of barium per 100 ml of liquid would be reported as 40% w/v. Concentrations of 20%-40% w/v are lower than the 60%, 100% or even 250% w/v concentrations that are typically used for esophageal and lower gastrointestinal tract imaging. These higher concentrations are commonly used for “double-contrast” imaging where there is a goal for the barium to leave a coating that outlines the surface of a lumen or cavity (such as the stomach). The goal of using lower barium concentrations in VFSS examinations of the oropharynx is to balance adequate and reliable visibility of the bolus against the coating properties of higher concentration barium, which can be confused for pharyngeal residue [52]. Wherever possible, clinicians should use barium products that have been specifically designed and standardized for use in the oropharynx, such as Bracco’s VaribarTM product line, which provides 40% w/v concentration products in a variety of different consistencies. In situations where Varibar products are not available, clinicians are strongly encouraged to use standard recipes for preparing barium for use in VFSS, such as those described on the Steele Swallowing Lab website (<https://stealeswallowin>

glab.ca/srrl/best-practice/barium-recipes/iddsi-barium-calculator/).

Why are Frame Rate and Temporal Resolution so Critical in VFSS?

As described in section [Fluoroscopy and fluoroscopic systems](#), pulsed fluoroscopy allows for a reduction in radiation dose relative to continuous fluoroscopy. Further dose reduction can also be obtained by using a lower pulse rate. However, the dose saving from pulse rate reduction comes at the expense of losing information in the OFF intervals between pulses. This issue is critical when determining the optimal pulse rate for VFSS. To illustrate this issue, imagine that each pulse of a VFSS performed at 30 pps is represented by a letter of the alphabet. Here we assume that each pulse corresponds to a possible image in the resulting image sequence, or a frame captured at the fluoroscopy system detector. When the pulse rate is reduced to 15 pps, this results in the loss of every second letter in the alphabet stream (or in the sequence of images captured by the detector). Additional letters of the alphabet would be lost with a further reduction to 8 pps. When one sees these recordings on the fluoroscopy system display, the image stream is displayed at the usual video frequency of 30 frames per second, but instead of seeing gaps where the empty frames are located, the preceding frame is copied over to cover the gap. This is illustrated in Fig. 12, where capital letters of the alphabet represent genuine images captured in each frame, black boxes represent gaps in the image stream where no information is captured, and lowercase letters represent frames in the output where genuine information from an earlier frame has been duplicated to cover over the blacked-out gap.

Imagine the impact of this type of information loss when trying to spell the common word “BELT”. Following the example in Fig. 12, the word BELT would appear as “AEKS” if generated at 15 pps and as “AEIQ” at 8 pps. Now imagine that critical information, such as a brief penetration-aspiration event, is visible only on a single frame of the 30 frames that would have been generated at 30 pps, and that this key frame corresponds to letter “B” in the figure. That event would be lost entirely from the image sequence in both the 15 pps and 8 pps examples depicted. This simple analogy illustrates the critical importance of high pulse rates for diagnostic accuracy in videofluoroscopy.

Herein lies the essence of debates regarding pulse rate and frame rate in videofluoroscopy. Guidance documents exhort us to follow the principle of ALARA and to limit unnecessary radiation exposure. However, those same guidance documents remind us that “Decreased fluoroscopic pulse rate... may also influence clinician judgments and findings during the assessment [23].” Swallowing is a dynamic behavior, in

30 pulses/second	What is generated	A B C D E F G H I J K L M N O P Q R S T U
	What you see	A B C D E F G H I J K L M N O P Q R S T U
15 pulses/second	What is generated	A C E G I K M O Q S U
	What you see	A a C c E e G g I i K k M m O o Q q S s U
8 pulses/second	What is generated	A E I M Q U
	What you see	A a a a E e e e I i i i M m m m Q q q q U

Fig. 12 Potential loss of diagnostic information arising from pulse rate reduction, illustrated using letters of the alphabet assigned to each pulse of a VFSS performed at 30 pulses per second. Detected frames are repeated to maintain expected display frame rate

which critical events can unfold during very short intervals of time so that they are visible on only a single frame at a pulse rate of 30 pps [54]. If we reduce pulse rate to the point where we miss these events, we have reduced the pulse rate too far – and the diagnostic accuracy of our videofluoroscopy examinations becomes compromised. Reducing the pulse rate to this extent means that the VFSS examination no longer complies with the ALARA principle, and that the radiation dose delivered to the patient is not medically justified, because it is insufficient to answer the clinical questions at stake. Emphasizing this point, Balter states “Fluoroscopic dose rate and frame rate should be determined by clinical requirements” [55].

