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Short-term repeatability of joint space width measurements using a magnetic resonance imaging compatible knee positioning device

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Abstract

The purpose of this study was to evaluate a magnetic resonance imaging (MRI) compatible knee positioning device to aid in minimizing intratechnologist and intertechnologist differences of minimum joint space width (JSW) measurements.

Five subjects were scanned by two separate technologists, with and without an MRI-compatible positioning device. A semi-automated program calculated the minimum JSW of the tibiofemoral and patellofemoral joints. The scan-to-scan repeatability was evaluated from measurements between serial scans without subject repositioning, and the intratechnologist and intertechnologist repeatabilities were evaluated when the subject was removed from the magnet and repositioned by an individual technologist. The root mean square (RMS) error of the JSW measurements was also calculated.

All measures of scan-to-scan repeatability and intratechnologist repeatability were unchanged with the MRI-compatible positioning device. The intertechnologist repeatability decreased from 0.70 to 0.42mm, and the RMS error was significantly reduced ($P = 0.0006$) from 0.26 to 0.15mm for the tibiofemoral joint. The variability of patellofemoral JSW measurements increased when using the positioning device; however, the increases were not statistically significant. The intertechnologist repeatability increased from 1.55 to 1.79mm, and the RMS error increased from 0.58 to 0.73mm.

The MRI-compatible positioning device was successful at reducing JSW measurement variability at the tibiofemoral joint. The increase in measurement variability at the patellofemoral joint may be due to local incongruities of the articular surfaces. An MRI-compatible positioning device may be beneficial for quantitative longitudinal studies evaluating knee joint health.

Keywords

magnetic resonance imaging; osteoarthritis; knee; equipment and supplies

1 INTRODUCTION

Osteoarthritis (OA) is a degenerative disease of articular cartilage and results in the fibrillation of the articular surface, reduction in the load-bearing capabilities of the tissue, and the thickening of subchondral bone. OA afflicts more than 21 million people and is the leading cause of disability for adults in the United States [1]. OA decreases the load-bearing capabilities of the tissue and leads to impaired joint function. Magnetic resonance imaging (MRI) is a powerful tool for non-invasive evaluation of cartilage pathology *in vivo*, specifically OA. MRI of diarthrodial joints has been effective not only for evaluating qualitative measures of OA within a joint [2, 3] but also for evaluating quantitative measures, such as minimum joint space width (JSW) [4], cartilage volume [5, 6], T_2 values of cartilage [7, 8], and T_1 values of cartilage in the presence of GD-DTPA²⁻ (dGEMRIC) [9, 10]. Previous investigators have indicated that examining changes of joint cartilage over time using MRI may be difficult owing to varied subject positioning and image slice definition between different exam periods [11, 12]. These difficulties arise when different technologists position the patient differently within the scanner and obtain different slice profiles during image acquisition.

Using an MRI-compatible positioning device is one potential method to reduce intra- and inter-technologist variability during scanning. Several MRI-compatible knee joint positioning devices have been proposed in the literature [13–17]. However, these positioning devices were typically used for kinematic analysis of patellar motion and not inter- or intrascanner repeatability of joint disease.

Muhle *et al.* [13] developed a positioning device to evaluate passive kinematics of the patella. The device consisted of a support for the thigh and a support for the lower leg. The two supports were connected by a hinge to create an axis of rotation, and the patient's leg was held in each support using straps. Static kinematic analysis of the knee was performed by advancing the lower leg support up a ladder to hold the lower leg at a fixed flexion angle. Dynamic kinematic analysis consisted of active knee flexion with fast image acquisition. For both analyses, static and dynamic, the authors did not examine the repeatability of measured joint kinematics.

Shellock *et al.* [14–15] developed an MRI-compatible knee positioning device to evaluate patellar tracking abnormalities. A subject is placed in a prone position with legs strapped to the device. The subject manually positions the knee flexion angle at set intervals [15] or with free flexion [14] during scanning. These studies were successful at discerning kinematic abnormalities of symptomatic patellofemoral joints; however, the authors did not perform a scan–rescan kinematic analysis to verify the consistency and repeatability of the results.

Finally, Zembsch *et al.* [17] constructed a positioning device to evaluate real-time motion of the patella during knee flexion/extension. The scan–rescan repeatability of kinematics was due to constraint of the upper leg; however, the device was not intended for clinical use.

