Contact Forces and Kinematics of Total Knee Arthroplasty During Squatting: A Simulation Study

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Background

- TKA contact mechanics and kinematics
  - Importance in both clinical and mechanical field
  - During ADL, potential of failure and wear of arthroplasties

Wimmer, M. A., and Andriacchi, T. P., 1997, “Tractive Forces During Rolling Motion of the Knee: Implications for Wear in Total Knee Replacement,” J. Biomech.

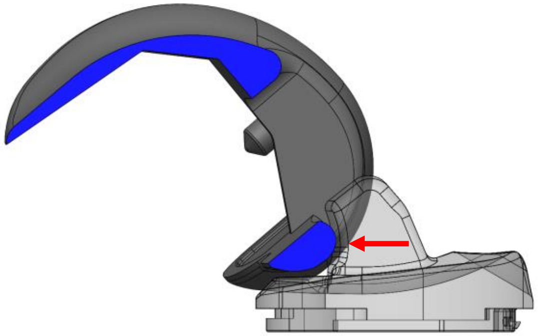
Kellett, C. F., Short, A., Price, A., Gill, H. S., and Murray, D. W., 2004, “In Vivo Measurement of Total Knee Replacement Wear,” Knee.

Huang, C.H., Liau, J.J., and Cheng, C.K., “Fixed or mobile-bearing total knee arthroplasty,” J Orthop Surg Res.

Background

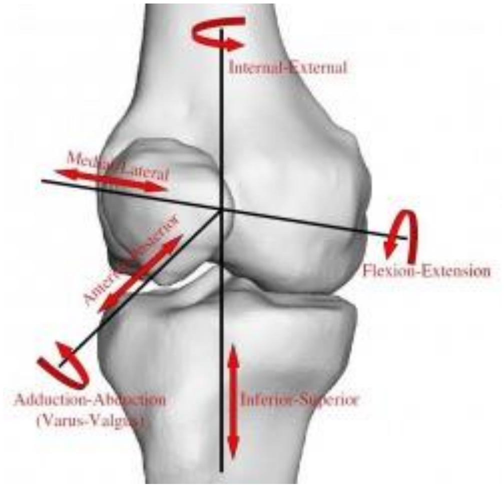
❖ **Cruciate-retaining (CR-type) total knee system**

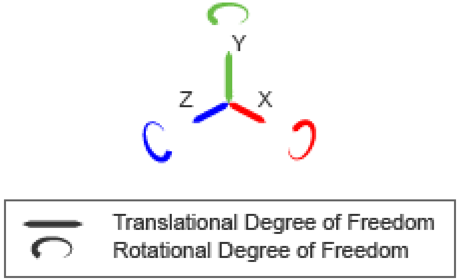
❖ **Posterior stabilized (PS-type) total knee system**



Background

❖ **6-DOF knee joint simulation is necessary for precise analysis of TKA implant**





Purpose of Study

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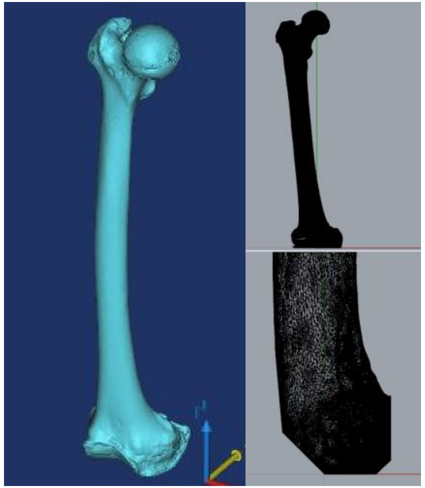
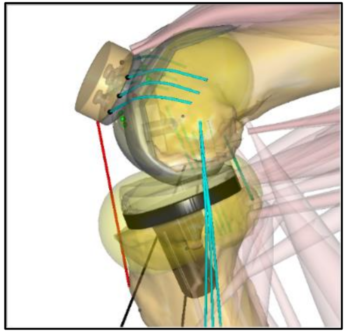
1) To construct the simulation framework using patient-specific computational musculoskeletal model for TKR evaluation with different activities of daily living (ADL).

