Reliability of Internal Skeletal Dimensions for Creating Computational Knee Models Using Volumetric Quantitative Tomography

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INTRODUCTION

- Excessive anterior cruciate ligament (ACL) force and distorted joint surface motion (kinematics) are components of tibiofemoral joint (TFJ) mechanics hypothesized as links to ACL injury and Osteoarthritis (OA) [1]. Several studies have investigated ACL injury mechanisms and gender differences by examining in vivo kinematics of anterior tibial translation and TFJ surface rolling and gliding using a 2-D geometric computational TFJ model (based on group cadaver knee geometry measures) during weight bearing and non-weight bearing activities in healthy and ACL injured knees. [2-5]. TFJ internal skeletal dimensions have not been determined previously in vivo from computed (CT) image data for use in creating skeletal based subject specific computational knee models.

Objectives

- Obtain TFJ internal skeletal dimensions from CT scan based solid 3-D knee images for use in creating a skeletal based subject specific computational knee model.
- Conduct intertester reliability analyses for the internal skeletal dimensions.

METHODS

Subjects

•Ten healthy adults, 4 men and 6 women, participated in this study (mean age 25.5±2.5; mean height 169±7 cm; mean body mass 74.9±14.9 kg).
•Subjects did not have a history of lower extremity or spine pain, injury, surgery, musculoskeletal disease, or neurological disease within the past year.

Procedure

•CT scans were performed with subjects' knees in a neutral position
• TFJ CT image data was converted to triangulated surface models using Materialize Mimics software version 13.1
•Twenty-eight skeletal anatomical landmarks (14 femoral and 14 tibial) used in this study are defined in tables 1 and 2 and shown in figures 1 and 2.
•Using Geomagic software, location coordinates were determined for each of the 28 skeletal anatomical landmarks from the converted TFJ CT image data.
•Twenty-four internal skeletal dimensions (Tables 3 and 4) were measured from the TFJ CT image data of the femur and tibia.

Data Analysis

Two testers performed landmark identification and internal skeletal dimension measurements independently. Inter-correlation coefficients (ICC) were calculated for the 28 internal skeletal dimension measurements between the two testers (tables 5 and 6).

Variables

Table 1. Distal Femur Skeletal Landmarks

1	Point of maximum width of lateral condyle
2	Point of maximum convexity of lateral epicondyle
3	Point of maximum height on lateral condyle
4	Point of intersection of anterior patella surface with shaft (lateral side)
5	Center intersection of ant. patella surface with shaft (indented feature)
6	Point of intersection of anterior patella surface with shaft (medial side)
7	Point of maximum height on medial condyle
8	Point of maximum convexity of medial epicondyle
9	Point of maximum width of medial condyle
10	Central, peak convex point on medial intracondylar ridge (peak point [approx. midpoint] of medial condyle intracondylar ridge)
11	Central deepest concave point - approx. midpoint of the medial condyle intracondylar fossa
12	Central point on intercondylar line (posterior side)
13	Central deepest concave point - approx. midpoint- of the lateral condyle intracondylar fossa
14	Central, peak convex point on lateral intracondylar ridge (peak point [approx. midpoint] of medial condyle intracondylar ridge)

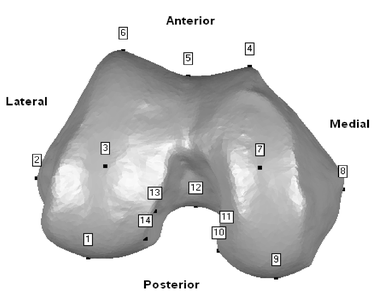

Figure 1. Femur Skeletal Landmarks

Table 2. Proximal Tibia Skeletal Landmarks

1	Maximum posterior point on posterior tibial ridge of lateral condyle
2	Most lateral point on transverse view of lateral condyle ridge
3	Maximum anterior point on anterior tibial ridge of lateral condyle
4	Deepest central point on lateral condyle
5	Lateral intercondylar tubercle
6	Maximum posterior point on posterior tibial ridge of medial condyle
7	Most medial point on transverse view of medial condyle ridge
8	Maximum anterior point on anterior tibial ridge of medial condyle
9	Deepest central point on medial condyle
10	Medial intercondylar tubercle
11	Deepest point of intersection of intercondylar eminence and shaft
12	Point on anterior medial edge of tibial shelf with tibial tuberosity
13	Point on anterolateral edge at point of interface between the tibial shelf and tibial tuberosity
14	Point of maximum convexity of tibial tuberosity