Although these previous studies demonstrate the effectiveness of knee positioning devices for diagnosis of patellar anomalies, the scanning protocols that were used are not part of normal clinical practice. Routine clinical MRI evaluation of knee OA uses static positioning of the joint without a knee positioning device. Patients lie in a supine position on the MRI tray and are imaged with a local surface coil or a dedicated knee coil. The authors believe it would be advantageous to use an anatomy positioning device for standard clinical evaluation. In addition, it is currently unknown how knee positioning by different technologists may influence the resulting quantitative measures of OA.

Therefore, the purpose of this study was to evaluate an easy-to-use, MRI-compatible knee positioning device to minimize the effect of intratechnologist and intertechnologist differences on quantitative measures of OA, such as minimum joint space width (JSW). The measurement of minimum JSW was chosen as the outcome measure of this study because it is a commonly used method to evaluate progression of OA in longitudinal studies [18–20]. The current method of evaluating the minimum JSW from MR images, although not a standard evaluation of OA within the knee, is a metric that provides the one-to-one comparison that is necessary when evaluating repeatability. It was hypothesized that an MRI-compatible knee positioning device would aid in reducing variability of JSW measurements from images acquired by two experienced MRI technologists.

2 METHODS

2.1 Subjects

Following local institutional review board approval and informed consent, five subjects (four males, one female, 30 ± 2 years of age, range 28–33) were enrolled in the study. None of the subjects had pain, stiffness, or other symptoms of OA in the knee that was scanned.

2.2 Subject orientation and slice definition

Two MRI technologists with six and 21 years of MRI scanning experience, respectively, independently positioned the subject and acquired all images for the study. Each technologist instructed the subject to lie on the MRI tray, with the subject's knee in the bottom half of a dedicated transmit–receive knee coil. The technologist then instructed the subject to shift proximally or distally to ensure that the centre of the knee was at the centre of the coil. The technologist finished subject preparation by securing the top portion of the knee coil to the bottom portion and by placing padding around the knee within the coil to minimize potential motion. Slice profiles were defined perpendicular to a line connecting the most posterior aspect of the medial and lateral femoral condyles seen in scout images (Fig. 1, left). The centralmost slice was positioned through the widest portion of the patella (cartilage + bone). The technologists were informed prior to scanning of how to prescribe the slices to ensure consistency across scanning subjects. A total of 31 image slices were obtained for each scan. Each technologist positioned the subject and defined the slice profiles while the other technologist was away from the scanning area.

2.3 Data acquisition

MR images of each subject's right knee were obtained using a 1.5T clinical MRI scanner (GE Health Systems, Milwaukee, Wisconsin). A dedicated transmit–receive knee coil was used for all imaging. Subject scanning was performed by the two technologists across eight scanning blocks (Fig. 2). A single scanning block consisted of one series of scout images and two series of oblique, sagittal, spiral, fast spoiled gradient-recalled (SPGR) images with frequency-selective fat suppression. The parameters for SPGR imaging were: number of arms 24, number of points 4096, number of excitations 2, flip angle 90° , slice thickness 3mm, slice spacing 3mm, FOV 15×15 cm, and number of image slices 31. The output images were 512×512 pixels in size, with an in-plane resolution of 0.29×0.29 mm. The two SPGR series were acquired in a back-to-back fashion with little to no pause between the scanning sequences and no repositioning of the subject within the scanner. The slice prescription for the second SPGR series was copied from the first SPGR series to acquire data along identical slice planes. The scanning time of an individual SPGR series was approximately 5 min. The total scanning time for each subject across all eight scanning blocks was approximately 2 h.

Each scanning block was considered to be a unique scan for each technologist. This was performed by removing the subject from the scanner entirely after each scanning block, having the subject walk around the room for a brief period of time, and having the next technologist independently position the subject's knee within the knee coil, per standard-of-care clinical evaluation. The selection of which technologist was to start scanning was randomized for each subject in the study.

