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Revisiting Image Formation in Videofluoroscopic Swallowing Studies: The Role of Frame Integration/ Frame Averaging

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ABSTRACT

Purpose: Fluoroscopy education and clinical literature dealing with video fluoroscopic swallowing studies commonly emphasize frame rate as the primary determinant of temporal resolution and diagnostic accuracy. However, frame integration or frame averaging, a fundamental image formation process in fluoroscopy, is rarely described or taught in connection with these studies. This educational work highlights the role of frame integration and its importance in image quality and patient dose optimization beyond frame rate alone.

Educational gap: A review of published swallowing fluoroscopy studies shows consistent focus on frame rate selection, such as 15 versus 30 frames per second, with higher frame rates favored to avoid missed events and diagnostic error. Despite this, the literature discussing optimal techniques for swallowing studies rarely discusses frame integration or how the multiple frames are combined to form individual displayed image frames. This omission limits understanding of alternative noise reduction strategies that preserve temporal fidelity.

Educational approach: Concepts of frame rate, pulse rate, and frame integration are explained using basic fluoroscopy physics and simplified imaging workflows. The relationship between temporal resolution, noise reduction, and radiation dose is described with emphasis on how frame integration affects displayed image quality independent of the frame rate.

Key teaching points: The x-ray pulse rate can determine the imaging frame rate, while frame integration defines how those frames created from individual pulses are combined to create the displayed frames. Increasing frame integration can reduce image noise, but introduces motion blurring, degrading diagnostic information. Maintaining high pulse rates while reducing or eliminating frame integration may be necessary to preserve diagnostic accuracy when performing swallowing studies.

Conclusion: Frame integration is a critical but an under-taught component of fluoroscopic imaging. Education in fluoroscopy should move beyond frame rate alone and incorporate frame integration as a core concept for diagnostically reliable imaging.

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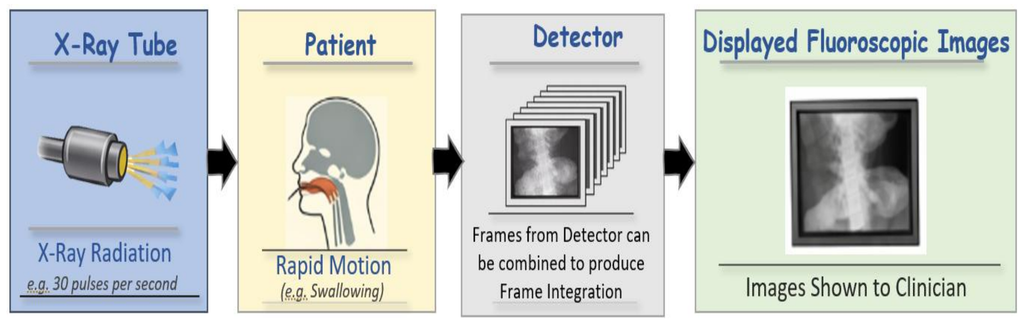
INTRODUCTION

Videofluoroscopic swallowing studies require high temporal fidelity because clinically important swallowing events can occur over very short time intervals. For this reason, fluoroscopy education and swallowing literature commonly emphasize frame rate, particularly the difference between 15 and 30 frames per second, as a major determinant of diagnostic accuracy. However, frame rate alone does not fully describe how fluoroscopic images are formed or displayed.

Frame integration, also known as frame averaging or temporal filtering, determines how the information from current and previous frames is combined to produce each displayed image. Although this process can reduce image noise and potentially support dose reduction, it can also introduce motion blur and obscure rapid swallowing events.



THEORY

Videofluoroscopic swallowing studies are frequently performed without any knowledge of the amount of frame integration that is being applied to the imaging. On some systems the amount of frame integration can be adjusted by adjusting the level of "noise reduction" but even at its minimum setting there is often still a substantial amount of frame integration applied to the images. For some systems the amount of frame integration can be adjusted in the service mode, but the default setting often applies substantial frame integration. For one manufacturer the amount of frame integration is determined by adjusting the "k" factor in a service mode that sets up a protocol. Here k=1 produces no frame integration. Typical default settings for k on our systems are 1.4 to 2. As k increases, the amount of frame integration increases. This is shown in the images to the right.