What are the Key Swallowing Events that Need to be Captured and How is the Diagnosis Impacted if They are Not?

The duration of the oral and pharyngeal phases of swallowing is conventionally described to span approximately 2 s: 1 s for the oral phase and 1 s for the pharyngeal phase [2]. Within this time interval, a sequence of key events transpires, beginning with transfer of the bolus from the oral cavity to the pharynx, followed by movement of the bolus through the pharynx, during which hyolaryngeal movement and laryngeal vestibule closure (LVC) ensure airway protection, and finally opening of the upper esophageal sphincter to allow bolus entry into the esophagus. Recent reference data in healthy adults suggest that the pharyngeal phase in healthy adults actually lasts only 225 ms, on average (i.e., 7 frames at a frame rate of 30 fps) [5]. In smaller patients, such as children, these events are likely to unfold within even shorter time intervals. However, it is not simply the typical

duration of events that we need to consider when determining whether VFSS temporal resolution is adequate, but also the sequencing of physiological events relative to bolus flow [54, 56]. Thin liquids move fast—and evidence increasingly points to late or mistimed LVC being a key mechanism behind penetration-aspiration [57]. If the temporal resolution of a VFSS is too low, clinicians may miss key details that explain how or why penetration-aspiration occurs. They may also be unable to properly investigate the benefit of compensatory strategies such as the chin-down position, altered bolus consistencies, or cued swallows [58–61].

What Aspects of Image Recording are Critical for an Effective VFSS?

A key feature of VFSS examinations is the fact that they are recorded for later frame-by-frame review by clinicians. Here, it is important for the clinician to understand the temporal resolution settings of the image recording system, to ensure that those recordings do not lose or corrupt information from the original image stream shown on the fluoroscopy system monitor during the exam. Ideally, the frame rate of the recording (i.e., number of frames stored per second) needs to match the number of frames generated per second by the fluoroscopy system. Additionally, the recording system needs to be properly synchronized with the fluoroscopy system output. Unfortunately, ensuring these two details is not as straightforward as it might sound.

It is not uncommon for there to be a mismatch in frame rate between the fluoroscopy system and any supplementary image recording systems that have been attached to it. In another increasingly common scenario, an organization may impose limits on the number of images per second that can be stored on the hospital’s electronic digital servers or PACS

system (Picture Archiving and Communication System). It is helpful to think of these situations as “lowest common denominator” scenarios. The number of frames in the final product directly follows from the lowest number of frames that are either generated or captured at any point in the process. Frequently these situations involve straightforward dropping of every 2nd frame, or perhaps the retention of only the 1st out of every 4 frames, as depicted previously in the middle and lower rows of Fig. 12. However, sometimes the math is more challenging, such as the conversion from a fluoroscopy system acquiring images at 30 fps to a recording system with a frequency of 25 fps. In these situations, image processing algorithms inside the recording system need to down-scan or up-scan the incoming image stream frequency to match the recording system’s frequency settings. This is analogous to what happens when a skilled piano player plays a piece of polyrhythmic music where one tune is played in 3/4 time with the right hand, while a second tune in 3/3 time is simultaneously played with the left hand. Over the course of the entire piece of music, the two lines miraculously begin and end at the same time, but the temporal correspondence between the hands is off in the middle. And, in the example of converting an incoming image stream of 30 images per second to a recording with 25 images per second, the information in those extra 5 images must be compressed or dropped.

Additionally, there is a risk of image corruption in cases where the recording system is not properly synchronized with the fluoroscopy system output. This is analogous to listening to speech through a delayed auditory feedback device. When image input and recording frequencies are not properly aligned, the resulting recording may contain all sorts of distortions and artifacts due to the mismatch, and these can interfere with image quality and diagnostic accuracy.

Finally, as discussed in section [Are the X-Ray pulse rate and the frame rate always the same?](#), post-processing algorithms, such as temporal averaging, may be implemented that impact the frame rate in the recorded image stream. The clinician needs to be aware of all of these potential issues, and should work with other staff, from Radiology, Medical Physics, Biomedical Engineering, and Information Technology, to ensure that the frame rate of the image sequence recorded for offline review matches that of the acquired fluoroscopic image sequence.