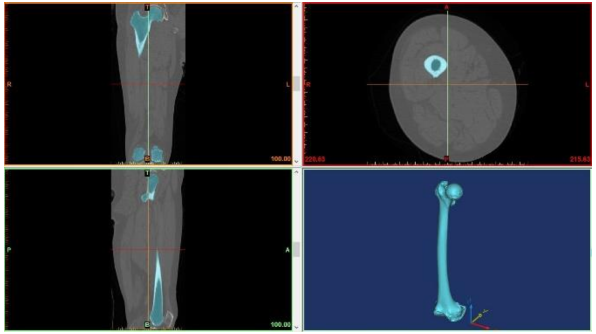
2) To estimate the knee contact forces and kinematics in tibiofemoral and patellofemoral joint.

Materials and Methods



- ❖ Subject
  - ❖ Male, right OA knee, pre-operative CT scan
  - ❖ Weight: 55kg, Height: 150cm, Age: 73yr
- ❖ Bone Reconstruction: Mimics V16.0
- ❖ Simulation: AnyBody Modeling System v6.0
- ❖ Scaling
  - ❖ Subject-specific scaling for lower extremities (femur, tibia)
- ❖ Ground reaction force predicted

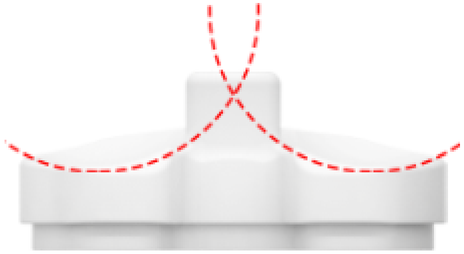


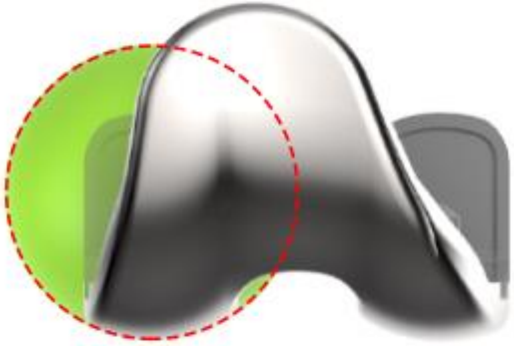


Materials and Methods - LOSPA

❖ **LOSPA Primary Knee System PS-type - TKR system of Corentec, Co., Ltd.**

Spherical condyle and constrained liner design

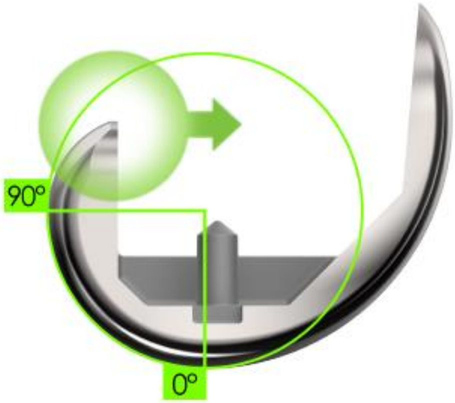




Materials and Methods - LOSPA

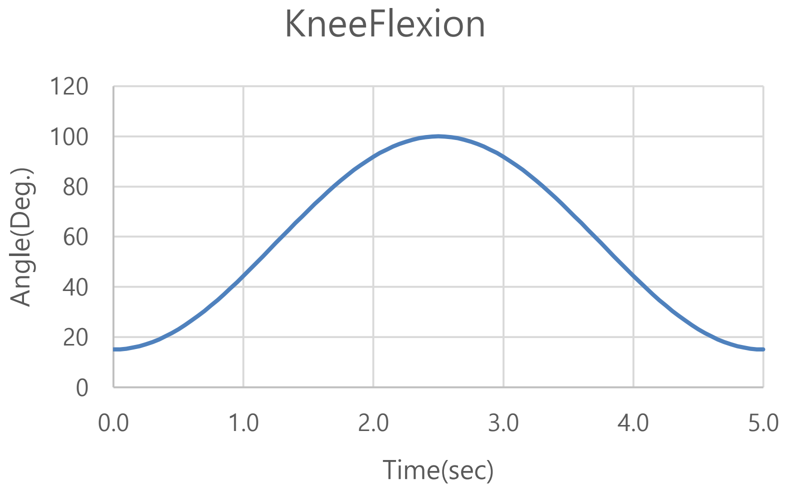
❖ **LOSPA Primary Knee System PS-type - TKR system of Corentec, Co., Ltd.**

