J Digit Imaging (2012) 25:486–491
DOI 10.1007/s10278-012-9458-6

Accuracy and Reliability of Length Measurements on Three-Dimensional Computed Tomography Using Open-Source OsiriX Software

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Published online: 20 January 2012

Abstract There is a growing interest in three-dimensional computed tomography (3D-CT) as a research tool for the study of bone, joint anatomy, and kinematics. However, when CT data are processed and handled manually using image processing programs to yield 3D image and coordinate value, systematic and random errors should be validated. We evaluated the accuracy and reliability of length measurement on CT with OsiriX software. 3D-CT scans were made of 14 frozen pig knees with five transosseous holes in the metaphyseal portion of femur. The lengths between tunnel orifices were measured using Mitutoyo Digimatic digital calipers to establish the gold standard, and with the OsiriX program in 3D multi-planar reformatting mode for comparison. All measurements were recorded by a principal (replicate 1, trial 1) and a secondary observer (replicate 2, trial 1) and were repeated once by each observer (trial 2). The mean differences between OsiriX and real measurements were less than 0.1 mm in both replicates, and maximum differences were less than 0.3 mm. There were no significant differences between the replicates and real measurements (p=0.544 and 0.622 for replicates 1 and 2, respectively). The intraclass correlation coefficients (ICC) were very high between trials and between replicates (ICC=0.998 and 0.999, respectively). For kinematic analysis of the knees, length measurements on 3D-CT using OsiriX program can be used as alternatives to real measurements with less than 0.3-mm accuracy and very high reliability.

Keywords Computed tomography · Accuracy · Reliability · Length · OsiriX

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Introduction

Improvements of geometric resolution and computational power for computed tomography (CT) have led to increased utilization of CT images in the development of three-dimensional (3D) models, thus providing a comprehensive outline of shape and 3D coordinate data. Recently, there has been a growing interest in 3D-CT as a research tool for the study of bone and joint anatomy and kinematics [1–5]. The resolution of CT is half the voxel size of CT scan [6, 7]. Because 3D-CT scans used for bony reconstruction are currently performed with 0.3 to 0.6 mm voxels, the resolution of 3D-CT scans are close to 0.15 to 0.3 mm; this resolution is regarded as negligible in research involving human joint kinematics. When CT data are processed by image processing programs (i.e., volume or surface rendering programs), systematic errors must be considered. In addition, because measurements are made by human observers even when using an image processing program, both random and systematic errors should be validated.

We are currently using the open-source, FDA-approved, Digital Imaging and Communication in Medicine (DICOM) software, OsiriX, as a research tool for joint kinematics and isometric ligament reconstruction. OsiriX is a highly