While temporal resolution is critical in the accurate assessment of swallow physiology, adequate spatial resolution and general image quality is also necessary. This important aspect has not been the focus of much research in VFSS since it is not necessarily unique to the dynamic capture of a swallow. However, there is evidence that degradation of spatial resolution and general image quality can occur in VFSS due to the recording system [62]. Given that our assessment of function is dependent on grayscale perception,

noise in the image may impair the clinical use of a VFSS if the recording system does not allow for adequate spatial resolution. Thus, it is important that clinicians work with the medical physicist to ensure that the images captured are of adequate image quality to meet the clinical goals of the VFSS.

What Aspects of Video Storage and Review are Critical for VFSS?

It is critical that the examination be recorded and the recording maintained in the patient’s medical records. Clinicians should ensure that the stored version of the recording retains all frames from the original exam. This allows for future use of the examination, reducing the need for repeat examinations. It also provides a comparison to allow for the visual evaluation of improvements or degradation of swallowing function. It can also be shared with treating clinicians outside of the facility conducting the VFSS for improved continuity of patient care. Lastly, it is necessary to maintain complete medical records in the case of the need to review for best practice or legal issues.

Recordings should be viewed in a manner that allows for continuous and frame-by-frame visualization of the swallow [1]. Software should allow the clinician to move forward and backward within the recording. It has been shown and is now part of standardized evaluation protocols that assessments of some swallow physiology, for example initiation of pharyngeal swallow, should occur at very specific frames in the recording [63].

What are the Benefits of a Standardized Protocol for Maximizing Diagnostic Yield?

In general, the benefits of standardized protocols for medical examinations are well known and have been longstanding. Specific benefits for maximizing diagnostic yield in VFSS have been the topic of several articles. Interested readers are directed to Martin-Harris et al. (2008) [63], Martin-Harris et al. (2020) [1], and Hazelwood et al. (2017) [64].

When Should I Use Magnification in VFSS?

It may be necessary to use magnification to achieve diagnostic objectives. For example, adequate visualization of the smaller structures present in young children may require its use [1]. In order to minimize unnecessary patient dose, use of magnification should be limited to only those instances when it is required.

What Should I do if the Best Pulse Rate I Can Get is 8 pps?

It would be advised to use continuous rather than pulsed fluoroscopy in this case. Research indicates that the diagnostic accuracy of VFSS for detecting penetration-aspiration and for evaluating time-dependent aspects of swallowing, such as initiation of pharyngeal swallow, is negatively impacted by pulse rate reduction to 15 pps. A further reduction to 8 pps would result in even greater loss of diagnostic accuracy. If continuous fluoroscopy is not available and the choice is between 8 pps or no VFSS, a clinician may choose to proceed with the VFSS. However, the clinician should be aware that it would not be possible to confidently determine whether there was normal / typical function with such an exam. The clinician would only be able to report on the visualization of frank evidence of impairment (aspiration that remains visible after the swallow, residue). Reporting on any aspect of swallow physiology that is temporally dependent is not advised. Clinicians should work with their clinic administration to provide an adequate fluoroscopic examination.

How do we Minimize Patient and Clinician Risk in Videofluoroscopic Swallowing Studies?

To discuss minimizing patient and clinician risks during VFSS, we first need to understand the magnitude of risks for this exam.

Patient and Clinician Dose and Risk Levels

What is the Typical Patient Radiation Dose From a VFSS?

The effective dose for adults undergoing an VFSS using the MBSImP administration protocol is 0.27 mSv [65]. One way to understand these values is in comparison to regulatory limits, average radiation received by a population, and radiation exposure from other medical uses of ionizing radiation. The annual public dose limit for radiation exposure in the US, established by the US Nuclear Regulatory Commission, is 1 mSv [22] compared to the 0.27 mSv for an VFSS. Of note, there is no limit for medical exposure as the risks and benefits are considered on a patient-by-patient basis. When equating radiation exposure from VFSS to the average natural background radiation that one would be exposed to just by living on Earth, the 0.27 mSv equates to 32 days of natural background radiation.