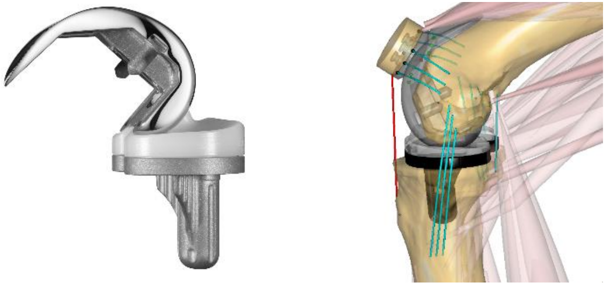
Single radius axis	Rotated articular surface



Materials and Methods

- ❖ Squat motion: 15° to 100° knee flexion in 100 frame, 20Hz
- ❖ 6-DOF knee joint model
  - ❖ Force-dependent kinematics (FDK)
- ❖Medial/lateral tibiofemoral contact force





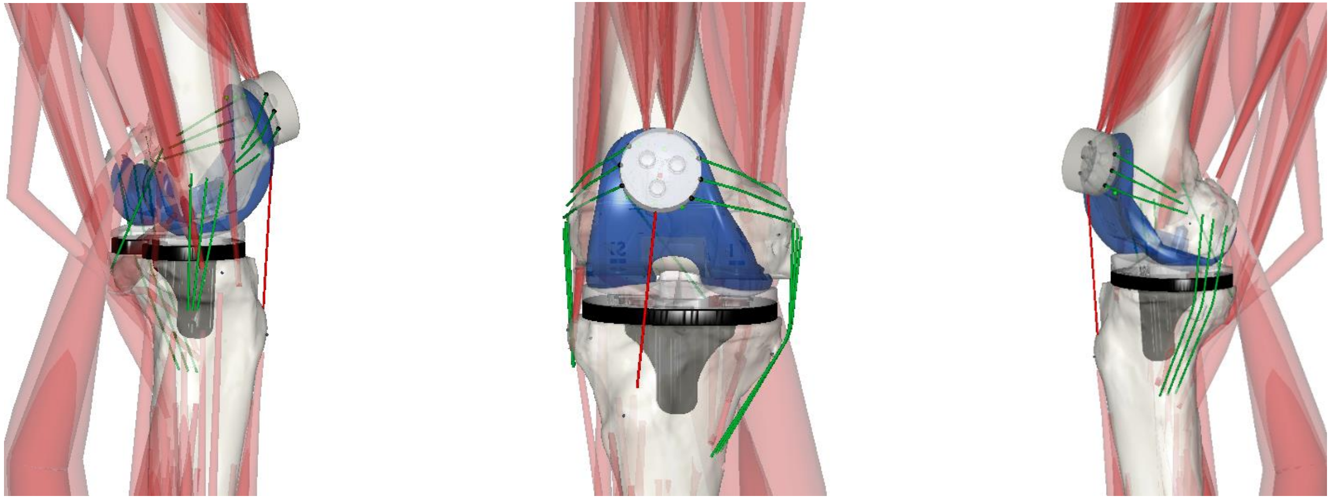
(Left) LOSPA PS-type Primary Knee System. (Right) LOSPA implanted in AnyBody Modeling System.

Materials and Methods

❖MCL, LCL, MPFL, LPFL in three bundle line elements

❖ Medial and lateral collateral ligaments, medial and lateral patellofemoral ligaments were divided into three bundles (Blankevoort, 1991)

Blankevoort, L., et al., 1991, “Articular Contact in a Three-Dimensional Model of the Knee,” J. Biomech.