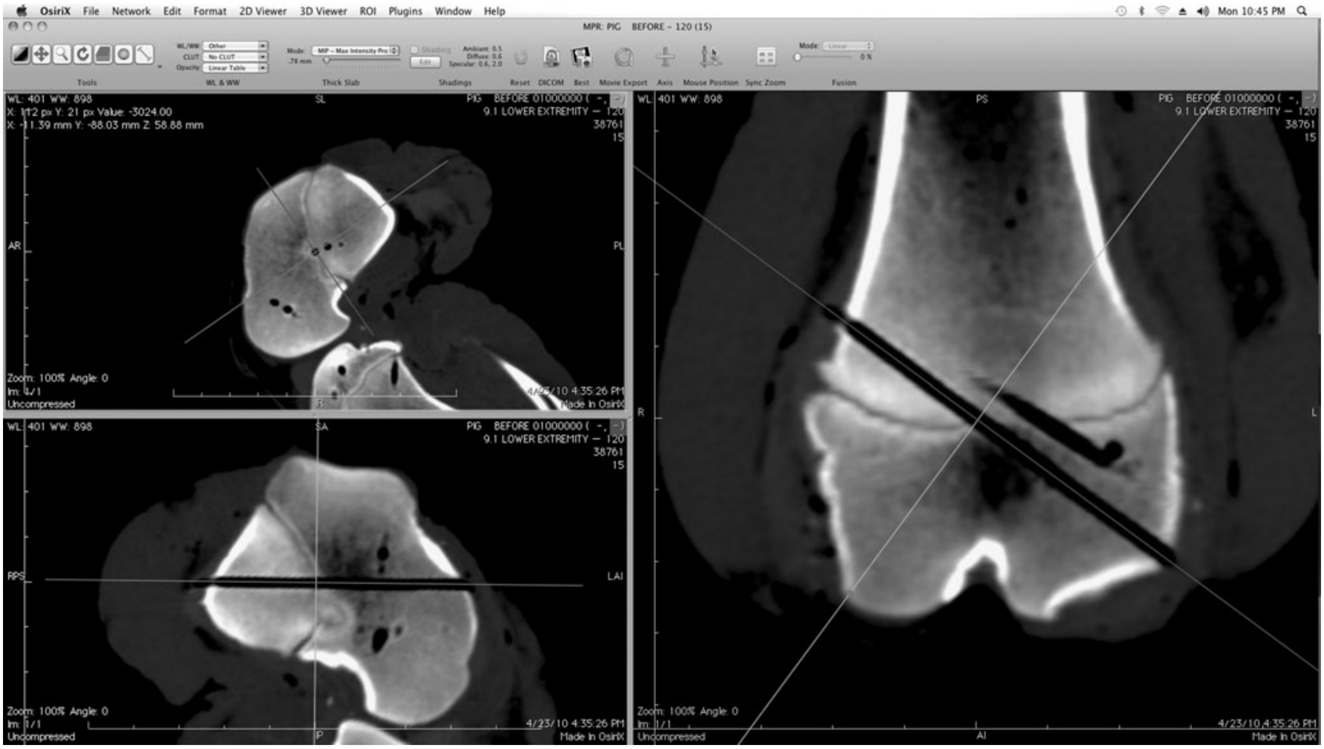

Fig. 1 3D multi-planar reformatting mode (3D MPR) in OsiriX

functional software program that allows users to reconstruct and manipulate 3D images and coordinate data [8, 9]. To our knowledge, there are no reports that describe the accuracy and reliability of OsiriX for length measurement on 3D CT data.

In this study, we aimed to evaluate the accuracy and reliability of length measurement on CT with OsiriX software. We hypothesized that the accuracy for length measurements on 3D-CT using open-source OsiriX software would be less than 0.3 mm.

Materials and Methods

Fourteen frozen stifle (knee) joints from male pigs (body weight 30–40 kg) were obtained from a local abattoir. The

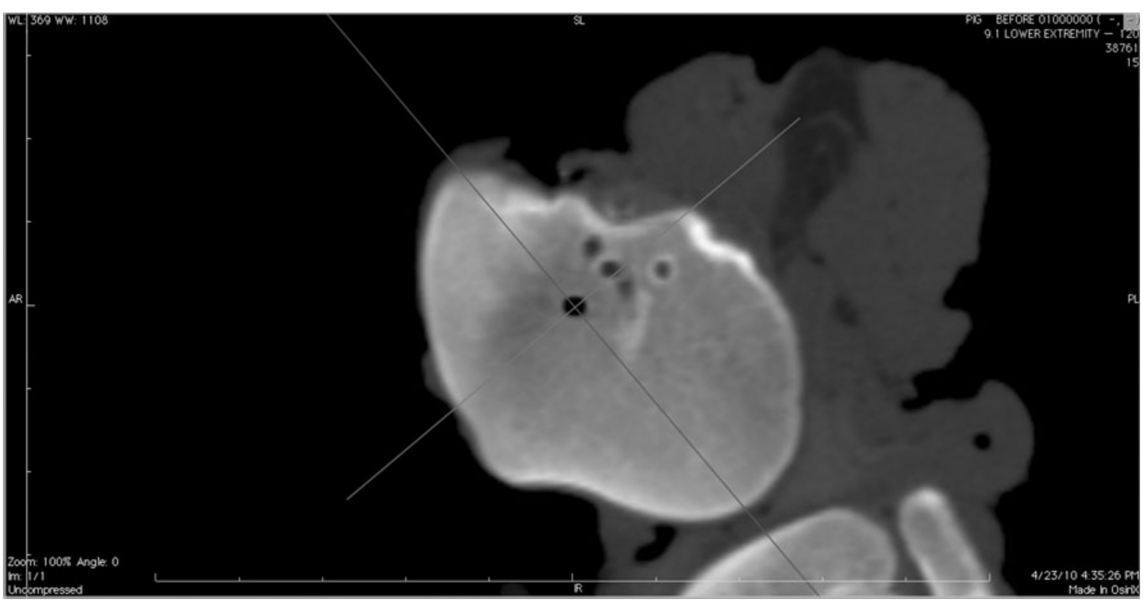

Fig. 2 The axial planes were adjusted to intersect in the center of the bone tunnel