Frame integration is typically applied using an recursive filter to combine the current frame with fractions of the previous frames:

$$F_n = \frac{1}{\alpha + 1}(f_n + \alpha F_{n-1})$$

Where Fn is the current displayed frame and fn is the acquired current frame. α = 0 indicates no frame integration, and the amount of frame integration increases as α increases. The effect of α is shown in the images to the right.

CLINICAL DEMONSTRATION

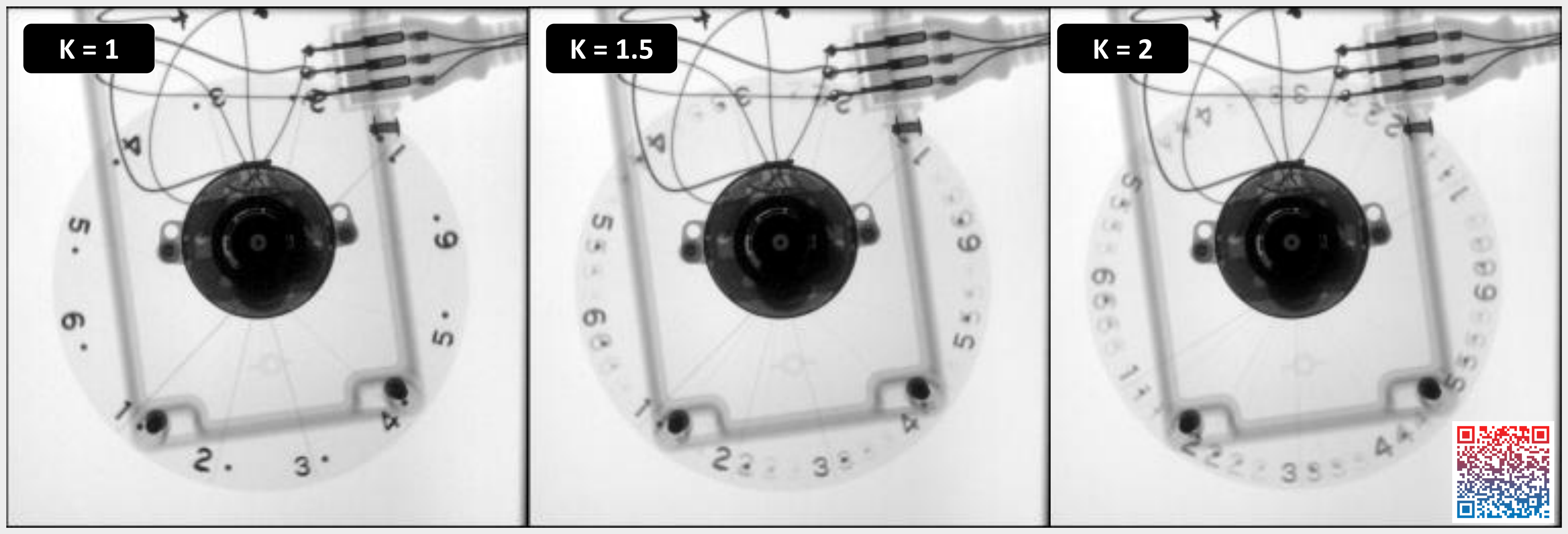
In this educational study we demonstrate the effect of frame rate and frame averaging using one clinical system. For this study we imaged a test object that is a rotating wheel at 30 rpm and we also use the images from an actual swallowing study that was originally obtained with no frame integration.

We imaged the test object using different values of the "k" parameter and also used the k=1 images and applied different levels of α to obtain similar effects. As k or α increases, the amount of frame integration increases and the motion blur increases. Since this system uses pulsed fluoroscopy, you can see the temporal blurring as multiple images for the frames shown.

