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Editorial
Optimization of the fixed-flexion knee radiograph[1]

H. C. Charles Ph.D.†*, V. B. Kraus‡, M. Ainslie†, M.-P. Hellio Le Graverand-Gastineau§

† *Duke Image Analysis Laboratory, Department of Radiology, NC, United States*

‡ *Department of Medicine, Duke University, Durham, NC 27710, United States*

§ *Pfizer, Inc., Ann Arbor, MI, United States*

Summary

Purpose: To develop a user-friendly method of achieving optimal radiographs for measurement of joint space width of the knee with minimal radiation exposure. In order to accomplish this the X-ray technologist must (1) be able to identify the anterior and posterior rims of the tibial plateau at a variety of X-ray head angles and (2) be able to choose the direction to adjust the head angle to get a better view based on the criteria for acceptable radiographs.

Methods: We have developed a training manual and materials to instruct investigators and radiology technologists in a method that uses a commercially available Plexiglas positioning frame (Synaflexer™) and standard X-ray equipment to achieve optimal X-rays with regard to tibial plateau alignment of the knee. This should be accomplished with four or fewer radiographs.

Results: Optimized radiographs for joint space width measurements are achieved without the need for fluoroscopy or foot maps.

Conclusions: This method is readily understood and instituted by radiology technologists in the field.

Key words: Knee, Radiography, Optimization, Joint space width, Osteoarthritis.

Introduction

The goal of this study is to develop a user-friendly and readily deployable method for achieving optimal tibiofemoral knee alignment on a knee radiograph for joint space width measurements and measurements of joint space narrowing. The importance of joint space width and joint space narrowing as a validated measure of knee osteoarthritis (OA) progression has led to the development of a variety of methods to optimize tibiofemoral plateau alignment[1–3]. Optimal alignment is generally characterized by superimposition of the anterior and posterior margins of the tibial plateau in the projection X-ray. Alignment of these two margins (intermargin distance or IMD) to within 1.2 mm has been established as the goal in specific clinical trials[4,5]. Because the majority of knee OA occurs in the medial compartment, optimal alignment is usually sought for the medial tibiofemoral plateau.

Images of the knee in flexion are now generally considered superior to standing anteroposterior (AP) views[6], however, in other respects, the methods vary for achieving optimal medial tibial plateau alignment. Variations include the use of either AP or posteroanterior (PA) views, the use of a Plexiglas frame to standardize knee flexion and foot positioning, and the use of fluoroscopy to adjust the X-ray beam angle. Unlike the AP views, the PA views of the knee in flexion minimize the need for magnification correction[6]. One approach has been to use fluoroscopy for optimal alignment of the medial tibial plateau and the Plexiglas frame to improve standardization of the angle of knee flexion[7]. The fluoroscopic devices (R&F systems) for this approach require: (1) fluoro head angulation control independent of table angulation; (2) the ability to position the table vertically and support the weight of a 350 pound subject; and (3) the ability to reproducibly adjust the fluoro head in small ($\sim 1°$) increments. Radiologic practices vary regionally and such units have been more widely used in Europe compared to the US, thus hampering the potential for international standardization of a method based upon the availability of this instrument. Further, earlier models are reaching end of life and currently, not all manufacturers have models with the above capabilities. In addition to these practical difficulties, it is often difficult to adequately visualize both the anterior and posterior tibial margins using fluoroscopy due to the lower contrast resolution obtained with fluoroscopy compared to a Bucky/grid acquisition. This training manual describes a simple method of achieving optimal tibial plateau alignment without the use of fluoroscopy but with the use of a commercially available Plexiglas positioning frame (Synaflexer™).

Method

TECHNICAL MANUAL DEVELOPMENT

Fixed-flexion PA knee radiographs were taken with the Synaflexer™ X-ray positioning frame [Synarc, Inc., San

[1]Supported in part by Pfizer, Inc.
*Address correspondence and reprint requests to: Dr H. Cecil Charles, Ph.D., Duke University, Duke Image Analysis Laboratory, Department of Radiology, DUMC Box 2702, Durham, NC 27705, United States. Tel: 1-919-684-7921; Fax: 1-919-684-7147; E-mail: cecil.charles@duke.edu

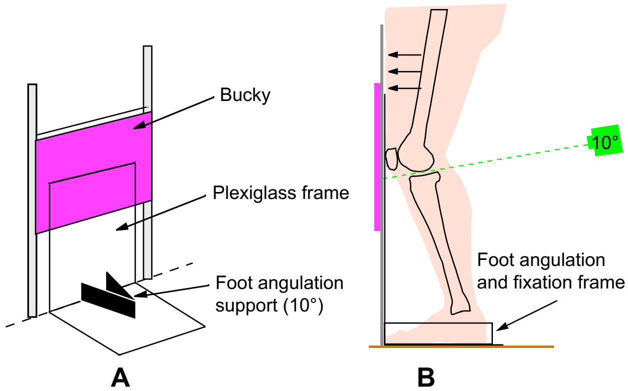

Fig. 1. General example of the Synaflexer™ device (A) showing the foot angulation, and (B) showing the subject placement and knee and thigh positioning and the starting head angulation (figures courtesy of and with the permission of Synarc, Inc.).