2.4 Knee positioning device

Scanning was performed with and without a custom-designed, MRI-compatible knee positioning device (an overview of the positioning device is shown in Fig. 3). The device is approximately 1.5m long and 36cm wide, the width of the moving table gantry. The positioning device is constructed from plexiglass material and has restraining capabilities for anatomy proximal and distal to the knee. The proximal end of the device secures the thigh by using medial and lateral supports. These supports utilize a pegboard design of holes drilled into the positioning device. This enables easy adjustment of the thigh supports, depending on the subject's size. The middle portion of the device has a hole cut to the dimensions of the underside of the knee coil. The tightness of the fit of the knee coil within the hole, combined with the weight of the subject's leg, ensures that the knee coil is fixed in place and will not move in the positioning device during scanning. The distal portion of the device can be set for incremental changes of anterior/posterior, medial/lateral, and superior/inferior translations, as well as incremental changes of dorsal/plantar and internal/external rotations. A hinged ankle foot orthosis and toe strap secures the foot to the device. For the present scanning, the medial/lateral positioning of the leg was centred to position the knee at the magnetic isocentre of the magnet. The remaining degrees of freedom of the device were individually positioned to each subject's comfort and to ensure that the centre of the subject's knee was in the centre of the knee coil.

The four scanning blocks using the MRI-compatible knee positioning device were always performed after scanning without the device to ensure the subject's initial comfort within the scanner and with the scanning protocol.

2.5 Data analysis

Measurement of JSW from all SPGR acquisitions was made using a custom-written MATLAB (Natick, Massachusetts) program [4]. Briefly, the program assigns each pixel a value based on the ratio of signal intensity differences in the local 8 pixel neighbourhood to maximal signal intensity differences in the image. Next, the user defines a seed point to initialize the computer algorithm to search for the cartilage–bone interface. This seed point is placed on the anterior or posterior margins of the femur and tibia for calculating tibiofemoral JSW, or on the proximal or distal margin of the patella and corresponding region on the femur for calculating patellofemoral JSW. The program then performs a semi-automated line search on the image, starting at the seed point, and follows along a calculated path of maximal signal intensity differences to determine the edges of the joint space, from which the minimum JSW is calculated. This methodology has been shown to result in a significant reduction in intra- and interexaminer repeatability measurements of JSW using MR images as opposed to manual measurements [4]. An example output image from the program is shown in Fig. 4. All JSW measurements were performed by a single examiner. The minimum JSW measurements were obtained for the medial and lateral compartments of the tibiofemoral joint and for the patellofemoral joint. Each subject produced approximately seven slices of image data for the combined tibiofemoral joints, and approximately six slices of image data for the patellofemoral joint. It was assumed that the subjects were scanned in a relaxed state; muscle contraction was negligible and was not considered in the minimum JSW calculations.

2.6 Statistical analysis

The scanning protocol enabled analysis of JSW measurements without the positioning device (scanning blocks 1 to 4) and with the positioning device (scanning blocks 5 to 8) (see Fig. 2). The scan-to-scan JSW repeatability within each scanning block (scanning blocks 1 to 8), the intratechnologist repeatability (scanning blocks: 1 versus 3, 2 versus 4, 5 versus 7, 6 versus 8), and the intertechnologist repeatability (scanning blocks: 1 and 3 versus 2 and 4, 5 and 7 versus 6 and 8) were analysed. JSW measurements from matching slice numbers between each technologist across all acquired series for each subject were used for the analyses. The scan-to-scan analysis used JSW measurement output from the individual SPGR series within each scanning block. The JSW measurements from the two SPGR series were averaged for the subsequent intratechnologist and intertechnologist analyses. Additional numerical measures of scan-to-scan, intratechnologist, and intertechnologist variability were calculated using the root mean square (RMS) error, the 95 per cent confidence interval of the RMS value, and the coefficient of variation (COV) of the JSW values. The average and 95 per cent confidence interval of the RMS and the COV were calculated using repeated measurements of each slice of each subject by each technologist, as outlined previously by Glüer *et al.* [21]. A *t*-test was performed using averaged JSW measurements from each examiner to detect differences in JSW values between the patellofemoral and tibiofemoral joints with and without an MRI-compatible knee positioning device.

