Reliability and Reproducibility of Subject Positioning with EOS Low-Dose Biplanar X-ray

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Abstract *Background:* EOS low-dose biplanar X-ray used with tantalum bead implantation is an appealing imaging modality to evaluate limb length and physeal growth due to its relatively low radiation exposure, excellent inter- and intra-observer reliability, and minimal magnification/shrinkage error. *Questions/Purposes:* The purpose of this study was to establish the error in total length and inter-bead distances using EOS and tantalum beads due to variable positioning in the EOS gantry, by assessing variation in measurements made on the same subject repeatedly positioning by one positioner (intra-positioner measurement error) and variation in measurements made on the same subject with positioning by multiple positioners (inter-positioner measurement error). *Methods:* Tantalum bead markers were placed about the distal femoral physis of a cadaveric lamb femur. Three investigators positioned the femur in the EOS gantry 10 times, totaling 30 EOS scans. Total limb length and inter-bead distances were measured on AP and lateral views; mean and standard error were calculated. A random effects analysis of variance for nested data was used to determine the proportion of variation due to differences between positioners and differences between positioning by the same positioner. *Results:* Intra-positioner measurement error ranged from 0.01 to 0.06 mm. Inter-positioner measurement error ranged from 0.00 to

0.09 mm. *Conclusions:* EOS has relatively low radiation and allows standing assessment of limb length and alignment. In this study, length measurements and inter-bead distances demonstrated minimal error due to positioning in the EOS gantry, documenting that there is minimal error from positioning, minimal magnification/shrinkage error, and exceptional inter and intra-rater reliability. EOS is the preferred method for length and angular measurements, and with tantalum beads, is ideal for measuring growth about the physis.

Keywords tantalum beads · positioning · EOS · measurement · reproducibility · repeatability · inter-positioner · intra-positioner · reliability · error

Introduction

EOS low-dose biplanar X-ray is emerging [1–4, 7, 9–11] as a preferred modality for measuring anatomic length and deformity. Escott et al. assessed EOS, CT scanogram, and X-ray compared to true length as reported by the manufacturer of a phantom limb and found that EOS measurements were significantly more accurate than CT scanogram and X-ray, with X-ray having 42.2 mm error (8.8% magnification) and CT scanogram having –6.3 mm error (–1.3% magnification) [5]. EOS, using the fast protocol, showed –3.6 mm error and with the slow protocol –2.6 mm of error (–0.8% magnification and –0.5% magnification, respectively). Using the EOS fast/low dose setting, radiation exposure was just 0.68 mrad; 5.5 times lower than in CT scanogram and 42.8 times lower than X-ray.

Tantalum beads, as radio-opaque markers about the physis, have been used to monitor physeal growth for research purposes [8, 12] and the technique is transitioning into clinical practice as a method to measure growth accurately. In previous work, the intra-rater and inter-rater agreement for the measurement of total length, as well as

Work performed at Hospital for Special Surgery.

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between-bead length using both EOS and CT scanogram, approached 100% [6]. Bead implantation about the physis allows for exceptionally accurate and reliable determination of whether or not further growth has occurred at the physis.

Error in length measurement could originate from magnification or shrinkage compared to the actual length, variation in positioning of the subject, movement of the subject once positioned, or errors made by a measurer in their selection of landmarks for measurement. It is known that the inter-rater reliability of making the measurement (comparing different measurers) and the intra-observer reliability of making the measurement (comparing repeat measurements made by the same measurer) for this type of measurement with EOS are excellent [6]. It is known that the error from magnification/shrinkage is very small for EOS fast and slow protocols [5], and that this error is not clinically important if serial imaging is performed using the same modality. However, it is unknown how much length measurements might vary simply from positioning of the subject in the EOS gantry. The purpose of this study was to establish the error in total length and inter-bead distances using EOS and tantalum beads due to positioning in the EOS gantry, specifically to determine the technique's repeatability (variation in repeat measurements made on the same subject under identical conditions: one positioner repeatedly positioning one subject) and reproducibility (variation in measurements made on a subject under changing conditions: multiple positioners placing the subject).