When comparing the adult VFSS to other medical uses of radiation, the adult VFSS is more than a dental X-Ray (0.005 mSv) or a chest X-Ray (0.1 mSv), but less than a mammogram (0.4 mSv), a head CT (2 mSv), a chest CT

(7 mSv), or a PET/CT (25 mSv) [66]. These comparisons with other medical uses of ionizing radiation may help SLPs develop their risk–benefit assessment when weighing the importance of the diagnostic information versus radiation exposure. For example, how often is radiation risk discussed in the decision to order a head CT? Rarely, based on our experiences, as the risks of not having the critical medical information provided by the head CT outweighs the relatively minimal risk of radiation exposure. This comparison should serve as a model for SLPs and other clinicians in weighing the risks and benefits.

We do not have the same level of information for children undergoing VFSS; however, several research articles report the effective dose (mSv). These studies show a range of 0.03 to 0.8 mSv [67–71]. It is important to understand that these values reflect various clinical practices and that none of the studies used a standardized, validated administration protocol for the VFSS. These studies also reflect various methods of converting DAP to effective dose (mSv). There is an ongoing study to precisely model radiation exposure from VFSS in infants and children, conducted using a standardized protocol, which will then provide us information on organ doses and effective dose (mSv), which can be used to calculate cancer risks [72].

What Level of Cancer Risk is Associated with This Level of Effective Dose?

In adults undergoing VFSSs, we know that the cancer risks associated with radiation exposure are very low. Specifically, the lifetime risk of developing cancer from a single VFSS for a 20-year-old male is 0.0011%, for a 20-year-old female is 0.0032%, for a 60-year-old male is 0.00049%, and for a 60-year-old female is 0.00072% [73]. Clinicians can compare this data to the average lifetime cancer incidence risk of an adult in the USA, which is 40.14% for males and 38.7% for females [74]. Of note, cancer incidence risk from VFSS is highest for young females; this is due to age, time for cancer to develop, and the higher radiosensitivity of a female's thyroid than a male's thyroid. While these cancer risk data are comforting for our VFSS practice with adults, it has led us to extend our research to radiation exposure and cancer risks in children due to age and the higher cancer incidence risk in females. Our ongoing study aims to provide cancer incidence risk data for infants through adolescents for clinicians and parents to use in their risk–benefit analysis [72].

How can I Communicate Radiation Dose and Associated Risks to my Patients?

Radiation dose information from VFSS is generally available in the literature and these values can be used to discuss expected radiation dose with patients and caregivers

(section [What is the typical patient radiation dose from a VFSS?](#)). Radiation dose information should be recorded for each VFSS using AK and/or DAP values available on the fluoroscopy system during and immediately after the exam. These values can be used to confirm the radiation dose to a specific patient for a given VFSS. Fluoroscopy system values can also be compared with those in the literature to ensure that the individual fluoroscopy system is operating properly. These values can also be used to monitor VFSS practice at a given facility.

Associated cancer risks to patients are available for adults undergoing VFSS, see section [What level of cancer risk is associated with this level of effective dose?](#) above. This information, in addition to comparisons of radiation exposure from VFSS with daily environmental radiation exposure and radiation exposure from other medical uses of ionizing radiation, can be used to help patients and caregivers understand the minimal risks associated with VFSS in adults. While research is ongoing to determine cancer risks to children undergoing VFSS, comparisons to background environmental radiation and radiation from other medical uses of ionizing radiation can be used to communicate risks associated with VFSSs of children. Cancer incidence risk can be compared against the lifetime risk of cancer to provide perspective. Additionally, risks can be compared against other mortality statistics from everyday activities, car accidents, choking, etc. It is ultimately the clinician's judgment to determine the best type of risk comparison for an individual patient with the understanding that some patients will not respond well to learning about cancer risks and mortality statistics.

How Much Radiation Exposure Does an SLP Get During a VFSS?

Per Hayes et al. (2009) [75], the average radiation exposure for SLPs during VFSSs (not shielded) is 0.0015 mGy. Given the US radiation worker limits of 50 mSv per year [22], this would indicate that SLPs can perform 33,333 VFSSs without exceeding the limits. If an SLP performed an average of 10 VFSSs per week (520 VFSSs/year), their annual exposure would be 0.78 mSv. These calculations are based on data collected outside of the lead apron and do not reflect the reduced risk provided by lead shielding, which should be part of standard clinician protocol during VFSSs. Data from Crawley et al. (2004) [76] are in line with this estimation of radiation exposure for clinicians during VFSSs.

Optimizing Patient Dose and Minimizing Clinician Dose

There are many ways to optimize patient dose and minimize clinician dose. In this section, we evaluate which methods make sense for dose reduction during VFSSs.