Bland–Altman plots were created to evaluate the variability of the JSW data. These plots are effective at highlighting trends and differences between two independent measurements of a single variable [22]. The plots display the average JSW value of matching slices on the abscissa and the difference in the JSW values on the ordinate. A repeatability coefficient was calculated from the Bland–Altman analysis as 1.96 times the standard deviation of the differences. Therefore, an increase in repeatability denotes a reduction in measurement reproducibility. In addition, the mean of the absolute differences in average JSW values was calculated.

3 RESULTS

3.1 Tibiofemoral joint

The average minimum JSW for the tibiofemoral joint with and without the positioning device was 2.75mm (SD 0.41mm) and 3.25mm (SD 0.83mm) respectively. This difference was not significant ($P = 0.05$). The mean JSW difference from scan-to-scan imaging for both technologists combined was 0.00mm (SD 0.14mm) without the positioning device and 0.03mm (SD 0.18mm) with the device (Table 1). The scan-to-scan repeatability increased slightly from 0.28 to 0.35mm when using the positioning device. The corresponding increase in RMS error was not significant ($P = 0.16$) (Table 2). The mean intratechnologist JSW difference was -0.05 mm (SD 0.22mm) without the positioning device and 0.00mm (SD 0.21mm) with the positioning device. The intratechnologist repeatability was reduced from 0.43 to 0.42mm when using the positioning device. The corresponding reduction in RMS error was not significant ($P = 0.52$). The mean intertechnologist JSW difference was -0.08 mm (SD 0.36mm) without the positioning device and -0.02 mm (SD 0.21mm) with the device (Fig. 5). The intertechnologist repeatability decreased from 0.70 to 0.42mm. The RMS error was significantly reduced from 0.26 to 0.15mm ($P = 0.0006$). The intertechnologist COV was also reduced from 6.2 to 4.1 per cent.

3.2 Patellofemoral joint

The average minimum JSW for the patellofemoral joint with and without the positioning device was 3.94mm (SD 0.77mm) and 4.15mm (SD 0.78mm) respectively. This difference

was not significant ($P = 0.97$). The average JSW difference from scan-to-scan imaging for both technologists combined was 0.06mm (SD 0.28mm) without the positioning device and -0.01mm (SD 0.32mm) with the device (Table 3). The scan-to-scan repeatability increased slightly from 0.56 to 0.62mm when using the positioning device. The corresponding increase in RMS error was not significant ($P = 0.74$) (Table 4). The mean intratechnologist JSW difference was 0.04mm (SD 0.54mm) without the positioning device and 0.07mm (SD 0.58mm) with the positioning device. The intratechnologist repeatability increased from 1.06 to 1.14mm when using the positioning device. The RMS error increased as well, but was not significant ($P = 0.87$). The mean intertechnologist JSW difference was 0.23mm (SD 0.79mm) without the positioning device and 0.50mm (SD 0.91mm) with the device (Fig. 6). The intertechnologist repeatability increased from 1.55 to 1.79mm. The RMS error increased from 0.58 to 0.73mm but was not significant ($P = 0.09$). The intertechnologist COV also increased from 11.5 to 15.6 per cent.

4 DISCUSSION

Evaluating quantitative changes in joint pathology over time using MRI requires placement of image slice planes with high repeatability. It is likely that repeated scans at different time points will be performed by separate technologists, each with varying levels of MRI experience. Using a simple limb positioning device within the MRI scanner may increase measurement repeatability over different time points. This study used an MRI-compatible knee positioning device to evaluate intra- and intertechnologist scanning differences in tibiofemoral and patellofemoral joint minimum JSW measurements.

The results when using the positioning device were not consistent for the tibiofemoral and patellofemoral joints. The MRI-compatible knee positioning device consistently reduced the variability of the JSW measurements for the tibiofemoral joint. The intra- and intertechnologist repeatabilities were both reduced, by 3.5 and 39.7 per cent respectively. Using the device resulted in a small increase in the scan-to-scan repeatability of the JSW measurements; however, the increase was small compared with the effective pixel resolution of the acquired images. Similarly, use of the positioning device reduced the RMS error and COV of the JSW measurements.

Unlike the tibiofemoral joint, the intra- and intertechnologist repeatabilities of the patellofemoral joint both increased, by 7.4 and 15.6 per cent respectively, when the positioning device was used. Furthermore, all measures of RMS error and COV also increased when the positioning device was used; however, these increases were not statistically significant. The increases in repeatability and RMS error were less than the effective pixel resolution of the acquired images.