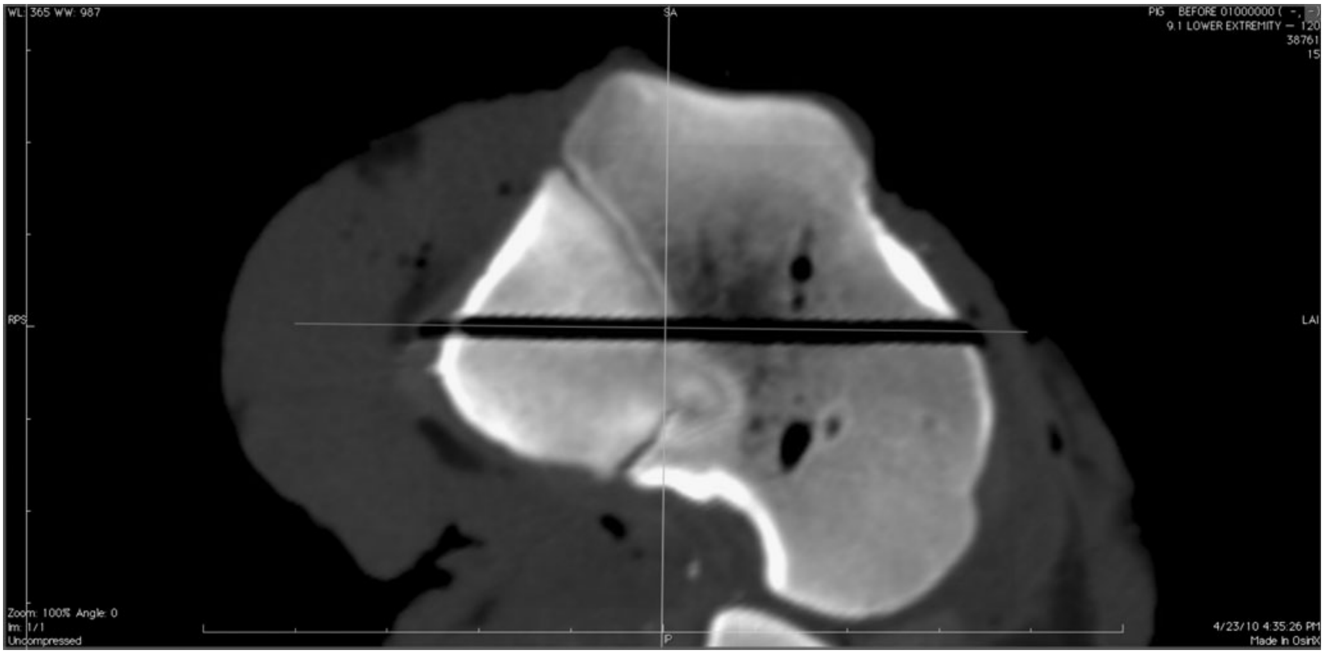

Fig. 3 From the axial view, the sagittal and coronal planes were moved to parallel the tunnel of the bone

joints were wrapped in saline-soaked gauze, stored in air-tight plastic bags, and kept frozen at −20°C until the day prior to testing to preserve bony quality and retain moisture [10]. After thawing overnight at room temperature, the surrounding tissues of the distal femur were dissected.

Using a 1.5-mm drill bit, five transosseous holes were made from the lateral to medial cortex at the metaphyseal portion of the distal femur. The lengths between tunnel orifices were measured with a Mitutoyo Digimatic digital caliper (Mitutoyo Digimatic, Japan), which is accurate to