Francisco, CA, Fig. 1(A)] according to the general procedures provided with the device[3]. The Synaflexer™ frame allows convenient, reproducible positioning of the knee for serial examinations within and across subjects without the need for creation and storage of foot maps. The feet are externally rotated 10°, the knees and thighs touch the vertical platform anteriorly, and the X-ray beam is angulated 10° caudally [Fig. 1(B)] for the fixed head angle radiograph proposed in the Synarc documentation. We have expanded upon this process, to obtain in a series of four or less radiographs, a tibial margin alignment of ≤1–1.5 mm using visual queues and fiducials on the Synaflexer™ device.

For purposes of training investigators and radiology technicians, a manual was developed incorporating the details in this document. All procedures were approved by the Institutional Review Board of Duke University Medical Center. For training purposes, PA knee radiographs of a knee phantom were taken with X-ray beam angles of 10° of caudal angulation to 10° of cranial angulation at 2.5° increments. The resulting series of PA knee radiographs is shown in Fig. 2. These images are used as a portion of the training materials. Further, the X-ray technologists can use the phantom to practice X-ray beam angle alignment and to test their skills at proper identification of the anterior and posterior rims.

To insure the proper starting beam angle (10° caudal angulation), a bubble inclinometer (Fabrication Enterprises, Inc.) was placed on the X-ray head and calibrated at the horizontal setting (Fig. 3). This is often necessary as many X-ray systems only provide crude visual angle markers (e.g., 10–15° intervals). Further, the physical detents that fix the X-ray head are usually in increments > 1° (e.g., 2° or even 2.5°). If no friction stop is available (typical scenario on most systems), these crude degree settings represent the 'best' incremental settings for a particular

