Reliability and Accuracy of MRI Scanogram in the Evaluation of Limb Length Discrepancy

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Abstract: The purpose of this study was to compare MRI scanogram with traditional radiographic methods for measurement of limb length. The authors hypothesized that MRI scanogram would be as reliable and accurate as radiographic scanogram in measurement of limb length without exposing patients to ionizing radiation. Twelve cadaveric femurs were measured using AP conventional radiographic scanogram, CT scanogram, MRI scanogram, and electronic caliper. Three orthopaedists performed two separate measurements using each technique. Intraobserver and interobserver variability was assessed for each of the three radiographic techniques. Accuracy was assessed by comparison of radiographic measurements to electronic caliper measurements of femur length. The reliability of all three radiographic limb length measurement techniques was excellent (ICC > 0.99). The accuracy of plain radiographic scanogram was slightly superior to CT scanogram and MRI scanogram. The mean absolute differences for radiographic, CT, and MRI scanograms compared with the gold standard, direct caliper measurement, were 0.52 mm, 0.68 mm, and 2.90 mm, respectively. All three scanogram techniques showed excellent reliability and accuracy. Radiographic scanogram remains the gold standard for leg length measurement. MRI scanogram is slightly less accurate compared with radiographic scanogram, but it does not use ionizing radiation. MRI scanogram merits clinical study and comparison with the traditional radiographic scanogram method for measurement of limb length.

Key Words: limb length discrepancy, radiographic scanogram, CT scanogram

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Accurate prediction of limb length discrepancy at maturity depends on both reliable acquisition of radiographic data and accurate prediction of future discrepancy.[1] Clinical assessment of limb length discrepancy is notoriously unreliable, with block measurements widely believed to be the most reliable clinical measurement technique.[2,3] A variety of radiographic techniques have been developed, including teleoroentgenogram,[3] orthoroentgenogram,[4] plain radiographic slit scanogram,[5–7] CT scanogram,[8–11] and ultrasound.[12,13]

Plain radiographic scanogram and CT scanogram have been shown to have extremely high reliability.[8,9,14] The interobserver intraclass correlation coefficient (ICC) for CT scanogram has been shown to be as high as 0.99.[9] CT scanogram may be advantageous in the setting of angular deformities of the limb, such as a knee or hip flexion contracture.[9] Our previous study showed that plain radiographic scanogram has an intraobserver ICC of 0.99 and an interobserver ICC of 0.98.[14] Both of these methods subject the patient to ionizing radiation that, with multiple studies over time, carry a not-insignificant radiation burden to patients, because often children with leg length discrepancies require new radiographs every 6 months over many years. The ideal method for determining limb length would be as reliable and accurate as plain radiographic and CT scanogram but would use nonionizing radiation.

Due to its superior tissue contrast, direct multiplanar capabilities, and lack of ionizing radiation, MRI has been adopted as a safe, sensitive, noninvasive method for evaluating the musculoskeletal system. Although traditionally used for soft tissue imaging, MRI has become an increasingly popular method to evaluate bony abnormalities as well. In addition to the ability of MRI to give detailed information about bony and soft tissue pathology, another important advantage of MRI over other imaging techniques is the lack of ionizing radiation exposure to the patient. Disadvantages of MRI include the increased time per study and the increased cost compared with CT scan and traditional radiography, although newer system capabilities have greatly reduced scan times.

Using MRI to evaluate limb length discrepancies has not been described previously in the literature. The purposes of this study were to assess the reliability and accuracy of MRI for measurement of limb length and to compare MRI scanogram with traditional radiographic methods for the measurement of limb length.

METHODS

Twelve dry adult cadaveric femurs from the anatomy laboratory at the medical school were used as the study specimens. Each femur was assigned a letter (A–L) and marked directly with a radiographic marking pencil (Dixon Ticonderoga

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Co, Heathrow, FL) and labeled with a radiolucent paper tab for identification purposes. Each femur was then imaged for the purpose of femur length assessment using three radiographic techniques: slit scanogram,[5] CT scanogram,[9] and MRI scanogram. The slit scanogram radiographic technique at our institution is performed with the patient placed on a long 36-inch cassette with both limbs in neutral alignment. The film focal distance is standardized at 40 inches.[14] The CT scan used was a Philips 16 Detector 2003 scanner (Koninlijke Philips Electronics, The Netherlands). The CT scanogram technique follows that of Huurman et al[11]: an AP scout scanogram of the femur was made, and the standardized computer program for measuring distances within the CT system was used to measure the distance from the tip of the femoral head to the most distal aspect of the medial femoral condyle. To use MRI for assessment of cadaveric femur length, the femurs were soaked in water overnight and coated with a nonferrous hand therapy putty (Theraputty, North Coast) to visualize the proximal and distal subchondral bone. All MR imaging was performed on a clinical 1.5-Tesla MR unit (Signa Horizon LX, General Electric Health Care, Milwaukee, WI), using a body coil. Images were obtained using a T1-weighted spin-echo sequence (repetition time [TR] 400–500 msec, echo time [TE] 14–15 msec, field of view 46–48 cm, matrix 512 × 224, slice resolution of 3 mm with no gap) at 2 excitations. The best coronal images were selected for standardized assessment of femur length from the top of the femoral head to the bottom of the medial femoral condyle. Length was measured off the MRI monitor using digital measurement in exactly the same manner as the CT scanogram measurements.