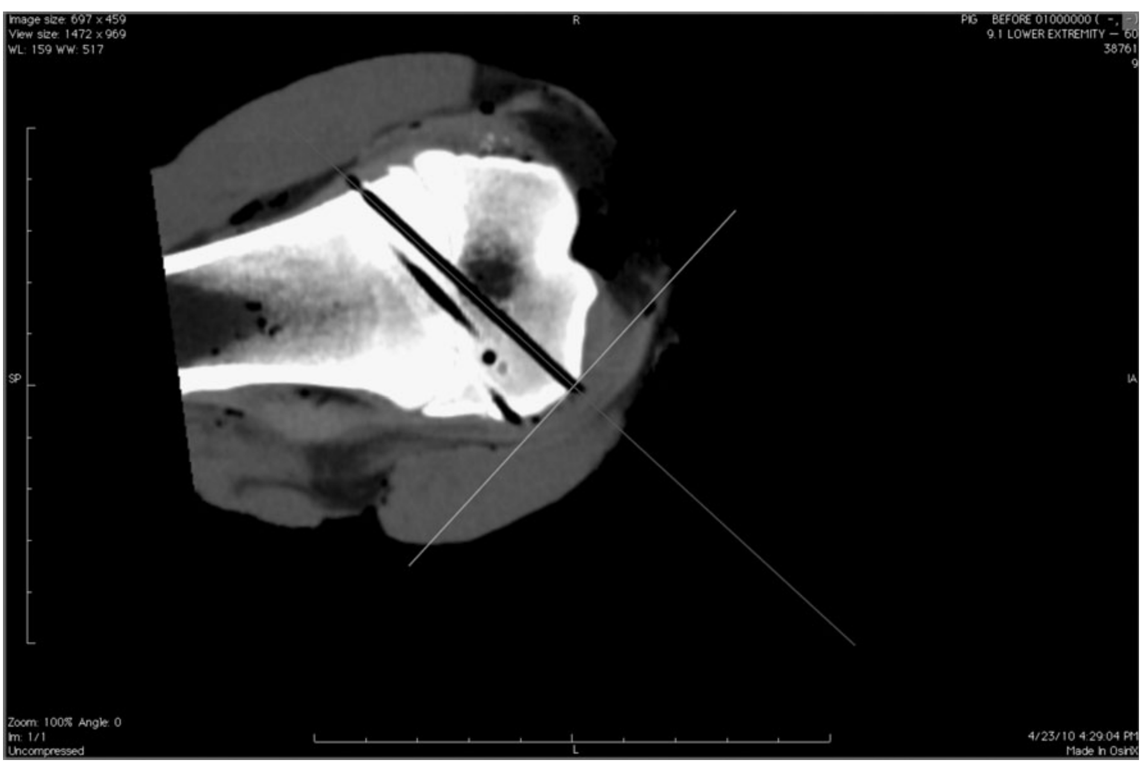

Fig. 4 The axial view was moved so that the coronal and sagittal planes passed through the outermost surface of the bony tunnel

within 0.01 mm. The averages of the values measured by all observers were defined as the gold standard length measurements between tunnel orifices.

Computed tomography (CT) of the knee was performed using a commercially available 256-detector row Brilliance iCT scanner (Philips Medical Systems, Eindhoven, The Netherlands). The raw data sets were acquired under 64× 0.625-mm collimation; rotation time 0.4 s; pitch 0.671, 120 kV; and automated mAs control.

Images were reconstructed and analyzed on a Mac Mini (2.4 GHz Intel Core 2 Duo Desktop Computer, 4 GB random-access memory; Apple Computer, Cupertino, CA, USA) running Mac Operating System X and OsiriX imaging software (OsiriX version 3.2; Apple Computer). For measurements made with OsiriX, the *x, y*, and *z* coordinate values of tunnel orifices were used for calculating length between tunnel orifices.

The coordinate values of both ends of each bony tunnel were derived in the 3D multi-planar reformatting mode (3D MPR) of the OsiriX program as follows:

1. The CT data were reformatted to a 3D multi-plane image (Fig. 1).
2. The axial planes were adjusted to intersect in the center of the bony tunnel (Fig. 2).
3. From the axial view, the sagittal and coronal planes were moved to parallel the bony tunnel (Fig. 3).
4. After establishing this axis of rotation, the axial view was moved so that the coronal and sagittal planes passed through the outermost surfaces of the bony tunnel (Fig. 4).
5. After recording the coordinate values of this point, the axial view was moved so that the sagittal and coronal planes passed through the outermost surfaces at the opposite end of the bony tunnel.
6. The coordinate values of this point were recorded.

All measurements were recorded by a principal (replicate 1, trial 1) and a secondary observer (replicate 2, trial 1) and repeated once by each observer (trial 2) at intervals of 2 weeks.