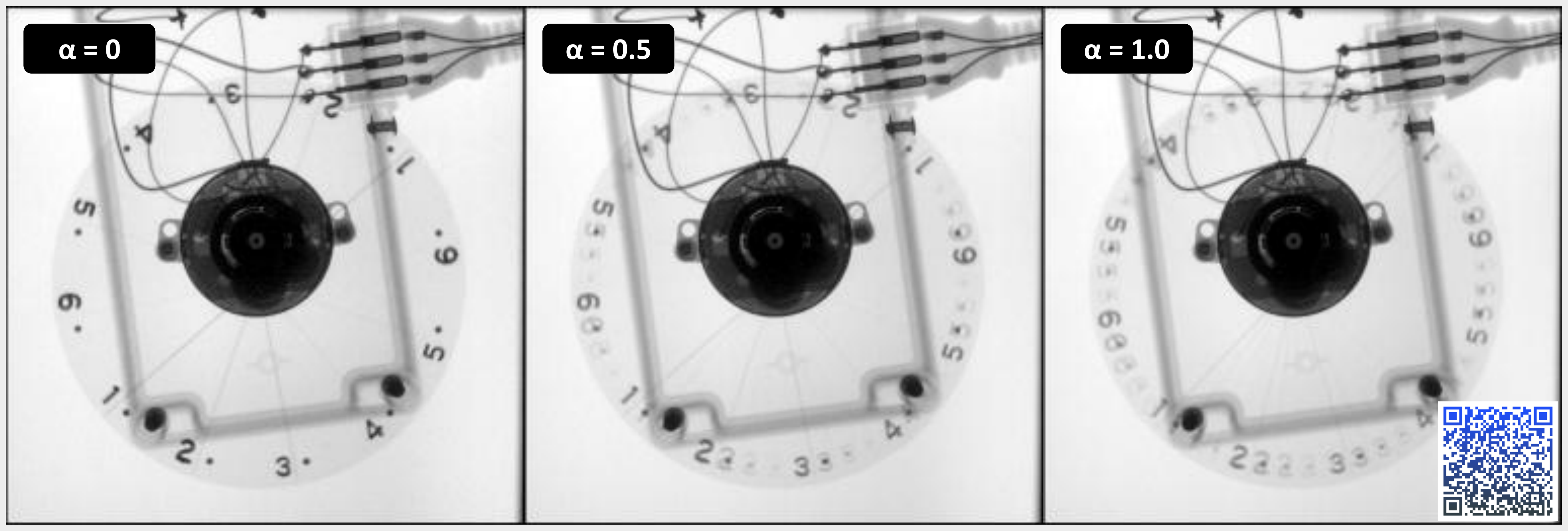
For the clinical study we applied different levels of α to the images to show the effects of different levels of frame integration. Frame integration can be seen to cause image motion blurring, obscuring some details.

For systems that cannot totally eliminate frame integration in swallowing studies, the effect of frame integration can be minimized by using the highest allowed frame rate, since the frame averaging will involve frames not as far in the past as with lower frame rates.

Proprietary Vendor K-Factor at 30 fps (1, 1.5, 2)