Should I Shorten my Exam to Decrease Radiation Exposure?

Individual clinicians need to evaluate the benefit of the information gained from the examination versus the radiation risks. In adults, we know that the radiation risks associated with VFSSs are minimal [73]. Therefore, it would be expected that an exam is not shortened, due to radiation exposure risks, before attaining information useful for diagnosis or treatment planning for adults. In fact, research supports the use of a thorough, standardized examination to increase patient safety. More specifically, it has been shown that the use of the MBSImP, a standardized approach to VFSSs, does not increase radiation exposure time [77].

We do not yet know the radiation risks associated with VFSSs in children. In general, we know that older children's risks are less than those of infants and young children, but the extent of radiation risks is unclear. Clinicians are responsible for analyzing risk and benefit for each child and determining whether to perform an VFSS. Research is ongoing to provide information on radiation risks in children so that clinicians will have better information related to risk to inform their clinical decisions [72]. While we do not know the cancer risks, we do have data that demonstrate that using a standardized protocol is associated with shorter radiation exposure times compared to exams without a standardized protocol [78]. Patel et al. (2020) [78] used a protocol described in McGrattan et al. (2020) [79] to intermittently sample swallow function of bottle-fed infants over the duration of a feed to capture fatigue-related changes while limiting radiation exposure. Riley et al. (2019) [80, 81] describe a different sampling method with a similar goal of radiation reduction while capturing clinically important information. In general, it is recommended that a standardized protocol with the goal of maximizing clinical yield and minimizing radiation exposure be used.

Should I Reduce Pulse Rate to Limit Radiation Exposure?

No. Due to the transient nature of swallowing, the dose reduction benefits of reducing the pulse rate are outweighed by the loss of diagnostic information. It has been demonstrated that low pulse rates (15 pulses per second or less) are related to diagnostic inaccuracy and impact clinical decision making for adults undergoing VFSSs [23, 82]. See section [How can we maximize diagnostic benefit in VFSS?](#) for the diagnostic implications of reduced temporal resolution

(via reducing pulse rate). Due to the shorter time of an infant's or young child's swallow, we can infer that the inaccuracies related to low pulse rate would be even greater. This impact of pulse rate is supported by Cohen's 2009 findings [83]. We have ongoing research to demonstrate the influence of pulse rate on the diagnostic accuracy of VFSSs in bottle-fed infants [72].

How Many Repeat Swallow Studies are too Many?

Repeat VFSSs should only be performed if the information will modify a patient's diagnosis or lead to a change in the patient's care. If the clinician deems that a VFSS will provide important patient care-related information, then radiation risks should be considered. As detailed in section [What is the effect of cumulative radiation exposure?](#), repeat VFSSs do not have greater risk. That is, the radiation exposure and associated cancer risks for a repeat VFSS is the same as that for the first VFSS. In adults, radiation risks from VFSS are minimal, and patient care benefits outweigh risks [73]. In children, the extent of radiation risks is unknown. Therefore, clinicians must carefully consider what information they genuinely need and when the patient status has changed significantly to compel a VFSS, repeat or otherwise.

How Important is it that I Narrowly Collimate?

There is no specific research related to the impact of collimation on radiation dose in VFSSs. General knowledge of the impact of collimation can be applied. We know that reducing the size of the radiation beam by collimating reduces the volume of irradiated tissue. The automatic brightness control or automatic dose rate control may increase the radiation beam intensity (kV, mA, or both) in response to this. However, due to the reduction in the irradiated volume, there may be an overall reduction in stochastic radiation risk [84]. Therefore, we can suggest that collimation, to the degree that it does not inhibit the capture of important anatomy, should be used during VFSSs. It is important that the SLP work with radiology staff operating the fluoroscopy system to agree on the study's anatomical capture goals. See questions related to collimation in sections [What is collimation and how should it be adjusted?](#) and [How can we maximize diagnostic benefit in VFSS?](#) above.

While collimation does provide some radiation risk reduction, it is essential to remember that radiation risks to adults undergoing VFSSs are low [73]. Thus, anything that diminishes diagnostic accuracy should not be advocated for based on radiation risk reduction in adults. While the radiation risks are unclear in children, it is still important to capture the diagnostically significant aspects of the swallow. Thus, the X-Ray beam should only be collimated to

the extent that diagnostic objectives of the VFSS are not compromised.