It is unclear why the results were not consistent for the tibiofemoral and patellofemoral joints. The inconsistencies are attributed to the inherent complex curvature characteristics of the patellar and the distal femoral articular and subchondral bone surfaces [23–26]. Kwak *et al.* found three prominent ridges on the patellar articular surface: a lateral transverse ridge, a proximal median ridge, and an oblique ridge. On the opposing femoral surface, the cartilage within the trochlea, the region of interest for the present study, was uniformly sellar (saddle-shaped). It is believed that the shape/curvature of these articular surfaces aids in maintaining a large contact area between the patella and distal femur during active knee flexion [23]. Staubli *et al.* [25, 26] used MR arthrograms and found a statistically significant difference between the location of the median patellar subchondral osseous prominence and the corresponding cartilage median ridge prominence. Shih *et al.* [24] also found significant differences in the subchondral bone contour from the contour of the articular surface in the femoral trochlea. The varying articular surface geometry and underlying subchondral bone

geometry across the patellar and femoral sulcus surfaces may have had a subtle effect in the present JSW repeatability measurements. Not only would any small change in the orientation of the defined slice profile through the patella result in imaging a slightly different region of patellar cartilage, but also its effect would be magnified by the widely varying local patellar curvature characteristics (this effect would probably be minimal in the femoral trochlea owing to its uniform saddle appearance). A planar geometry model corresponding to the sagittal slices of the scan was created to evaluate changes in minimum JSW measurements owing to small angulations of the slice planes (Fig. 1, right). Using the variables shown in Fig. 1, the original JSW = $(B - A)$. A change in angulation of the sagittal slices by h degrees results in a new JSW = $(D + \beta) - (E + \alpha)$. After making the appropriate geometric substitutions, the new JSW = $(B - A)/\cos \theta + (\beta - \alpha)$. The first term represents the effect of angulation of the slice plane, and the second term represents the effect of local curvature of the bony anatomy. For small θ , the first term remains unchanged, resulting in the local curvature of the subchondral bone being the dominant factor in altered minimum JSW measurements.

The effect of the varied anatomical curvature was also compounded by the potential mismatch of knee flexion angle between scanning without the positioning device and scanning with the positioning device. All attempts were made to place each knee at approximately 20° of flexion during scanning. This angle corresponds to the angle at which peak load occurs in the knee during walking [27]. A slight deviation from this flexion angle may have altered the position of the patella and the imaged articular surface used for the minimum JSW measurements. This too would increase the variability of the measurements. Conversely, the curvatures of the femur and tibia are locally constant over a larger range of flexion angles [23], and the resulting tibiofemoral minimum JSW measurements would be less susceptible to small changes in knee flexion position during scanning.

The repeatability of the present measurements is comparable with previous investigations of JSW measurements. Most published studies that have evaluated repeatability used radiographic images for their analyses. Kothari *et al.* [28] acquired radiographs with the knee at a fixed flexion angle at two time points. The study produced a short-term RMS error of 0.14mm and a COV of 4.3 per cent for the medial compartment, and a short-term RMS error of 0.23mm and a COV of 4.0 per cent for the lateral compartment. Similarly, Peterfy *et al.* [29] performed a scan-rescan study for minimum medial tibiofemoral JSW of the knee. The study reported RMS errors of 0.2–0.3mm and 0.1mm for manual and semi-automated measurements respectively. Finally, Grochowski *et al.* [30] used a semi-automated image analysis algorithm to evaluate minimum JSW of the patellofemoral joint. The study reported coefficients of repeatability of 1.24–1.66mm for between-day results of minimum JSW measurements. Even though these studies produced results that are similar in magnitude to the present study, direct comparisons are difficult to make. For instance, radiographic images are acquired at a much higher resolution than MR images, e.g. 0.02 mm/pixel [30] versus 0.29 mm/pixel for the present study. In addition, MR images are acquired with the subject in a supine position, while knee radiographs are typically acquired with the subject in a weight-bearing position.