Materials and Methods

A skeletally immature lamb femur was acquired from a local butcher. Four 1-mm tantalum beads (Halifax Biomedical, Inc., Nova Scotia, Canada) were inserted into the cortex distal and proximal to the distal femoral physis on both the

medial and lateral sides. The femur was attached to an external fixation device using two Steinman pins such that it could be positioned upright in the EOS scanner. Three separate medical professionals (a radiologist, a radiology technician, and an orthopedic resident) positioned the sample in the EOS scanner ten separate times, with complete removal of the sample between each positioning. The EOS scanner projects a laser line in two planes; the positioners were instructed to position the sample such that the laser line bisected the sample in both anterior-posterior (AP) and lateral planes. All testing was performed on the same day.

AP and lateral EOS images were obtained following each positioning of the sample, for a total of 30 AP scans and 30 lateral scans. The scans were viewed for measurement in PACS (Picture Archiving and Communication Systems, Sectra IDS7 Version 16.1.22.1566). Measurements of multiple parameters to the nearest hundredth millimeter were performed by a single reader (ED) on each image set, including the total length of the bone in the AP view (AP total), the distance between two medial beads in the AP view (AP medial bead), distance between two lateral beads in the AP view (AP lateral bead), the total length of bone in the sagittal view (Sag total), the distance between two medial beads in the sagittal view (Sag medial bead), and distance between two lateral beads in the in sagittal view (Sag lateral bead) (Fig. 1). The images were blinded, such that the reader did not know who had performed the positioning for each image.

The mean and standard error were calculated for each parameter measured. A random effects analysis of variance for nested data was used to determine the proportion of variation due to differences between positioners and differences between positioning by the same positioner. The standard error for each parameter was multiplied by the proportion of variation to estimate the amount of error attributable to each source. All analyses were performed using SAS Software version 9.3 (SAS Institute, Inc., Cary, NC).

Fig. 1. **a** Anterior-posterior and **b** lateral images showing position of tantalum beads and total length and inter-bead distances.

Table 1 Measurement mean, error, and variance for the measured inter-bead distance and total length

	Mean (mm)	Standard error (mm)	Source	Variance component	Percent of variation
AP total	186.69	0.01	Total	0.015	100.00
			Positioner	0.000	0.00
			Positioning	0.015	100.00
AP medial bead	33.66	0.04	Total	0.007	100.00
			Positioner	0.004	55.02
			Positioning	0.003	44.98
AP lateral bead	33.42	0.10	Total	0.035	100.00
			Positioner	0.030	85.53
			Positioning	0.005	14.47
Sag total	184.17	0.10	Total	0.073	100.00
			Positioner	0.029	39.34
			Positioning	0.044	60.66
Sag medial bead	33.22	0.11	Total	0.063	100.00
			Positioner	0.036	57.57
			Positioning	0.027	42.43
Sag lateral bead	35.29	0.05	Total	0.028	100.00
			Positioner	0.005	16.12
			Positioning	0.024	83.88

Results

Standard error of all measurements was small and below that of any clinical significance (Table 1). The standard error for each parameter was very small and ranged from 0.01 to 0.11 mm. The standard error due to intra-positioner measurement ranged from 0.01 to 0.06 mm, while the standard error due to inter-positioner measurement error ranged from 0.00 to 0.09 mm (Table 2).

Discussion

Total length and inter-bead length measurements acquired with EOS and measured with PACS were highly repeatable and reproducible with respect to positioning in the EOS gantry. Intra-positioner error from positioning in the EOS gantry was 0.06 mm or less for all parameters in this study and the inter-positioner error was no higher than 0.09 mm for any parameter. Although there is no established acceptable level of error for length measurements, in the authors' expert opinion, <1 mm of error in length measurements would be clinically insignificant. Errors due to positioning were well below this threshold.

