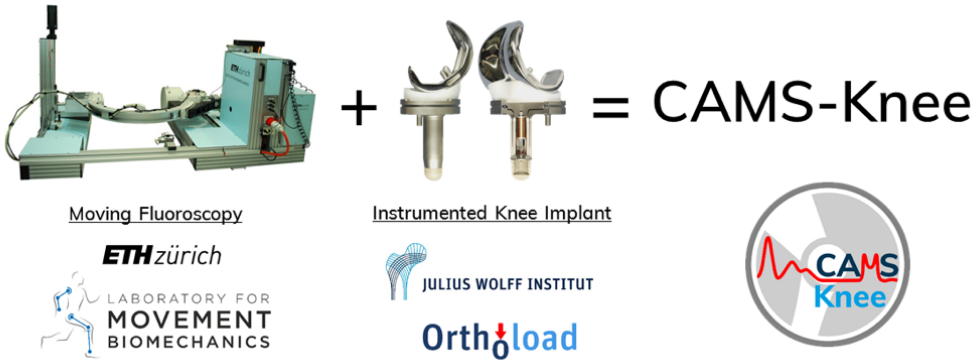
Description of the CAMS-Knee Database

(Sample Trials, K8L, normal walking & squat)



General notes:

The CAMS-Knee sample database contains processed data of a single gait and a single squat trial performed by one of the subjects (K8L) measured during the CAMS-Knee project.

Release notes

In February 2023, the CAMS-knee sample datasets were updated. The new release includes the following change:

- The sign of the free vertical torque (Tz_lab and Tz_lab_IfB) measured using the fixed (FP1-FP6) force plates has been corrected. Originally, the Tz values described the free vertical torque acting on the force plate, but for consistency, Tz now defines the free vertical torque acting on the foot. Signs for the mobile force plates (FP7-FP8) have not been corrected as these were already consistent with the forces.

Subject details:

The K8L subject (age: 70 years, height: 175 cm and weight: 773 N) is a male subject, from the Julius Wolff Institute in Berlin (Charité - Universitätsmedizin Berlin, Germany), with the instrumented implant in his left knee, and who was measured 64 months postoperatively.

Instrumented knee implant:

The instrumented knee implant measures the 3 contact forces and 3 contact moments, acting on the tibial component. Its design is based on the INNEX FIXUC total knee system (Zimmer GmbH, Winterthur, Switzerland) with an ultra-congruent tibial insert and a standard femoral component.

The centre of the coordinate system is fixed at the right tibial component on the extended stem axis at the height of the lowest part of the polyethylene insert (Fig 1). Forces and moments measured in left knees were transformed to the right side (https://cams-knee.orthoload.com/instrumented-knee-implant/). The coordinate system of the tibial component as also described by Kutzner et al. 2010.

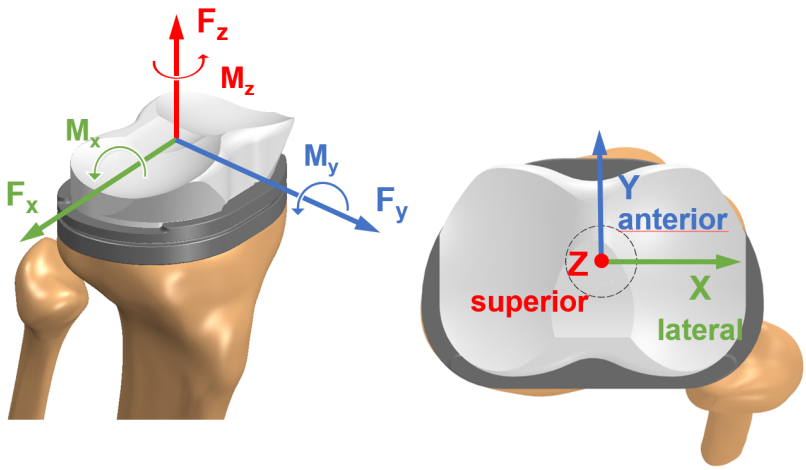


Figure 1: coordinate system of instrumented knee implant

Lab and equipment details:

All subjects were measured in the Laboratory for Movement Biomechanics, ETH Zürich, Switzerland in June 2014. Complete details about the lab setup and the equipment used for measuring the database are reported in Taylor et al., 2017. However, the following description may simplify understanding and practical use of the database contents.