Should I Remove the Anti-Scatter Grid for Small Patients or Children?

As explained in section [What is collimation and how should it be adjusted?](#), there is a trade-off between the dose reduction from not using an anti-scatter grid and the improved image contrast afforded by the use of an anti-scatter grid. For adult patients, given the low radiation exposure and low related cancer risks, anti-scatter grids should not be removed to reduce radiation at the cost of decreased image contrast, as this may impede the visualization of clinically important information. For young children, since we do not fully understand the cancer risks associated with VFSSs, the risk/benefit ratio of removing the anti-scatter grid is slightly more complex. However, as with pulse rate and other variables, if the loss of image contrast with the anti-scatter grid removed impedes the capture of clinically important information, then the removal should be carefully considered.

Is it Safe for a Pregnant Patient to have a VFSS?

Yes. There is very low exposure to the embryo or fetus during the VFSS. The embryo or ovaries are not directly irradiated. Even in the most sensitive period post conception, fetal doses must be higher than 50 mSv to have the potential to cause harm [85]. If a patient warrants a VFSS, the clinical importance will outweigh the minimal risks.

Should all Staff Wear Radiation Badges?

All radiation workers should wear dosimetry badges. These badges are used to ensure that radiation workers do not exceed the legal regulations for occupational exposure. In the United States, this limit is set at 50 mSv per year [22]. Staff and their managers should review their annual dosimetry (radiation exposure) reports. These badge reports confirm that radiation exposure to SLPs conducting VFSSs is minimal, often less than the detectable level [75]. See section [Where should I wear my dosimeter\(s\)?](#) for more information on dosimetry badges.

Where Should I Stand in the VFSS Suite to Minimize my Exposure as a Clinician?

In general, you should stand on the detector side of the fluoroscopy system, so that the patient and detector provide shielding from scattered X-Ray photons [37]. You should stand as far away from the X-Ray tube and from the point where the X-Ray beam enters the patient as is reasonable while completing the exam efficiently. Knowing that the

intensity of scattered radiation decreases proportionally with distance squared provides guidance—doubling your distance from the patient reduces your dose by 75% [86].

Specifically, for VFSSs, since the clinician exposure is very low (see section [How much radiation exposure does an SLP get during a VFSS?](#)), it is important that clinician position does not result in substantially increased exam duration or modify the exam in a way that sacrifices diagnostically important information. An example of when this may happen is if a clinician is moving a lot to get behind a shield between swallows and thus is having the patient attempt to hold a bolus in their oral cavity. If the patient is unable to hold the bolus in their oral cavity, the initiation of pharyngeal swallow, and possibly the entire swallow, will not be captured. In this situation, the clinician would need to remain closer to the patient to provide the bolus and allow the swallow to be imaged.

What Personal Protective Equipment Should I Wear?

A lead apron and thyroid shield are the main personal protective equipment (PPE) that SLPs should wear when conducting a VFSS. This shielding reduces radiation exposure by approximately 95% [47]. This protective equipment covers the main radiosensitive organs and reduces an already low radiation exposure to SLPs. Other PPE sometimes used in fluoroscopy suites includes lead glasses, gloves, and shields. On the one hand, it might seem that more protection is better. However, clinicians often find that these additional items may reduce their ability to perform the exam efficiently. The glasses may slip or may be difficult to see through, the gloves may inhibit their ability to handle the barium mixtures (and actually increase radiation exposure, see sections [What personal protective equipment is available?](#), [What about lead gloves?](#), and [What about lead glasses?](#) above), and the shield may require time going back and forth from behind to in front of it. Crawley et al. (2004) [76] reported annual clinician doses of 0.6 mSv for the whole body, 1 mSv equivalent dose for the eyes, and 1.8 mSv equivalent dose for extremities. These doses are in comparison to the annual U.S. regulatory limits of 50 mSv for the whole body, 150 mSv for the lens of the eye, and 500 mSv for extremities [22]. This information can be used to guide clinician decisions on PPE selection.

What Risks are There to Me as the Clinician if I am Pregnant?

If you are pregnant, you are advised to declare your pregnancy so you can be issued an additional dosimetry badge to be worn at waist level under your apron. This dosimetry badge serves as a fetal dose monitor and will be used to ensure that exposure is maintained under the regulated limits

of 5 mSv over the 9-month gestation period and 0.5 mSv for each month of the pregnancy [87]. Clinicians should be aware of the regulatory limits for their specific practice setting (country, regulating body).