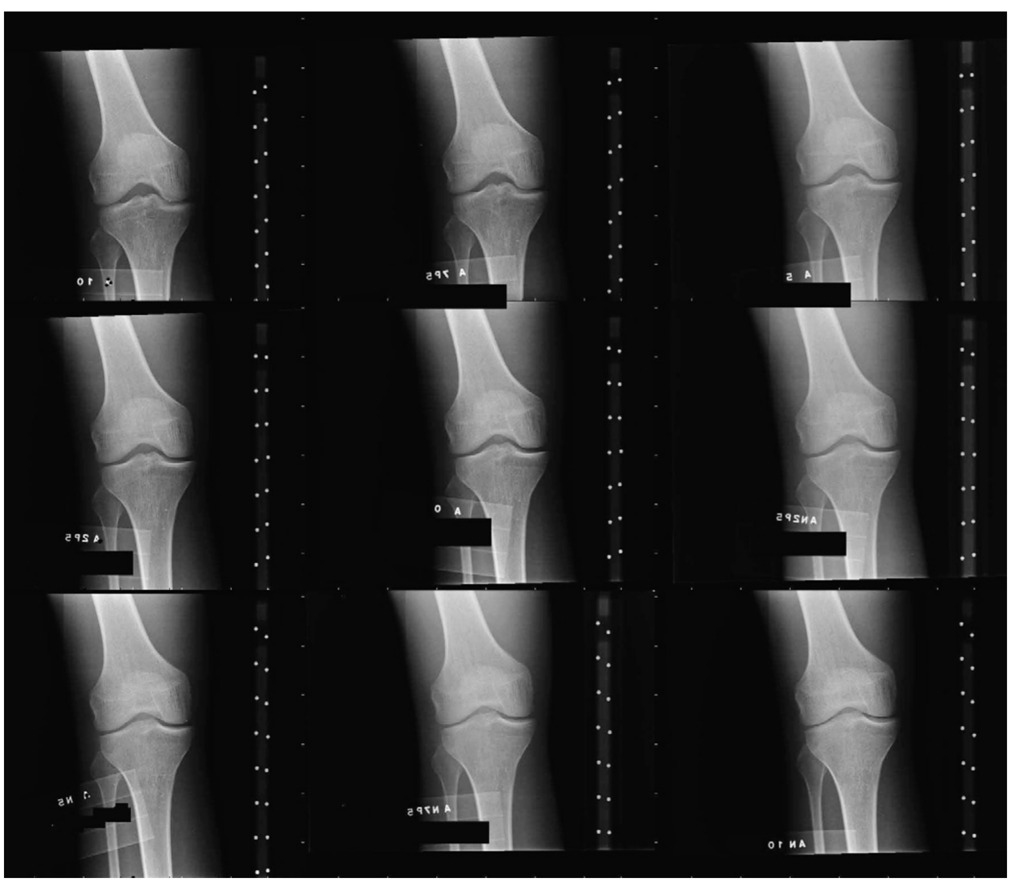

Fig. 2. Examples of radiographs for obtaining an optimal tibiofemoral plateau alignment (acquired with X-ray beam angulation ranging from 10° caudal to 10° cranial in 2.5° increments, upper left to lower right). Note the optimum at 2.5° cranial (middle right image) with an IMD ∼ 1 mm at the center of the medial compartment.

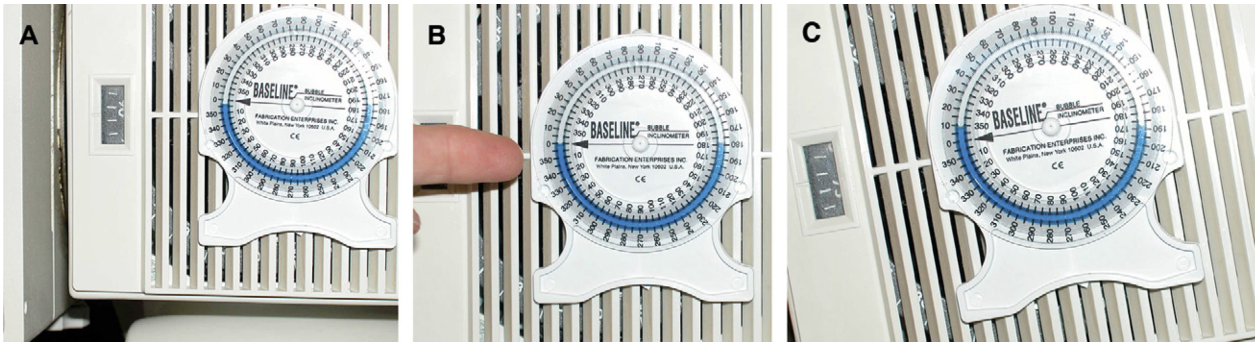

Fig. 3. X-ray head angulator calibration with a bubble inclinometer. (A) The bubble inclinometer is Velcro fastened to the X-ray head (left figure) with the head in the horizontal position. (B) The calibration dial is rotated to place the arrow at zero (right figure) prior to adjusting the head angle. Note the coarse indicator on the equipment to the left of the bubble inclinometer and the fact that the indicator is not accurately calibrated. (C) The head angle is read at the bottom of the concave air/blue water interface (see red arrow). Here we see a 9° caudal head angle. Again note the inability to determine the head angle on the actual equipment (and it's lack of calibration).

X-ray system. However, a few newer digital systems now exist with 1° setability.

RECOMMENDED PROTOCOL TO OPTIMIZE TIBIAL MARGIN ALIGNMENT IN A CLINICAL SETTING

The subject is presented in the X-ray suite to the Synaflexer™ device in stocking feet (no footwear is allowed). The subject is instructed to stand upright on the Synaflexer™ device with the great toes of both feet in contact with the anterior wall of the frame [Fig. 1(B)]. The index foot is placed against the V-shaped support at the base of the Synaflexer™ device to provide 10° external rotation. The non-index foot is placed away from the V-shaped support but with the great toe in contact with the anterior wall of the frame. The subject's body weight is distributed equally between the two legs. The knees and thighs are pressed directly against the anterior wall of the Synaflexer™ device to fix the flexion of the knee [Fig. 1(B)]. The subject will need to hold onto the support rails of the X-ray system or any step stool system if such is used, due to lower limits of Bucky adjustment. The X-ray beam is centered on the joint line of the index knee with a 10° caudal X-ray head angle (representing the 'starting angle') [Fig. 1(B)]. In subsequent visits, the technologist can start with the angle determined to be optimal at study visit 1. It is likely that an alternative indicator (e.g., a bubble inclinometer) will need to be used to set the angle as described above (see Fig. 3).

Protect the subjects' gonads with appropriate placement of a lead apron. Use appropriate exposure technique for a PA radiograph of the knee: FFD 40 in.; 65–72 kVp; 10 in. × 12 in. cassette (digital or film); Bucky technique; and left and right (L/R) Lead Markers (or digital markers if appropriate).