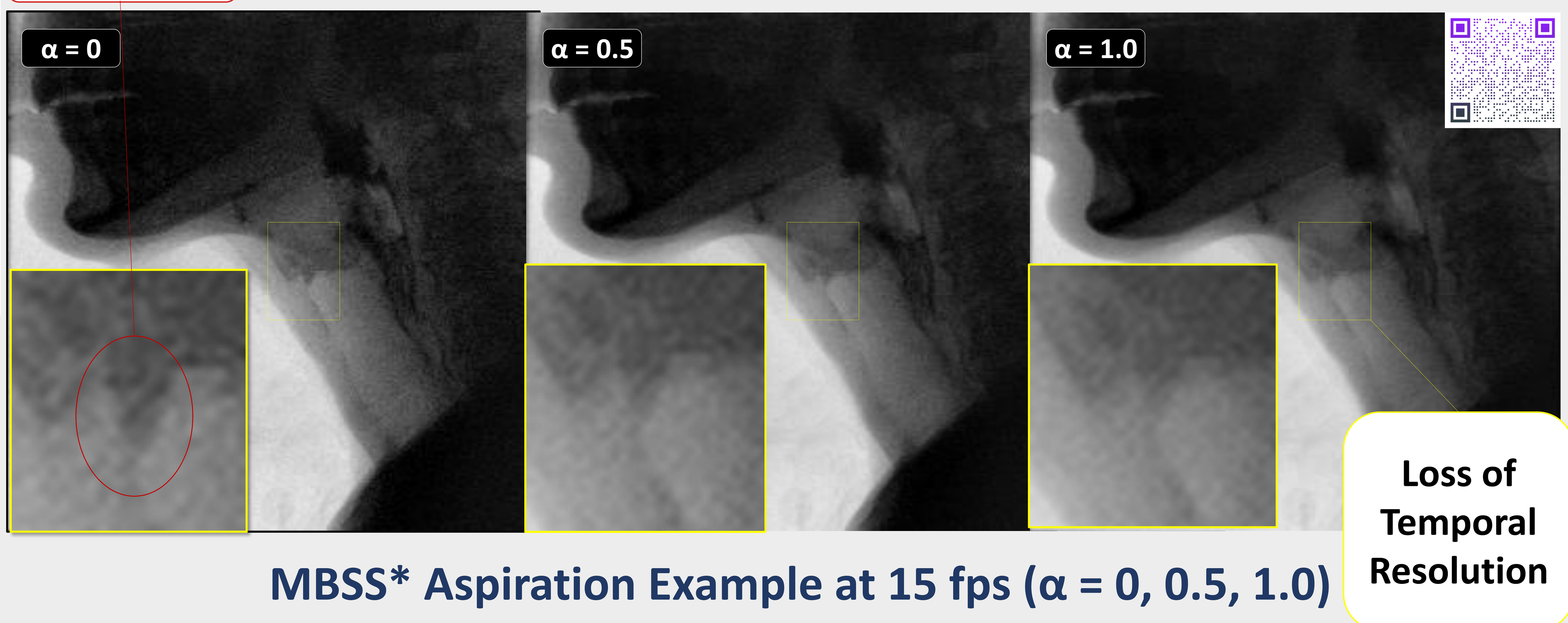


Manual Recursive Frame Integration at 30 fps (α = 0, 0.5, 1.0)

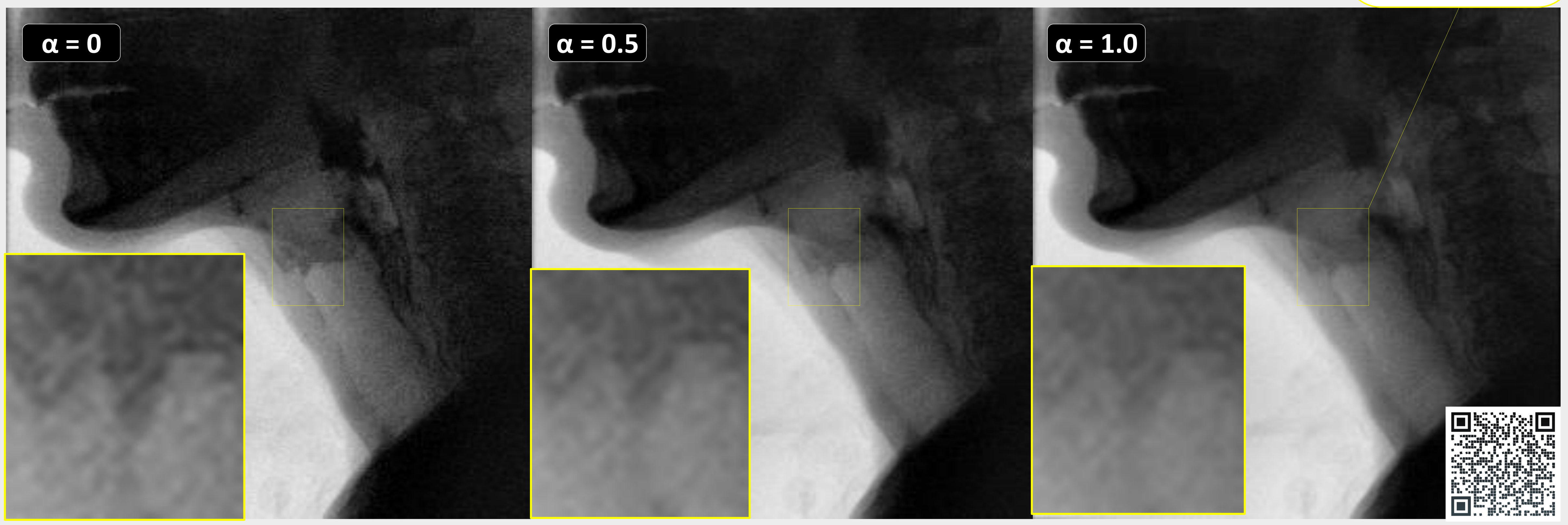


Barium entering trachea

MBSS* Aspiration Example at 30 fps (α = 0, 0.5, 1.0)



MBSS* Aspiration Example at 15 fps (α = 0, 0.5, 1.0)



*Modified Barium Swallowing Studies (MBSS)

THANK YOU !!