Eight force plates (FP1 and FP2, type 9281B, 400 × 600 mm; FP3 and FP4, type 9285, 400 × 600 mm; FP5, type 9281C, 400 × 600 mm; FP6, type 9287B, 600 × 900 mm; and FP7 and FP8, type 9286AA, 600 x 900 mm; 2000 Hz; all Kistler, Switzerland), were used to measure the ground reaction forces (GRFs) during the captured trials (n.b. FP7 and FP8 were not used during the activities presented in the sample datasets, but are included to ensure consistency with the complete CAMS-Knee datasets).

The Lab Coordinate System (CS_{Lab}) is a right-handed coordinate system with its origin defined at the centre of FP3. The y-axis is aligned with the walkway pointing from FP1 to FP5, the z-axis is perpendicular to the force plates and pointing upwards, and the x-axis is orthogonal and defined based on the right-hand rule (Fig 2). For the sample gait trial (K8L; with the implant in the left knee), the subject walked from FP5 towards FP1 (left to right in Fig 1). For the sample squat trial, the subject's right and left feet were positioned on FP6 and FP1, respectively.

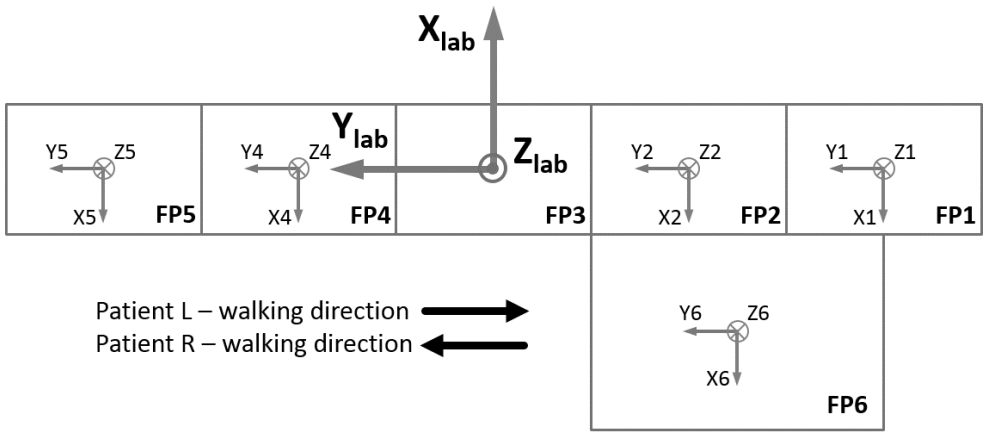


Figure 2: Arrangement of the force plates in the lab (mobile force plates FP7 and FP8 are not displayed)

All the processed kinematic and force data are reported in the CS_{Lab}, except *in-vivo* joint contact forces, which are presented in a local coordinate system attached to the tibial component (see Kutzner et al. 2010).

Note: The equipment used in the measurements had different sampling frequencies, which varied from 25Hz to 2000Hz (fluoroscope: 25Hz, instrumented implant: 90-100Hz, Vicon: 100Hz, all other analog channels: 2000Hz). All the processed kinematic and kinetic data reported in the database were synchronized using TTL trigger signals and reported based on the highest sampling frequency (2000Hz). As a result, the parameters obtained from systems with lower frequencies include some rows filled with 'NaN' to indicate that no measurement occurred at that time point.

Structure of the Database

The database for the CAMS-Knee sample gait/squat trials is subdivided into documentation, tools and subject (K8L) data (Fig 3):

