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Are static and dynamic kinematics comparable after total knee arthroplasty?

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ABSTRACT

Knee kinematics provide information about how the femoral, tibial and patellar bones or prosthetic components move relative to each other. Accurate knowledge of kinematics is valuable for implant design, comparisons between designs or surgical techniques, and to identify differences between patients with good and poor outcomes. Both static and dynamic imaging techniques have been used to evaluate kinematics. In general, static imaging is used to capture better quality images or to capture views that cannot be acquired by dynamic imaging, whereas dynamic imaging is used to capture real-life movements. How well static kinematics represent dynamic kinematics is subject to frequent debate and has not been adequately addressed, especially after total knee arthroplasty (TKA). We compared the static and dynamic weightbearing kinematics of 10 female subjects after TKA. Using the same clinical scanner for both methods, static images were taken using our standard protocol, sequential-biplane radiographs at multiple flexion angles, as well as with dynamic video fluoroscopy during a step up activity. The static method can reliably measure all 12 degrees of freedom (DOF) after TKA, however only seven were compared due to the poorer out-of-plane reliability in the single-plane dynamic imaging. No differences were found between the static and dynamic kinematics for nine out of ten subjects. For one subject, however, a difference of 5–8° in internal/external tibial rotation was found. The research question, study purpose and the advantages and disadvantages of each method need to be considered when determining which imaging method to use.

1. Introduction

Abnormal tibiofemoral and patellofemoral knee kinematics after total knee arthroplasty (TKA) can result in functional limitations, implant wear, pain, and dissatisfaction (Ezzet et al., 2012; Baldini et al., 2007; Shih et al., 2004; Saevarsson, 2012; Lützner et al., 2012). Methods are needed to compare patients with good and poor results. Numerous studies have shown that the kinematics after TKA are different than in the normal, healthy knee and vary with implant design and surgical technique (Harman et al., 2012; Dennis et al., 2003). To achieve the next generation of implant designs with more natural kinematics, it is necessary to measure kinematics accurately. Furthermore, to understand the range of normal knee kinematics after TKA and to correlate knee pain and discomfort accurately with abnormal kinematics it is important to use methods that represent normal knee movements.

Sequences of static images have been captured to simulate the joint movements of the natural knee in vivo. Capturing static images with the knee flexed at different angles has the advantage that better quality images can be collected compared to dynamic images, since dynamic images usually have motion artifacts and lower resolution. Static images can also be captured at a lower radiation dose due to the smaller number of images. Collecting static images provides the possibility of collecting three-dimensional (3D) images of the bones using either computed tomography (CT) or magnetic resonance imaging (MRI), with MRI providing information about the surrounding soft tissue. Standard MRI imaging, however, requires the subject to be stationary to collect images of good quality (D'Entremont and Wilson, 2010).

To our knowledge only two studies, both recent, have investigated whether capturing a series of static images represents dynamic knee movement; both studied young, healthy subjects and each study has limitations (Mu et al., 2011; D'Entremont et al., 2012). One of the studies compared the kinematic results from two different study methods, where one

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of the methods used static MRI images to evaluate knee kinematics and the other used video fluoroscopy (Mu et al., 2011). These were two separate studies with 2 different groups of subjects participating in the studies, with the purpose of comparing the averages of the two methods to determine normal movement. The MRI study had 10 male Caucasian subjects aged 20–30 years while the fluoroscopy study had six Asian male subjects aged 28–31 years. The authors concluded that dynamic knee kinematics, measured as the movement of the femoral condyles on the tibial plateau, can be represented by collecting static images for subjects with healthy knees (Mu et al., 2011). Another group compared the static and dynamic movement of the knees of 10 healthy subjects using MRI (D'Entremont et al., 2012). Making direct 3D/3D comparisons for the same subjects, they came to the opposite conclusion where they found that, for 8 of the 11 degrees of freedom (DOF) of the patellofemoral (PF) and tibiofemoral (TF) joints (excluding TF flexion, which was matched), differences did exist between dynamic and static kinematics. However, they were only able to compare the kinematics for knee flexions from 5° to 30° and the subjects were lying on a bed pressing very slowly on a knee rig loaded at 8% of their bodyweight rather than fully weightbearing during an everyday activity. PF kinematics have been shown previously to differ between no, partial and full weightbearing (Draper et al., 2011; McWalter et al., 2010; Baldini et al., 2007). It therefore remains unclear if capturing a series of static weightbearing images represents dynamic kinematics, especially in a TKA population. The purpose of this study was therefore to compare the static and dynamic kinematics of subjects with a total knee replacement when performing a step up, a typical weightbearing activity of daily living. Our goal was not to compare the two methods of measurement and analysis, which has been analyzed previously without showing a substantial difference (Acker et al., 2011). Rather, our goal was to determine if true differences exist between the static and dynamic movements in vivo, in other words, does the individual move in a different way dynamically than they do statically after TKA?