Three observers–an experienced pediatric orthopaedic surgeon, a pediatric orthopaedic fellow, and a third-year orthopaedic resident–performed the radiographic assessment of femur length. The observers were blinded to the identification of the specimens, and each physician measured the femur lengths independently. For the slit scanogram measurement, the most proximal aspect of the femoral head and the most distal aspect of the medial femoral condyle were marked with a radiographic marking pencil (Dixon Ticonderoga Co). The length was then measured directly using a standard woven tape measure (Abco Delaers, Nashville, TN). For the CT and MRI scanograms, the identical femur landmarks were used and the computer calculated femur length based on the "computerized ruler." Each of the three observers performed two independent measurements of each femur at two separate time intervals using all three radiographic modalities.

An electric caliper (Fowler 600-mm Electronic Caliper; accuracy ± [0.00008 + 0.000002 × length (inch)] mm) was used to perform direct measurement of femur length as a gold standard. Each observer measured each of the 12 femurs from the same anatomic landmarks once at two separate time intervals. The interobserver and intraobserver reliability of all of the measurements was assessed by calculating the ICC,[15] the absolute mean differences,[15–18] and the 95% confidence interval for the length measurements. The 95% confidence intervals (CI) were based on the actual data, not a theoretical distribution. The three radiographic measurements were compared with the direct caliper measurements to assess the accuracy of the radiographic techniques.

RESULTS

All three observers measured femoral length of 12 cadaver femurs directly via electronic caliper and indirectly using x-ray scanogram, CT scanogram, and MRI scanogram images. Each measurement was made two times during two different time intervals.

To determine intraobserver variability, we examined differences between the radiographic measurements of femur length made by the same observer. Reliability of the measurements was assessed using the ICC. The ICCs by the same observer were more than 0.99 for each of the radiographic measurements (Table 1). To determine the interobserver variability, we examined the radiographic measurements made by the different observers. Reliability was again assessed using the ICC, which was also above 0.99 (Table 2). Overall, the reliability of all three radiographic measurements was excellent.

The accuracy, determined by comparing the radiographic measurements to our gold standard (electronic caliper measurement), was calculated to be more than 0.99 for the x-ray and CT scanograms and more than 0.98 for the MRI scanogram. The mean absolute difference between the radiographic and CT scanogram measurements compared with the gold standard were quite small (<1 mm). The mean absolute difference for the MRI scanogram compared with the caliper measured 2.90 mm, a relatively large discrepancy compared with the other methods (Table 3). The accuracy of x-ray scanogram was slightly superior to CT scanogram and MRI scanogram.

DISCUSSION

Several methods exist for the radiographic assessment of leg length discrepancy, including teleoroentgenogram,[3] orthoroentgenogram,[4] slit scanogram,[5–7] CT scanogram,[5–11] and ultrasound.[12,13] The reliability of x-ray scanogram and that of CT scanogram have been studied extensively, with the two techniques showing similar reliability and accuracy.[8,9,11] The direct method of measuring limb length from the x-ray scanogram using a tape measure has been shown to be extremely reliable.[14] Direct scanogram measurement has an intraobserver ICC of 0.99 and an interobserver ICC of 0.98.[14] CT scanogram has shown some advantages over radiographic scanogram, including decreased radiation exposure and better assessment of limb length in the setting of knee flexion deformity.[8]

The results of our study confirm previous study results on the reliability and accuracy of both radiographic scanogram and CT scanogram. Additionally, we established that MRI scanogram produces comparable results and is both an accurate and reliable measure of limb length. With regard to the

TABLE 1. Intraobserver Variation

Measure	ICC	MAD	95% CI
X-ray scanogram	0.99	0.42	0.24–0.60
CT scanogram	0.99	0.87	0.67–0.11
MRI scanogram	0.99	0.99	0.74–0.13

ICC, intraclass correlation coefficient; MAD, mean absolute difference (mm); 95% CI, 95% confidence interval (mm).

TABLE 2. Interobserver Variation

Measure	ICC	MAD	95% CI
X-ray scanogram	0.99	0.44	0.26–0.63
CT scanogram	0.99	0.97	0.50–1.30
MRI scanogram	0.99	1.31	0.98–1.65
Caliper	0.99	0.45	0.32–0.58

ICC, intraclass correlation coefficient; MAD, mean absolute difference (mm); 95% CI, 95% confidence interval (mm).

TABLE 3. Accuracy: Comparison to the Gold Standard (Caliper Measurement)

Measure	ICC	MAD	95% CI
X-ray scanogram	0.99	0.52	0.42–0.63
CT scanogram	0.99	0.68	0.50–0.86
MRI scanogram	0.99	2.90	2.03–3.76

ICC, intraclass correlation coefficient; MAD, mean absolute difference (mm); 95% CI, 95% confidence interval (mm).