Results

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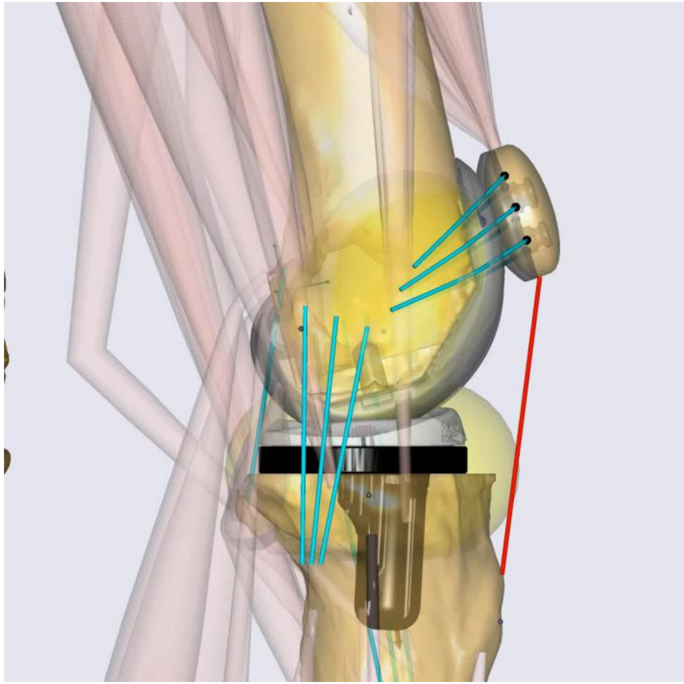
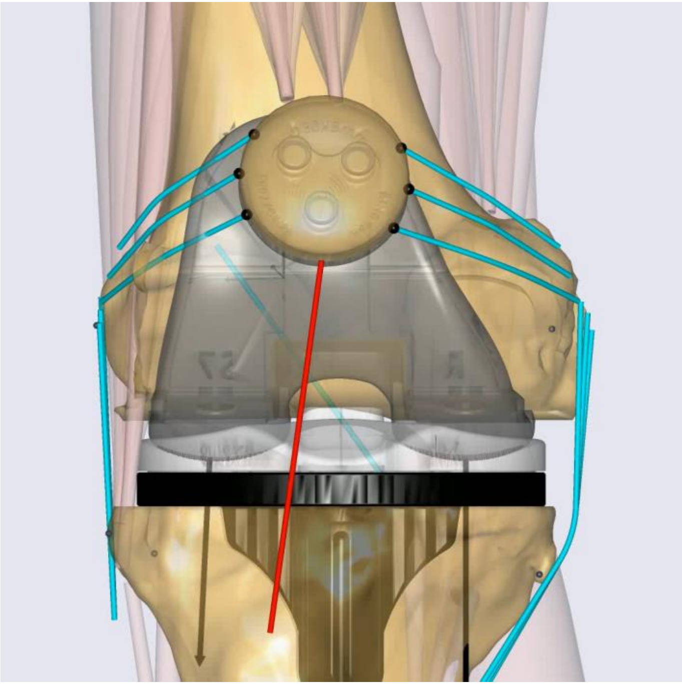
❖ **Animations in AnyBody Modeling System**





Results

❖ Tibiofemoral Contact Forces

❖ Lateral contact forces become larger than medial after 48° knee flexion

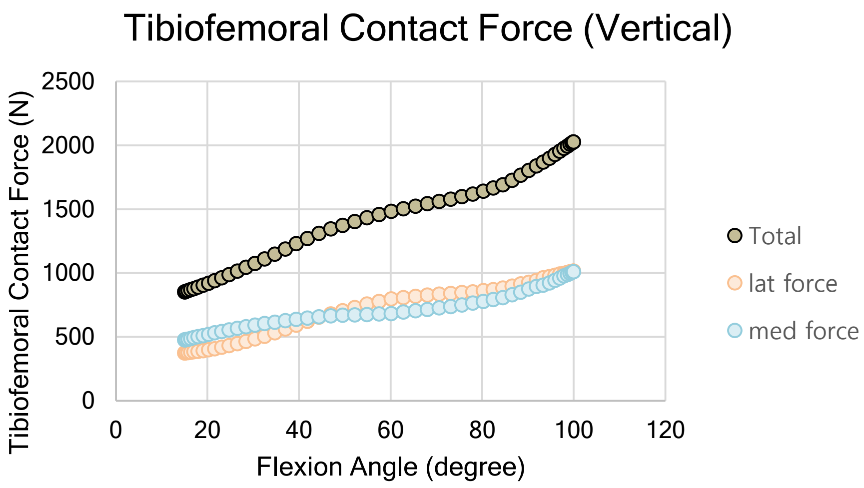


Figure. Tibiofemoral contact force of lateral(lat), medial(med) and total knee compartment.

