WHITE PAPER ON THE EFFECTIVENESS OF DELFTDI LLS-1 ONESHOT IMAGING MODALITY FOR NONAMBULATORY NEUROMUSCULAR SCOLIOSIS IMAGING

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Problem statement

Projectional imaging is considered the gold standard for scoliosis evaluation and is pivotal in determining the underlying aetiology in cases of structural scoliosis. Equally important is the reliability and reproducibility of angle measurements in follow-up examinations to reduce variation in patient outcome and treatment. However, imaging techniques such as rotational stitching, and biplanar x-ray are dependent on the patient's ability to stand or sit still for a short period of time. Patients who are unable to do so are subject to suboptimal images with possible stitching errors. When radiological examinations are deemed necessary, the choice of modality should therefore be selected on the basis of which equipment will provide the best images with the lowest possible dose.

This white paper examines the effectiveness of the DelftDI LLS-1 Oneshot imaging modality and compares it to conventional multi-exposure stitching systems. The argument being that the Oneshot imaging system may possibly improve patient outcome for nonambulatory neuromuscular scoliosis patients as the x-ray system provides instant projectional images without any motion artifacts, thus increasing angle measurement reproducibility in follow-up examinations. The paper is intended to be read by those in need of a solution to possible stitching errors on multi-exposure stitching.

BACKGROUND

Scoliosis is a relatively frequent spinal condition (Horne, Flannery and Usman, 2014) defined as a three-dimensional torsional deformity with a Cobb angle greater than 10 degrees when measured on a frontal plane radiograph (Negrini *et al.*, 2018; Khanna, 2009; Kim *et al.*, 2010; Van Goethem and Van Campenhout, 2007; Supakul *et al.*, 2012). Structural scoliosis may be either idiopathic (80%), congenital (10%) or associated with developmental, neuromuscular and/or paralytic diseases, or induced by secondary causes such as trauma or tumours (Cassar-Pullicino and Eisenstein, 2002; Oestreich, Young and Poussaint, 1998). The incidence depends on its aetiology, and even though idiopathic scoliosis is the most common form, the prevalence remains low, approximately 3-4% in the general population (Adobor, 2014). However, in children with neuromuscular disorders such as cerebral palsy, Duchenne, and Spinal Muscular Atrophy, scoliosis is especially common with a probable incidence as high as 90% (Halawi, Lark and Fitch, 2015).

Neuromuscular scoliosis (NMS) is furthermore associated with an early onset and rapid progression during growth, with a tendency to continued progression even after skeletal maturity (Halawi, Lark and Fitch, 2015; Kivle, 2019; Bodendorfer and Shah, 2019). An impaired function of spinal muscles can lead to progressive upper body imbalance. In the most severe cases, NMS involves the entire thoracolumbar spine, making a large rigid reversed C shaped curvature, often extending into the pelvis and forcing the pelvic to tilt (Halawi, Lark and Fitch, 2015; Kivle, 2019; Oestreich, Young and Poussaint, 1998; Bodendorfer and Shah, 2019). In addition, the greater the level of neurological involvement, the incidence, severity, and progression of scoliosis also increases (Murphy and Mooney, 2019; Hägglund *et al.*, 2018).

IMAGING

Patient positioning

Conventional radiographic imaging is the gold standard for determining the degree of spinal deformity and monitoring changes during growth, (Hansen *et al.*, 2003; Supakul *et al.*, 2012; Knott *et al.*, 2014). Reproducibility of patient positioning in follow-up imaging is paramount when observing imbalance, evaluating the biomechanics of the curve progression and planning treatment (Kim *et al.*, 2010; Cassar-Pullicino and Eisenstein, 2002). The ideal patient position is the upright standing posteroanterior (PA) and, if needed, lateral position (Knott *et al.*, 2014; Halawi, Lark and Fitch, 2015; Van Goethem and Van Campenhout, 2007). If the patient cannot stand, sitting x-rays can demonstrate maintenance of an erect alignment and sitting posture (Bodendorfer and Shah, 2019). Although standing radiographs of the entire spine are easy to achieve in ambulatory and communicative patients this may be extremely difficult, and perhaps impossible, in patients with neurological impairment. Non-communicative spastic patients also present challenges and inconsistent positioning may hinder reproducibility of angle measurements (Halawi, Lark and Fitch, 2015; Cassar-Pullicino and Eisenstein, 2002). Consequently, the supine position with a possible underestimation of the Cobb angle has to some extent become the accepted view when the reproducibility of sitting images is doubtful (Halawi, Lark and Fitch, 2015; Hägglund *et al.*, 2018; Alrehily *et al.*, 2019).

Imaging techniques

Prior to digital imaging, scoliosis examinations were acquired using wide beam exposure on a special long film format. The examination was easily executed, but the 91.5 cm (36'') long film had some disadvantages; it caused geometric distortion at the far ends and poor vertebral visualisation (Supakul *et al.*, 2012; Bassi *et al.*, 2013). The introduction of computed radiography (CR) facilitated a merging of several images obtained in a single exposure by specialised software. However, when digital detectors became available, these could not be used in a similar manner as the housing material caused artifacts in the final image. Subsequently, digital multi-exposure stitching techniques was developed requiring separate tube and detector movements to capture up to four source images which are digitally stitched into a single image.