MRI technique, our model also presented the "worst case scenario," given the lack of strong excitable water in the cadaveric specimens that is always conspicuous in the medullary fat of the subchondral bone in the clinical setting. Despite this challenge, by measuring the length of 12 cadaver femurs, we found that all three radiographic techniques showed excellent reliability (ICC $>$ 0.99) (Tables 1 and 2). Accuracy was also excellent, with radiographic and CT scanogram results slightly superior to MRI scanogram results (ICC $>$ 0.99 vs. ICC $>$ 0.98) (Table 3). The mean absolute difference of the MRI scanogram measurement compared with the caliper was significantly different, at 2.90 mm.

To our knowledge, no study has evaluated the use of MRI in measuring limb length discrepancy. The main advantage of using MRI scanogram versus CT or radiographic scanogram in vivo is that MRI does not expose patients to ionizing radiation. The disadvantages of MRI scanogram include the increased cost, the potential for patient claustrophobia, and the time needed to complete the study, although newer MRI units have enabled more rapid acquisition of image data. Claustrophobia is a potential risk, affecting 5% to 10% of patients undergoing a MRI examination.[19] MRI is contraindicated in patients with certain implantable devices, such as cerebral aneurysm clips; certain eye, ear, or penile implants; and electrical indwelling devices such as bone stimulators.[19] Although a radiographic scanogram takes 5 to 10 seconds and a CT scanogram takes about 30 seconds, MRI scanogram in the clinical setting will take less than 5 minutes. Children 6 years and older do not require sedation for MRI exams, and usually 4-year-olds tolerate the examination well with a parent in the room with them.

This study evaluated the use of MRI scanogram compared with x-ray and CT scanogram in determining leg length using 12 cadaver femurs. All three scanogram techniques showed excellent reliability and accuracy. The data in this study have shown that MRI is both highly reliable and accurate and does not use ionizing radiation. Although plain radiographic scanogram and CT scanogram are slightly more accurate, MRI scanogram merits further clinical study for the assessment of limb length.

REFERENCES

1. Moseley CF. A straight-line graph for leg-length discrepancies. *J Bone Joint Surg [Am]*. 1977;59:174–179.
2. Johnson SR, Gross MT. Intraexaminer reliability, interexaminer reliability, and mean values for nine lower extremity skeletal measures in healthy naval midshipmen. *J Orthop Sports Phys Ther*. 1997;25:253–263.
3. Moseley CF. Leg length discrepancy. In: Morrisy RT, Weinstein SL, eds. *Lovell and Winter's Pediatric Orthopaedics*. New York: Lippincott Williams & Wilkins, 2001.
4. Green W, Wyatt G, Anderson M. Orthoroetgenography as a method of measuring bones of the lower extremity. *J Bone Joint Surg [Am]*. 1946; 28:60.
5. Merrill V. *Atlas of roentgenographic positions*. St Louis, MO: C.M. Co, 1967.
6. Millwee RH. Slit scanography. *Radiology*. 1937;28:483–486.
7. Pugh DG, Winkler NT. Scanography for leg-length measurement: an easy satisfactory method. *Radiology*. 1966;87:130–133.
8. Aaron A, Weinstein D, Thickman D, et al. Comparison of orthoroentgenography and computed tomography in the measurement of limb-length discrepancy. *J Bone Joint Surg [Am]*. 1992;74:897–902.
9. Aitken AG, Flodmark O, Newman DE, et al. Leg length determination by CT digital radiography. *AJR Am J Roentgenol*. 1985;144:613–615.
10. Helms CA, McCarthy S. CT scanograms for measuring leg length discrepancy. *Radiology*. 1984;151:802.
11. Huurman WW, Jacobsen FS, Anderson JC, et al. Limb-length discrepancy measured with computerized axial tomographic equipment. *J Bone Joint Surg [Am]*. 1987;69:699–705.
12. Junk S, Terjesen T, Rossroll I, et al. Leg length inequality measured by ultrasound and clinical methods. *Eur J Radiol*. 1992;14:185–188.
13. Terjesen T, Benum P, Rossroll I, et al. Leg-length discrepancy measured by ultrasonography. *Acta Orthop Scand*. 1991;62:121–124.
14. Terry MA, Winell JJ, Green DW, et al. Measurement variance in limb length discrepancy: clinical and radiographic assessment of interobserver and intraobserver variability. *J Pediatr Orthop*. 2005;25:197–201.
15. Rosner B. *Fundamentals of Biostatistics*. Toronto: Duxbury Press, 1995.
16. Bland J, Altman DG. Comparing methods of measurement: why plotting difference against standard method is misleading. *Lancet*. 1995;346:1085–1087.
17. Bland JA, Altman DG. A note on the use of the intraclass correlation coefficient in the evaluation of agreement between two methods of measurement. *Comput Biol Med*. 1990;20:337–340.
18. Bland JA, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurements. *Lancet*. 1986;1:307–310.
19. Shellock FP, Kanal E. Magnetic resonance: bioeffects and safety. In: Stoller DW, ed. *MRI in Orthopedics and Sports Medicine*. Philadelphia: Lippincott-Raven, 1997.