Statistical Analysis

A priori power analysis performed using G*Power software, version 3.01 (Franz Faul, Christian-Albrechts-Universität Kiel, Kiel, Germany) indicated that 70 measurements would be needed to detect a difference of 0.3 mm in length between real and OsiriX measurements with an overall $\alpha=0.05$ and a power of 0.8 [11]. The Kolmogorov–Smirnov test was used to confirm that the data were normally distributed. To assess the accuracy of measurements made with OsiriX by each observer, differences between real measurements (gold standard) and each replicate were evaluated. Trials 1 and 2 were averaged for all accuracy assessments. The mean value, standard deviation, and maximum and minimum values of the differences were described for each observer.

To assess the reliability of measurements made with OsiriX, the intraclass correlation coefficient (ICC) between trials (intra-observer variability) and between replicates (inter-observer variability) was assessed. Statistical significance was set at $p<0.05$. All statistical analyses were performed using SPSS for Windows, version 12.0 (SPSS, Chicago, IL, USA).

Table 1 Accuracy of measurements made with the OsiriX program

	Mean difference (mm)	SD (mm)	Maximum difference	*P* value
RM vs replicate 1	0.043	0.103	0.21	0.544
RM vs replicate 2	0.071	0.172	0.28	0.622

RM real measurement, *SD* standard deviation

Results

For assessment of accuracy, mean differences between OsiriX and real measurements were less than 0.1 mm in both replicates, and maximum differences were less than 0.3 mm. There were no significant differences between replicates and real measurements ($p=0.544$ and 0.622 for replicates 1 and 2, respectively; Table 1).

For assessment of reliability, the ICC between trials and between replicates was very high (ICC=0.998 and 0.999, respectively; Table 2).

Discussion

A growing interest in using accurate descriptions of tunnel position for cruciate ligament reconstruction instead of the clock position method [12–16] has increased the importance of 3D anatomical information for knee surgery. Recently, image processing programs for 3D-CT have been used to describe the location of anatomical land marks or to measure angles and lengths [12, 13, 17–20].

Table 2 Reliability between trials and between replicates

	ICC
Trial 1 vs trial 2	0.998
Replicate 1 vs replicate 2	0.999

ICC intraclass correlation coefficients

OsiriX is a free DICOM software program developed by Rosset et al. at the University of Geneva that can reconstruct many types of 3D images [8, 9]. In particular, volume rendering and multi-planar reformatting (MPR) images are most useful for preoperative evaluation of disease pathology and for surgical planning. With a sophisticated user interface, not only radiologists, but also clinicians and clinical researchers, can easily manipulate and generate reconstructed 3D images and acquire whole 3D images of anatomical structures. In addition, 3D coordinates can be plotted in MPR mode so that anatomical and kinematic analyses are possible. It is also possible to build a Picture Archiving and Communication System (PACS) with OsiriX independently, as the DICOM server is also included in the software.

On the basis of these advantages, several reports have featured the use of OsiriX software in broad clinical and research fields. Sugimoto et al. developed a new and less invasive method of virtual 3D pancreatography using the OsiriX system and reported its feasibility in minimally invasive pancreatectomy for neoplasms [21]. Melissano et al. demonstrated precise 3D analysis of the Adamkiewicz artery by reconstructing data from multi-detector row CT angiography with OsiriX and reported its potential benefits for planning therapeutic procedures [22]. Recently, Greiner et al. reported femoral and tibial attachment of the posterior cruciate ligament using 3D-CT and the OsiriX program in MPR mode [18]. In MPR mode, surgeons can easily capture any slice they want and can acquire the trajectory of tunnels or screws preoperatively. These functions are available on OsiriX and the software is continually being updated and developed.

However, to our knowledge, the reliability and validation of measurements made in MPR mode have never been reported. The goal of this study was to validate the accuracy and reliability of measurements made using OsiriX for studies of knee kinematics. We observed a strong and highly significant correlation between real measurements and measurements made with OsiriX. In addition, reproducibility was excellent and the ICC for inter- and intra-observer reliability was very high. However, OsiriX is currently only compatible with the Mac operating system, thus presenting a potential obstacle for clinicians and researchers who want to use this program.

Conclusion

For kinematic analysis of the knees, length measurements on 3D-CT using OsiriX can be used as alternatives to real measurements with less than 0.3-mm accuracy and high reliability. With OsiriX and 3D-CT, clinicians and researchers can perform non-contact anatomical measurements at their own computers.

Acknowledgment This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2010-0006066)

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