An acceptable X-ray will meet the following criteria: an open joint space; the long axis of the tibia should be parallel to the radiograph margins; the knee joint should be in the middle of the radiograph; the entire joint should be visible; L/R markers should be visible; the Synaflexer™ device markers must be visible [the 3 mm (0.12 in. nominal) diameter holes that are 25.4 mm (1 in.) apart in the central spine of the device seen in Fig. 2]; and the radiograph must have optimal exposure (cone beam to cassette size). Finally, the IMD at the center of the medial compartment must be in the range of 1–1.5 mm or <1/3 or 1/2 of the diameter of the Synaflexer™ device marker holes (nominal 3 mm diameter). If this is not achieved, change the head angle in the appropriate direction and expose another radiograph. Careful examination of the phantom images should help to guide the identification of the posterior and anterior margins. If the anterior margin is above the posterior margin, adjust the beam more cranial. If the posterior margin is above the anterior, adjust the beam more caudal. The amount is proportional to the size of the IMD, a large IMD means a greater angle change must be effected to improve the image. It is often easier to note the margins

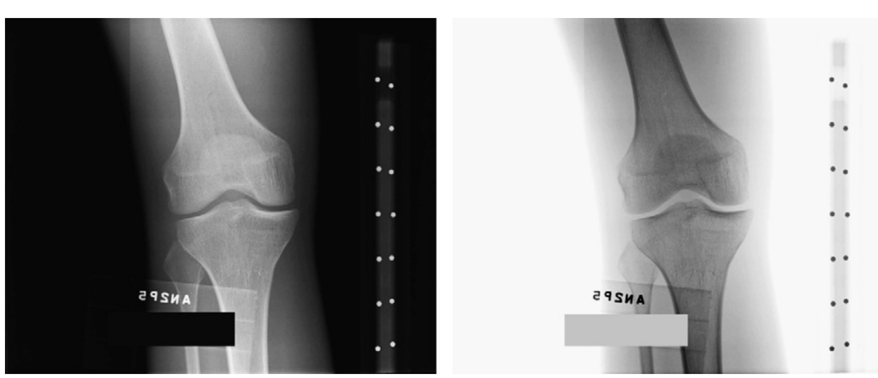

Fig. 4. Comparison of inverted vs conventional display for visualization of the IMD.

on an inverted contrast display, which is easily done on digital X-ray machines that are becoming more prevalent (Fig. 4). In subsequent visits, the technologist should start with the optimum baseline angle established at visit 1.

Conclusions

The developers of the fixed-flexion knee device (Synaflexer™) have shown previously that a mean beam angle of $9.0^{\circ} \pm 3.6^{\circ}$ achieves optimal alignment of the anterior and posterior tibial plateau margins[3]. The goal of achieving optimal alignment in a multi-site clinical trial requires adequate training of the radiology technologist to enable appropriate visual recognition and identification of the margins, and to understand the direction and magnitude of adjustment of the beam angle needed to achieve optimal alignment, as well as visual comparison to a fiducial marker on the Synaflexer™ device. We have chosen to focus training on the recognition and achievement of the "endpoint" of minimizing the EMD. To accomplish this, radiology technologists must also usually overcome limitations related to X-ray equipment that was not designed for fine angulation adjustment and backlash inherent in such adjustment. This training approach provides this information for the technologist. This variation on the fixed-flexion knee radiographic method yields knee radiographs that are optimized for joint space measurements. Moreover, these are achieved with a minimum of radiation exposure to the study participant, especially compared to the combined fluoroscopic technique. For instance, radiation exposures accrued from four PA knee radiographs equals 0.12 mSv in contrast to the radiation exposure due to 30 s of fluoroscopy followed by one PA or AP view which equals 0.24 mSv (exposures calculated using the Duke Radiation Safety Radiation Risk Wizard developed by Robert E. Reiman, MD, OESO). We have found this method to be readily understood and instituted by radiology technologists in the field in a recent multicenter magnetic resonance imaging (MRI)/X-ray study. As an evidence of this, the mean final IMD 0.92 mm (0.40 standard deviation [SD]) has been achieved in a study based upon knee radiographs from 96 subjects at seven centers using this approach. This represents a user-friendly method for achieving optimal knee radiography for quantitative assessment of joint space widths.

Appendix

The following radiation exposures were calculated using the Duke Radiation Safety Radiation Risk Wizard developed by Robert E. Reiman, MD, OESO:

1. Four PA or AP X-ray views (0.12 mSv).
2. 30 s of fluoroscopy followed by one PA or AP view (0.24 mSv).

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