2. Materials and methods

2.1. Subjects

We imaged and analyzed 10 female subjects who had undergone a TKA 2–5 years before testing (age, 68 ± 10 years; body mass index (BMI), 30 ± 8 kg/m^2; range of motion, 114 ± 10°) (Table 1). All subjects had NexGen Legacy Posterior Stabilized (LPS) components (Zimmer, Warsaw, IN). Five subjects had gender-specific high-flexion implants whereas the other five had traditional (non-gender-specific, high-flex) implants. Although we identified a small but significant difference in mediolateral patellar tracking between these two different designs in a separate study (Saevarsson, in press) (no other degrees of freedom were significantly different), differences in implant design should not affect this study since we are comparing static and dynamic movements for the same subject. All subjects were satisfied with their knee replacement, and had good reported quality of life (QOL) (Table 1). Our institutional review board approved the study, and written informed consent was obtained from all subjects.

2.2. Imaging methods

With the goal of comparing static and dynamic kinematics, we collected images of the subjects both with static radiography (Sharma et al., 2012) and dynamic fluoroscopy using a Siemens AXIOM Luminos dRF flat-bed fluoroscopy unit (Siemens; Berlin, Germany). Radiographs were chosen over static fluoroscopic acquisitions due to the higher resolution and quality. Since our focus was on detecting differences in movement rather than differences in measurement technique, we chose the best available static method (sequential bi-plane, which is our standard protocol) and the best available dynamic method (single-plane). Mediolateral (ML) translation (TF and PF), and two PF rotations (tilt and spin) were excluded from the comparison because these DOF are less reliable in single-plane analysis (Tersi et al., 2012; Acker et al., 2011; Fregly et al., 2005).

2.2.1. Static radiography

Static radiographs were taken at 0°, 15°, 30°, 45°, 60°, 75°, and 90° knee flexion and at maximum flexion, from two different X-ray angles (horizontal, and 10° below horizontal) in rapid succession (less than 5 s). The small angle

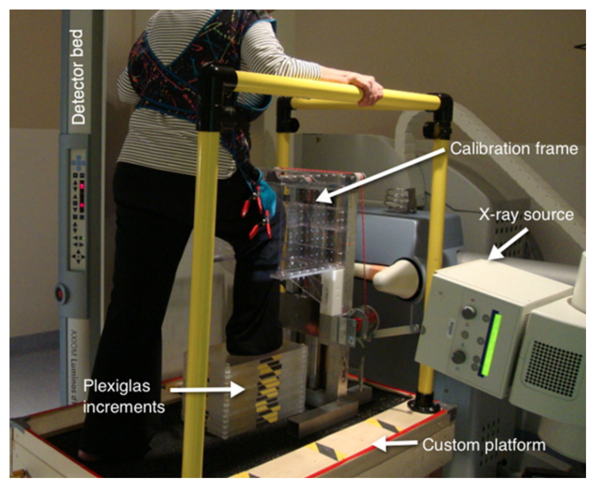

Fig. 1. Setup for capturing the images. The calibration frame can be moved up and down with the subject's knee and the number of Plexiglas increments can be adjusted, making it possible to capture static weightbearing images at different knee flexion angles. The X-ray source can be electronically moved to capture images rapidly from two different angles.

Table 1
Quality of life scores and subject characteristics, with standard deviations. BMI = body mass index; G = gender-specific, high-flex NexGen LPS implant; T = traditional NexGen LPS implant. SF-12 abbreviations: physical component summary (PCS) and mental component summary (MCS).

Subject number	BMI (kg/m^2)	Age (years)	Years since surgery	Implant type	HSS patella score	KSS knee core score	WOMAC score	Oxford score	SF-12 PCS	SF-12 MCS
1	26.0	67	−3	T	100	94	0	48	65.2	24.8
2	29.1	65	−5	T	95	99	5	45	54.1	59.0
3	27.6	48	−4	G	85	95	1	45	57.2	51.8
4	19.4	70	−4	G	90	80	0	47	60.5	51.1
5	26.4	78	−2	G	90	84	4	44	43.6	63.8
6	34.6	72	−5	T	85	76	35	29	33.7	56.0
7	28.3	86	−5	T	75	52	37	27	36.0	53.3
8	24.2	65	−4	G	100	92	7	45	43.5	57.9
9	48.6	70	−3	G	95	83	5	39	27.3	66.6
10	35.5	61	−5	T	85	83	15	41	38.9	61.9
Average	30.0	68.2	−4.0		90.0	83.8	10.9	41.0	46.0	54.6
± SD	8.0	10.1	1.1		7.8	13.4	13.9	7.3	12.6	11.7