Establishing the variation due to intra- and inter-positioner reliability of positioning the subject in the EOS gantry, combined with the known inter-rater and intra-rater

reliability of making the measurement on PACS, and known magnification/shrinkage associated with this modality provides useful information for the clinician, who may be making serial measurements and using these measurements to predict future height and bone length, or establish whether growth has ceased at the physis. The overall intra- and inter-positioner reliability of the technique may also be helpful to researchers who need to know the features of measurements captured with EOS and measured with PACs in designing studies using such measurement techniques.

To our knowledge, there are no previous studies that have reported on the intra- and inter-positioner reliability of positioning for X-ray, CT scan, or EOS. The error due to magnification/shrinkage of the modality itself has been reported at 42.2 mm (8.8% magnification) for X-ray, −6.3 mm (−1.3% magnification) on CT scanogram, and for EOS −3.6 mm (0.8% magnification) using the fast protocol and −2.6 mm (−0.5% magnification) using the slow protocol [5]. The error due to positioning within the EOS gantry was significantly lower than error related to magnification, with 0.11 mm being the maximum overall standard error related to positioning in the EOS gantry.

This study has a number of limitations. First, use of a cadaveric bone, rather than a living child means that we have measured the error in positioning, and have not been able to take into account any error from patient movement once positioned in the gantry. Second, as no growth was actually monitored, the clinical utility of EOS combined with tantalum beads for measurement of total length and physal growth cannot be ascertained from this study design. Moreover, EOS is still a relatively new technology with limited availability in some regions. While currently EOS machines are primarily located at large, tertiary care centers in North America and Europe, their numbers continue to grow. EOS imaging reported selling 41 units in the first 9 months of 2016, in contrast to 30 systems in the same period the year prior. Over half the revenue from this time period came from North American sales. The company has also recently expanded to more remote locations, including Tunisia and South Korea. [13]. While EOS imaging is not

Table 2 Intra- and inter-positioner measurement error for the measured inter-bead distance and total length

	Intra-positioner error (mm)	Inter-positioner error (mm)
AP total	0.01	0.00
AP medial bead	0.02	0.02
AP lateral bead	0.01	0.09
Sag total	0.06	0.04
Sag medial bead	0.05	0.06
Sag lateral bead	0.04	0.01

universal, it will likely continue to increase in market share and eventually will be more readily available worldwide.

This study demonstrates a number of strengths. Primary among them is that is a novel assessment method, as no prior study, to our knowledge, has evaluated intra- and inter-positioner reliability of positioning for EOS. As such, this adds novel support for the accuracy of this imaging modality in measuring anatomic length. In affirming that EOS is accurate in measuring distances with little error related to positioning, this study supports the use of EOS over other currently used modalities, such as CT scanogram or standing X-rays. In addition to being accurate, it is also cost-effective, time-efficient, and of lower radiation risk. Moreover, as this is a weight-bearing study, it may be a more useful clinical modality than CT scanogram, which is performed supine, as it can account weight bearing angular deformities as well as length measurements. Lastly, as this study asserts the intra- and inter-positioner reliability of EOS for measuring anatomic distances, it prompts future study. This may include, but is not limited to, assessing positioning error in clinical practice on real patients and determining the actual clinical error in positioning in measuring physal growth.

In conclusion, positioning in the EOS gantry is both repeatable and reproducible for overall length measurements and inter-bead length measurements measured with PACS. In addition to the high intra- and inter-positioner reliability of positioning, and the inter-rater and intra-rater reliability of the measurer found in previous work, other prior studies have established that the technique allows for rapid acquisition in a weight-bearing position with minimal radiation exposure.

Compliance with Ethical Standards

Conflict of Interest: Christine Goodbody, MD, Paz Kedem, MD, Michaela Thompson, BA, Roger F. Widmann, MD and Emily R. Dodwell, MD, MPH, FRCSC have declared that they have no conflict of interest. Huong T. Do, MA, reports grants from Clinical and Translational Science Center, outside the work. Douglas N. Mintz, MD, FACR, reports personal fees from Current Concepts in Rheumatology and other from Virtualscopies, outside the work.

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