Linear stitching

When utilising linear stitching, the detector and tube move simultaneously along the patient between exposures. Linear stitching systems are easy to develop, but can cause some geometric parallax errors as some structures are duplicated whilst others are missed completely. To minimise this effect, linear stitching often requires the cone of the x-ray beam to be as narrow as possible, necessitating a high Source-Image-Distance (SID). Furthermore, due to the image overlap, several more source images are needed to complete a full spinal image, thus increasing examination time (Bassi et al., 2013).

Rotational stitching

Rotational stitching is the most common system used today for long-length imaging and the examination time is approximately 20 seconds. During the examination the detector automatically moves between exposures while the tube angle rotates. The system benefits from a high SID due to a more slight tube angulation which in turn reduces peripheral geometric distortion in the stitched image compared with a short SID and steeper angulation (Bassi *et al.*, 2013).

Wide beam stitching

In smaller rooms, wide beam stitching may be utilised depending on the tube anode inclination. With this method the tube is completely stationary, using internal shutters to collimate the wide beam to only cover the detector surface for the source image exposures. SID is dependent on the inclination of the anode, where a shorter SID can be used if the inclination is high enough. However, this can cause geometric blurring as a higher inclination creates a larger focal spot on the anode with increased penumbra. The examination time is similar to rotational stitching, taking up to 20 seconds to perform (Bassi *et al.*, 2013).

EOS® imaging system

The EOS® imaging system is a recent development involving two x-ray tubes and detectors that simultaneously capture two orthogonal images, one frontal and one lateral. This technology has significantly reduced the radiation dose compared with conventional diagnostic scoliosis imaging, especially with the introduction of microdose and nanodose protocols. Furthermore, EOS® can produce 3D images of the whole spine and two images simultaneously when using the biplanar mode in less than 15 seconds (Garg *et al.*, 2020).

The challenge of motion artifacts and stitching errors

However, all the digital imaging techniques mentioned above require the patient to stand or sit still for a short period of time. Any movement during the acquisition may cause problems when the source images are stitched together to a single image. Movement such as spasms, or even breathing, can cause stitching errors, potentially leading to incorrect diagnosis and treatment.

A number of techniques may be employed to minimise motion artifacts and potential stitching errors, but all have their disadvantages. Radiopaque markers are usually placed directly on the patient so any movement during the acquisition of source images may still result in motion artifacts and stitching errors. Similarly, although a radiopaque ruler placed next to the patient may remain stationary, patient movement during acquisition may still occur. EOS® may be used with a specially designed chair to immobilise neuromuscular patients and nonambulatory patients but its success is limited due its small size and its inability to prevent movement due to spasms. Suspension of breathing may also minimise motion artifacts but neurological impairment may limit patient cooperation. Therefore, nonambulatory patients with a high level of neurological impairment necessitate an instantaneous acquisition to minimize any possibility of motion and resultant stitching errors and the DelftDI LLS-1 Oneshot imaging modality offers this solution.

ADVANTAGES OF THE DELFTDI ONESHOT IMAGING SYSTEM

Detectors

The projectional imaging system from DelftDI utilizes up to three separate digital detectors and a single wide beam exposure to image the entire spine, identical to the earlier use of CR cassettes. Similar to the previous CR method, there can be some distortion at the upper and lower end of the full image but with a high SID this distortion is reduced. The digital detectors are placed inside a tailored support stand. The large detectors, 43x43 cm, are particularly useful for wide scoliotic angles, for lateral bending radiographs, sagittal alignment, or if there is severe kyphosis in the lateral view, however the smaller 35x43 cm detectors are usually sufficient for seated patients. Depending on the SID and subsequent beam collimation, all three detectors may be utilised if sagittal alignment is needed for standing radiographs, however two detectors are more commonly used for seated patients.

Support stand

The DelftDI oneshot support stand is solid and secure which is reassuring for both NMS patients and their caretakers. Although the stand is fixed in an upright position and can only acquire images in a portrait view, landscape images, traction views and supine images may still be acquired when necessary as the system can be connected to an already existing system that will be able to perform the additional images. For patients standing in the PA position, handlebars on each side provide support, while handlebars suitable for patients seated in the AP position would be a welcomed addition to the system. In their absence, our department has installed two wall-mounted, height-adjustable grab-bars which are also handy for the lateral view as they are secure enough for patients to steady themselves. These fold away when not in use.

Acquisition Time

The most important advantage of the DelftDI oneshot system is the short examination time. With multi-exposure rotational stitching the acquisition time for two images is approximately 10-12 seconds with the risk of motion artifacts and stitching errors as previously mentioned. The instantaneous acquisition facilitated by DelftDI oneshot greatly reduces the risk of motion artifacts and eliminates the risk of stitching errors. It also facilitates greater reproducibility of the scoliotic angle measurement in follow-up examinations when assessing the progression of the curve. The single, wide beam exposure acquiring motion free images may also reduce the radiation dose incurred due to the absence of overlapping exposures and a reduced need for retake examinations.

SUMMARY

The DelftDI LLS-1 oneshot projectional image system is deemed quick and easy to use by radiographers and considered solid and secure by patients and their caretakers. As imaging is an instantaneous, single exposure, the need for retakes is significantly reduced as patient movement between acquisitions is no longer relevant. It also ensures greater reproducibility of angle measurements, potentially improving patient outcome. These benefits may in turn facilitate a higher throughput and more efficient time management.

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