Results

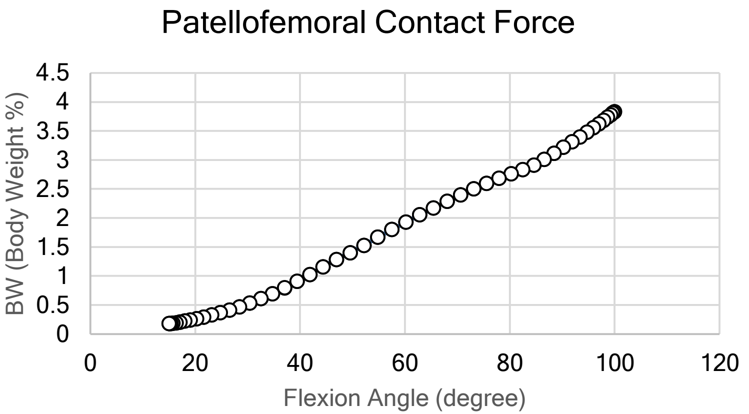


Figure 4. Patellofemoral contact force during squatting motion.

Table 1. Comparison of patellofemoral contact forces with previous study at flexion angle 30°, 60°, 90° and at maximum.

Flexion Angle	Our study [%BW]	Innocenti et al., 2011 [%BW]
30°	0.53	-
60°	1.93	2.5
90°	3.22	2.9
Max.	3.77	3.0

Innocenti, B., et al., 2011, "Contact forces in several TKA designs during squatting: A numerical sensitivity analysis.," J. Biomech.

Results

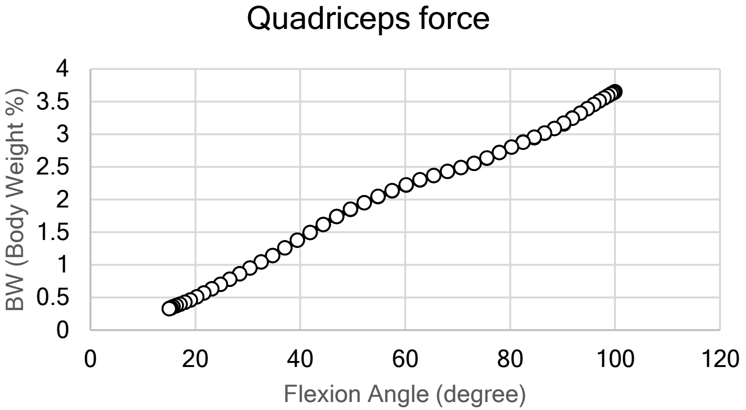


Figure 5. Quadriceps force during squatting motion.

Table 2. Comparison of quadriceps force with previous study at flexion angle 30°, 60°, 90° and at maximum.

Flexion Angle	Our study [%BW]	Innocenti et al. [%BW]
30°	0.94	-
60°	2.22	2.5
90°	3.16	2.6
Max.	3.65	3.3

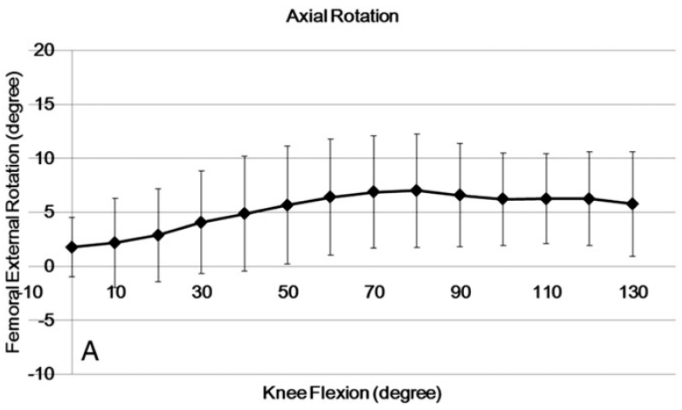
Innocenti, B., et al., 2011, "Contact forces in several TKA designs during squatting: A numerical sensitivity analysis.," J. Biomech.