One previous study evaluated between-day repeatability of minimum JSW measurements using MRI [4]. The study found minimum JSW differences of tibiofemoral and patellofemoral JSW measurement to be 0.09mm (SD 0.39mm) and 0.09mm (SD 0.52mm) respectively. Although the repeated scans of the present study were not truly between day, each subject was removed from the scanner and walked around the exam room for several minutes. This required the next scanning technologist to reposition the subject in the scanner as if it were a completely new exam. The present results for the intertechnologist tibiofemoral joint JSW measurement differences, repeatability, and COV are comparable

with those of the previous study. The results for the patellofemoral joint measurements were slightly elevated. The differences in magnitude are relatively small and may be due to the larger number of slices analysed in the present study ($n = 66$) than were analysed in the previous study ($n = 30$). It should be noted that this previous study produced a higher COV value for the patellofemoral joint (8.3 per cent) than for the tibiofemoral joint (5.8 per cent) and also found that *manual* measurements of JSW were slightly better than *automated* measurements. The statistical results of the previous and the present study indicate that the patella may not be best suited for the algorithm.

The present study used a two-dimensional (2D) image acquisition, as this is the basis of a longitudinal study of knee OA in the authors' laboratory and the current clinical image acquisition method for examining OA of the knee. It is uncertain how the results may change if newer, three-dimensional (3D) image acquisition methods are used or if different quantitative measures of cartilage degeneration during OA, e.g. measuring cartilage volume, are employed. The results of this study highlight the importance of MRI-compatible positioning devices to increase measurement precision from MR images.

5 CONCLUSION

MR scans on a single subject performed at different time points may have different results owing to the varying experience level of MRI technologists. The authors' limb positioning device was successful at reducing JSW measurement variability at the tibiofemoral joint. The increase in measurement variability at the patellofemoral joint may be due to local incongruities of the articular surfaces. The newly developed knee positioning device may be beneficial for longitudinal studies evaluating knee joint health using MRI.

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Geometric Model of JSW Measurement
With Slice Plane Angulation Altered by θ degrees

Fig. 1.

(Left) Schematic diagram indicating the location of the central image slice. Slice profiles were defined perpendicular to a line connecting the most posterior aspect of the medial and lateral femoral condyles seen in scout images. The central slice was positioned through the widest portion of the patella (cartilage + bone). The joint space width is calculated as the distance between the cartilage–bone interface of opposing bones, shown as segment AB. (Right) A change in angulation of the central slice results in $JSW = (B - A) / \cos \theta + (\beta - \alpha)$. For small θ , the first term remains unchanged, but the second term is representative of the local bony curvature and is the dominant factor for detected changes in measured JSW

Fig. 2.

Scanning was performed across eight scanning blocks, with and without an MRI-compatible knee positioning device (scanning blocks 1 to 4 and 5 to 8, respectively). A single scanning block consisted of one series of scout images and two scan-to-scan series of oblique SPGR images. The subject was removed from the scanner between each scanning block. Statistical analyses included scan-to-scan JSW repeatability within each scanning block (scanning blocks 1 to 8), intratechnologist repeatability (scanning blocks: 1 versus 3, 2 versus 4, 5 versus 7, 6 versus 8), and intertechnologist repeatability (scanning blocks: 1 and 3 versus 2 and 4, 5 and 7 versus 6 and 8)

Fig. 3.

(a) Oblique view of MRI-compatible positioning device proximal to knee coil. Medial and lateral thigh supports are placed around the leg once a subject is positioned in the device. The pegboard design for securing the medial and lateral thigh supports easily allows for different-size subjects. (b) Oblique view of positioning device distal to knee coil. The distal portion of the device can be set for different degrees of anterior/posterior (A/P), medial/lateral (M/L), and superior/inferior (S/I) translations, as well as dorsal/plantar and internal/external rotations. A hinged ankle foot orthosis (AFO) and velcro strap secures the angle and holds the foot on the device

Fig. 4. Representative SPGR scan of the lateral compartment of the tibiofemoral joint. The inset shows graphical output from the semi-automated minimum JSW calculating program. Red lines display the cartilage–subchondral bone surface, and the blue line indicates the minimum distance between the two surfaces. A similar method was used to define the minimum JSW of the patellofemoral joint

Fig. 5. Bland–Altman plots for intertechnologist JSW measurements of the tibiofemoral joint without (left) and with (right) an MRI-compatible knee positioning device. The mean difference of each plot is shown as a solid line, and the upper and lower limits of agreement are shown as dashed lines. The intertechnologist repeatability coefficient without the device is 0.70mm, and 0.42mm when the device is used. The precision of the measurements increased significantly when using the positioning device

Fig. 6.