There is no specific research on pregnant SLPs conducting VFSSs; however, we can use data from pregnant interventional radiologists to infer risks. When doing so, it is critical to understand that radiation exposure of interventional radiologists (IRs) is many times higher than that of SLPs performing VFSSs. Englander and Ghatan (2020) [88] summarized our knowledge to date on radiation exposure to pregnant IRs and the related risks. They reported very low levels of exposure to the fetus, between 0 and 0.1 mSv, and that there is no increased risk of miscarriage or other effects for the fetus or child. Using animal studies, they demonstrated that the radiation exposure related to such risks would have to be much higher, in the range of deterministic effects, to cause any risk to the fetus. Vu & Elder (2013) [89] also provide a useful review of pregnancy-related issues for IRs that may be a useful perspective for SLPs. While Ghatan et al. (2016) [90] found that most IRs continued radiation work during pregnancy, a pregnant SLP has the right to decide whether she wants to continue her VFSS practice [91].

Is it Safe for Me to Feed the Patient if my Hand Enters the Radiation Field?

Any time you approach the patient (the source of scattered radiation) when the radiation beam is on, you increase your radiation exposure. This exposure of course increases significantly if your hands or arms enter the beam. Ideally, then, you should only approach the patient for feeding when the beam is off. However, this is not always possible. There are two encouraging facts to help understand the risks. One, SLPs are typically exposed to very, very low levels of radiation during VFSSs [75, 76]. Often these levels of radiation are not even detectable on radiation badges. Two, the hand and forearm of the SLP are the anatomy most likely to be irradiated and these are less radiosensitive than blood-forming organs or reproductive or gastrointestinal tract organs [15, 22]. The use of lead gloves may (see section [What about lead gloves?](#)) provide some protection to the clinician, but at the cost of increased patient dose. Regardless, it is best practice to minimize radiation exposure, and limit proximity to the radiation beam to times when it is absolutely necessary.

Conclusions on Best Practices for Balancing Risk and Benefit in VFSS

With any diagnostic procedure using ionizing radiation, there is a possibility of associated risk. This risk is generally extremely small [15], particularly relative to other risks encountered in everyday life, and may be negligible [9]. We can attempt to quantify this potential risk using concepts such as effective dose to estimate lifetime cancer risk [14].

It is much more difficult to quantify the expected benefit of a given procedure, although some work has been done on this [92]. Evaluating benefit versus risk is, thus, very challenging, as one is usually comparing qualitative benefit against quantitative risk, and this may lead to biased judgments, as the quantitative nature of the risk side may make the risk seem more concrete than the benefit [92].

Comparing the extremely low potential risks from ionizing radiation in VFSS of adults with the very tangible benefits should make it clear that the probable benefits greatly outweigh the possible risks in general. This comparison is somewhat less clear for VFSS of children, as we do not have the same understanding of related cancer risks for children that we do for adults undergoing VFSS. Nevertheless, every VFSS, for each individual patient, should be evaluated by the clinician in terms of benefit and risk to ensure that it is medically justified. The clinician should, thus, make every effort to ensure that they are fully informed on both risk and benefit in VFSS.

In order to maximize benefit and minimize risk in VFSS, the following represent best practices:

- Conduct VFSSs when they will influence patient care
- Use a image capture frame rate of 30 fps (or the closest available rate), ideally with a fully synchronized X-Ray pulse rate of 30 pps, but with continuous fluoroscopy if that is the only available option
- Consult with a medical physicist, medical radiation technologist, and radiologist to determine the optimal dose mode, magnification, collimation and other settings for use in VFSS
- Adhere to a standard videofluoroscopy protocol to limit unnecessary radiation exposure and allow for a thorough assessment of swallow function
- Use barium with adequate concentration to ensure visibility (i.e., 20–40% w/v); when possible use a standardized pre-mixed barium product specific for conducting VFSSs
- Establish a radiation dose-related, not fluoroscopy time-related, guideline for your facility
- Complete regular radiation safety training and review; follow recommendations for limiting dose to the clinician through shielding and distance
- Ensure synchronized recording of the exam on equipment/software that will allow for sufficient image quality and subsequent frame-by-frame review

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Declarations

Conflict of interest The authors have no conflicts of interest to disclose.

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