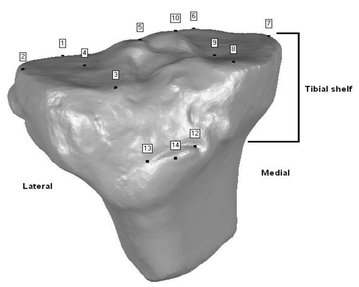

Figure 2. Tibia Skeletal Landmarks

Variables

Table 3. Femur Internal Skeletal Dimensions

1.Angle between medial and lateral femoral condyles (two vectors formed by points 1 to 6, and points 9 to 4)
2. Anterior-posterior (A-P) length of medial condyle (between points 4 and 9)
3.A-P length of lateral condyle (between points 1 and 6)
4.Anterior intercondylar width (between points 4 and 6)
5.Posterior intercondylar width: Length between maximum height on medial (point 7) and lateral (point 3) inferior condylar surfaces
6.Femur Angle: Angle between the long axis of the femur and points 7 and 3
7.Interepicondylar width: Length between points of maximum convexity of lateral (point 2) and medial epicondyles (point 8)
8.A-P intercondylar section length (between points 5 and 12)
9.Length between central maximum height on lateral intercondylar facet (point 14) and central maximum height on medial intercondylar facet (point 10)
10. (a) anterior lateral condyle width (between points 6 and 5); (p) posterior lateral condyle width (between points 1 and 14)
11. (a) anterior medial condyle width (between points 4 and 5) ; (p) posterior medial condyle width (between points 10 and 9)

Table 4. Tibia Internal Skeletal Dimensions

1.Medial condyle anterior width: Length between medial intercondylar tubercle (point 10) and maximum anterior point on medial condyle (point 8)
2.Medial condyle posterior width: Length between medial intercondylar tubercle (point 10) and maximum posterior point (6) on medial condyle
3.Medial condyle A-P length: Length between maximum anterior (8) and posterior (6) points of medial condyle
4.Mid-intercondyle length: The distance between the deepest central concavity point on lateral condyle (4) and the deepest central concavity point on medial condyle (9)
5.Anterior Tibial Angle: Angle formed between the long axis of the tibia and the vector formed by points 7 and 2
6.Lateral condyle anterior width: Length between lateral intercondylar tubercle (point 5) and maximum anterior point on lateral condyle (point 3)
7.Lateral condyle posterior width: Length between lateral intercondylar tubercle (point 5) and maximum posterior point on lateral condyle (point 1)
8.Lateral condyle A-P length: Length between maximum A-P point (anterior point 3) and maximum A-P point (posterior point 1) of the lateral condyle
9.Anterior tibial width (between points 8 and 3)
10.Posterior tibial width (between points 6 and 1)
11.Maximal tibial width (between points 7 and 2)

RESULTS

- Internal skeletal dimension intertester reliability was fair to good. Only nine of twenty-eight dimensions had low ICC values [ICC(1,K) < 0.7] between the two testers (tables 5 and 6).

Table 5. Femur Internal Skeletal Dimension Measurements

Femur	Tester 1		Tester 2		
Dimension	Mean	STD	Mean	STD	ICC(1,k)
1 (radians)	0.45	0.15	1.13	0.07	-0.618
2 (mm)	62.59	11.07	81.05	6.96	0.359
3 (mm)	63.74	5.10	71.68	6.18	0.720
4 (mm)	36.02	7.68	31.17	5.55	0.835
5 (mm)	51.63	11.64	49.23	6.02	0.592
6 (radians)	1.66	0.04	1.67	0.06	0.655
7 (mm)	80.34	10.43	82.76	9.02	0.820
8 (mm)	54.50	5.64	54.14	4.71	0.935
9 (mm)	21.41	4.07	21.29	4.39	0.996
10a (mm)	21.48	2.21	13.24	2.61	0.786
10p (mm)	18.06	2.15	16.96	1.44	0.858
11a (mm)	15.04	3.49	19.79	3.26	0.855
11p (mm)	21.99	2.69	16.45	2.55	0.755

Table 6. Tibia Internal Skeletal Dimension Measurements

Tibia	Tester 1		Tester 2		
Dimension	Mean	STD	Mean	STD	ICC(1,k)
1 (mm)	26.45	2.25	25.18	2.85	-0.182
2 (mm)	24.58	3.15	25.96	2.74	0.295
3 (mm)	40.94	4.10	41.61	4.48	0.985
4 (mm)	36.54	4.76	40.78	4.66	0.586
5 (mm)	27.46	3.57	21.74	2.94	0.698
6 (mm)	20.98	2.15	28.18	3.57	0.773
7 (mm)	34.37	4.86	33.49	5.22	0.981
8 (mm)	45.11	5.34	38.17	3.35	0.346
9 (mm)	34.48	3.95	43.81	5.08	0.796
10 (mm)	70.62	7.57	70.58	7.69	0.998
11 (mm)	1.48	0.05	1.50	0.04	0.669

CONCLUSIONS

- In this study, internal skeletal dimensions from CT image based solid 3-D TFJ models were used to mathematically describe TFJ geometry. High consistency was observed for most of the measured dimensions. The primary reason for the lower intertester correlation coefficients on some of the dimensions may be due to inconsistent identification of skeletal landmarks. We believe refinement of the skeletal landmark definitions and improved training and additional experience of testers can improve the intertester reliability.

References

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