Bland–Altman plots for intertechnologist JSW measurements of the patellofemoral joint without (left) and with (right) an MRI-compatible knee positioning device. The mean difference of each plot is shown as a solid line, and the upper and lower limits of agreement are shown as dashed lines. The interexaminer repeatability coefficient without the device is 1.55mm, and 1.79mm when the device is used

Table 1

Bland–Altman analysis of tibiofemoral JSW measurements

		Without device	With device
Scan-to-scan	JSW difference (mm)*	0.00 ± 0.14	0.03 ± 0.18
	Absolute value of JSW difference (mm)*	0.11 ± 0.09	0.13 ± 0.13
	Repeatability coefficient (mm)	0.28	0.35
Intratechnologist	JSW difference (mm)*	−0.05 ± 0.22	0.00 ± 0.21
	Absolute value of JSW difference (mm)*	0.17 ± 0.15	0.15 ± 0.15
	Repeatability coefficient (mm)	0.43	0.42
Intertechnologist	JSW difference (mm)*	−0.08 ± 0.36	−0.02 ± 0.21
	Absolute value of JSW difference (mm)*	0.26 ± 0.25	0.16 ± 0.15
	Repeatability coefficient (mm)	0.70	0.42

* Expressed as mean ± standard deviation.

Table 2

Repeatability of tibiofemoral JSW measurements

		Without device	With device	P-value
Scan-to-scan	RMS error (mm)	Mean	0.10	0.13
		95% CI LCL *	0.09	0.12
		95% CI UCL †	0.11	0.15
Intra-technologist	COV (%)		2.4	3.5
	RMS error (mm)	Mean	0.16	0.15
		95% CI LCL *	0.14	0.13
Inter-technologist		95% CI UCL †	0.12	0.18
	COV (%)		3.8	4.1
	RMS error (mm)	Mean	0.26	0.15
		95% CI LCL *	0.22	0.13
		95% CI UCL †	0.31	0.18
	COV (%)		6.2	4.1

* Lower limit of the 95 per cent confidence interval of all precision errors calculated using the χ^2 distribution.† Upper limit of the 95 per cent confidence interval of all precision errors calculated using the χ^2 distribution.

Table 3

Bland-Altman analysis of patellofemoral JSW measurements

		Without device	With device
Scan-to-scan	JSW difference (mm)*	0.06 ± 0.28	-0.01 ± 0.32
	Absolute value of JSW difference (mm)*	0.20 ± 0.21	0.21 ± 0.24
	Repeatability coefficient (mm)	0.56	0.62
Intratechnologist	JSW difference (mm)*	0.04 ± 0.54	0.07 ± 0.58
	Absolute value of JSW difference (mm)*	-0.44 ± 0.31	-0.43 ± 0.39
	Repeatability coefficient (mm)	1.06	1.14
Intertechnologist	JSW difference (mm)*	0.23 ± 0.79	0.50 ± 0.91
	Absolute value of JSW difference (mm)*	0.70 ± 0.43	0.82 ± 0.63
	Repeatability coefficient (mm)	1.55	1.79

* Expressed as mean $\pm$ standard deviation.

Table 4

Repeatability of patellofemoral JSW measurements

		Without device	With device	P-value
Scan-to-scan	RMS error (mm)	Mean	0.20	0.22
		95% CI LCL *	0.18	0.20
		95% CI UCL †	0.23	0.25
Intra-technologist	COV (%)		4.1	4.7
	RMS error (mm)	Mean	0.38	0.41
		95% CI LCL *	0.33	0.35
Inter-technologist		95% CI UCL †	0.46	0.50
	COV (%)		7.6	8.7
	RMS error (mm)	Mean	0.58	0.73
		95% CI LCL *	0.49	0.63
		95% CI UCL †	0.70	0.88
	COV (%)		11.5	15.6

* Lower limit of the 95 per cent confidence interval of all precision errors calculated using the χ^2 distribution.† Upper limit of the 95 per cent confidence interval of all precision errors calculated using the χ^2 distribution.