Results

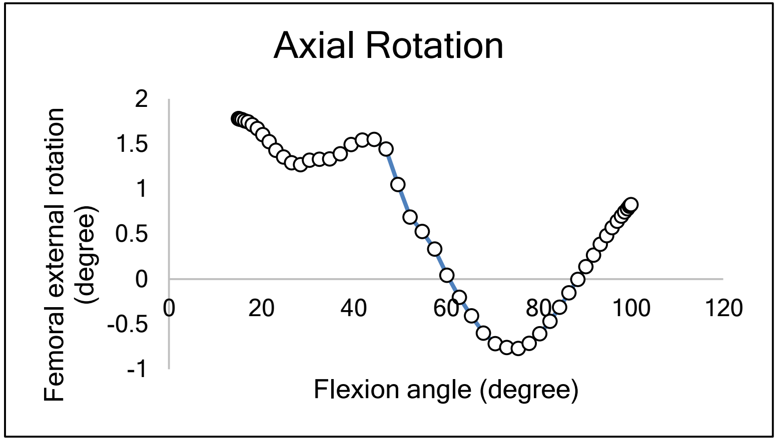
❖ Knee Kinematics

- ❖ **Femoral external rotation: Maximum 1.8°, minimum -0.8°**
- ❖ **Our results were compared to the results from previous in-vivo study (Shimizu, 2014)**

Shimizu N., Tomita T. et al., 2014, "In Vivo Movement of Femoral Flexion Axis of a Single-Radius Total Knee Arthroplasty," J. Arthroplasty.



(Shimizu et al., 2014) Femoral external rotation during squatting motion.



(Our study) Femoral external rotation during squatting motion.

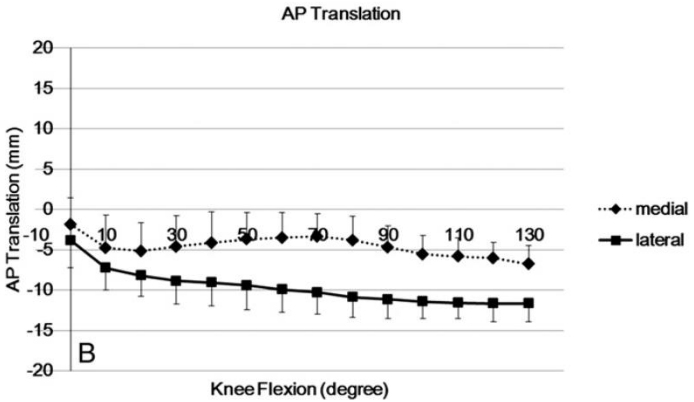
Results

❖ Knee Kinematics

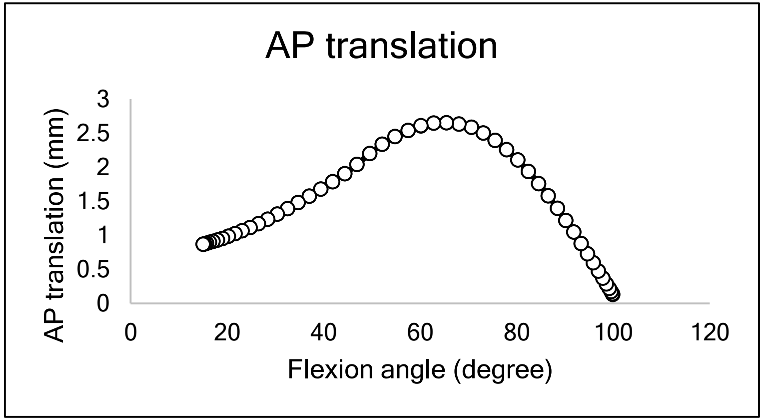
❖ Femoral AP translation: Maximum 2.7 mm, minimum 0.1 mm

Shimizu N., Tomita T. et al., 2014, “In Vivo Movement of Femoral Flexion Axis of a Single-Radius Total Knee Arthroplasty,” J. Arthroplasty.

❖ Post-cam impingement at 65° knee flexion



(Shimizu et al.) AP translation of femoral component relative to tibia components during squatting motion.



(Our study) AP translation of femoral component relative to tibia components during squatting motion.

Limitations

What should be improved for future?

- **Better wrapping surfaces for muscles and ligaments**
- **Newer human model lower extremity version**
  - **currently TLEM v1.2 used**
- **Ligament property calibration is needed**

Conclusion

What we tested to achieve by using AnyBody Modeling System:
Construct the simulation framework of computational musculoskeletal TKR models for various evaluations

What TKR musculoskeletal simulation can provide:
Tibiofemoral and patellofemoral kinematics
Tibiofemoral and patellofemoral contact forces
Ligament lengths and forces