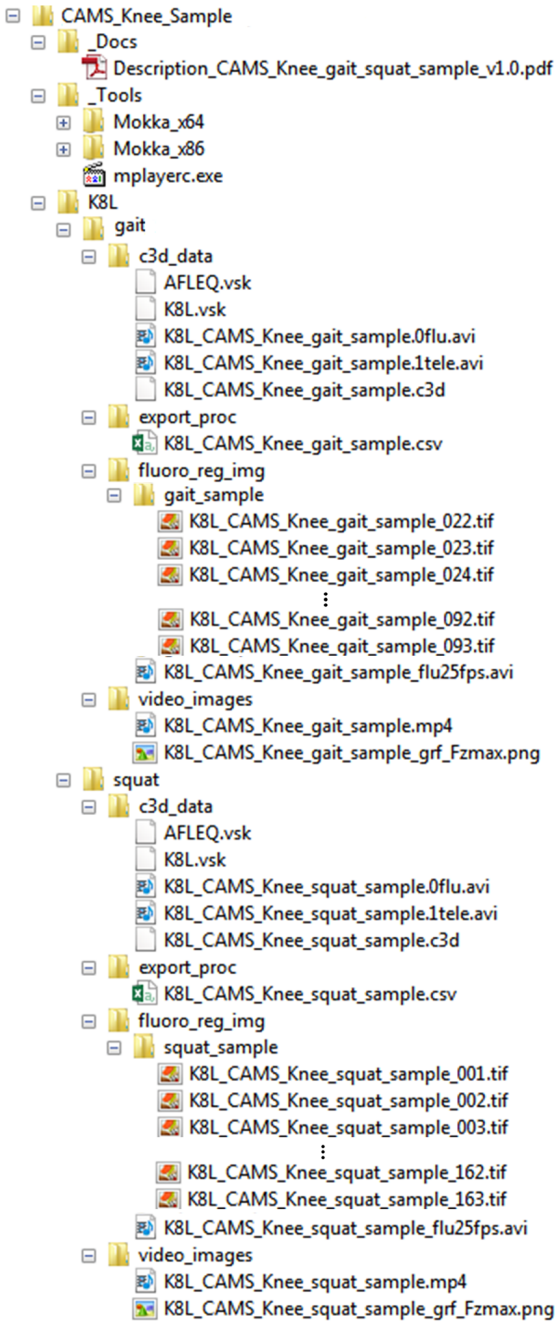


Figure 3: Structure of the sample gait and squat database

1. Documentation

The folder 'CAMS_Knee_Sample_Docs' contains the current document describing the structure and content of the database.

2. Tools

The folder 'CAMS_Knee_Sample_Tools' comprises installation files for Mokka (http://biomechanical-toolkit.github.io/mokka/). Mokka (Motion Kinematic & Kinetic Analyzer) is an open-source and cross-platform standalone application for assessing C3D files. It can visualize the acquisition data in the form of 3D views, 2D charts, as well as multimedia. Definition and manipulation of the gait events, smoothing/filtering of marker trajectories and analog signals, exporting gait data to ASCII/text files, and other features are available. Alternatively, it is possible to use the standalone Media Player Classic 'mplayerc.exe' for playing the videos. You can view the movements frame by frame using the arrow keys.

3. Processed data

All the processed kinematic, kinetic, telemetric and video data are presented according to activity (**task**) in either 'CAMS_Knee_Sample\K8L\gait\', or 'CAMS_Knee_Sample\K8L\squat\':

3.1. c3d_data

The folder 'CAMS_Knee_Sample\K8L**task**\c3d_data' contains 'AFLEQ.vsk' and 'K8L.vsk' (the labelling templates made for the subject and the fluoroscopic c-arm in VICON Nexus or Mokka), the processed c3d file 'K8L_CAMS_Knee_**task**_sample.c3d', and two synchronized video files made for visualisation purposes in Mokka (http://biomechanical-toolkit.github.io/mokka/). In the processed c3d file the *in-vivo* forces/moments were integrated as analog channels for visualization in VICON Nexus or Mokka.

3.2. export_proc

All the processed motion data are reported in 'CAMS_Knee_Sample\K8L**task**\export_proc\' in the file 'K8L_CAMS_Knee_**task**_sample.csv' file, which includes the following data:

- ***Gait events***
  - Heel-strike and toe-off of the sequential gait cycles included in the trial (in seconds).

- ***Time***
  - starting from 0, in seconds.

- ***Samples***
  - The ratio between the analog and video sample rate is 20 (2000Hz/100Hz)
  - **frame_a**; analog frame number, starting from 0
  - **frame_v**; video frame number, starting from 0

- ***Marker trajectories***
  - **X, Y and Z**; coordinates of the labelled markers (in mm), presented in the CS_{Lab} (Fig. 1)
  - No filtering or gap filling was performed on the processed marker trajectories
  - See Taylor et al., (2017) for more details about the marker set used in the experiment.

- ***Force plate data***
  - **Ref_X_lab, Ref_Y_lab and Ref_Z_lab**; position of the centre of each force plate in the CS_{Lab} (in mm)
  - **Fx_lab, Fy_lab and Fz_lab**; components of the ground reaction force vector acting on the foot measured by the force plate and presented in the CS_{Lab} (in N). The force level was set to zero when the force plate was not loaded (i.e. <15N) or was set to NaN when the force plate was not used in the measurement. All force plates were reset to zero before each trial measurement.
  - **COPx_lab, COPy_lab and COPz_lab**; location of the centre of pressure (CoP) in the CS_{Lab} (in mm). The CoP was calculated using the equation provided by the manufacturer (Kistler, Switzerland).
  - **Tz_lab**; free vertical torque (in Nm) acting on the foot and presented in the CS_{Lab}.
  - **COPx_lab_IfB, COPy_lab_IfB and COPz_lab_IfB**; location of the corrected centre of pressure (CoP) in the CS_{Lab} (in mm). The CoP was corrected with an in-situ point-of-force application based on the calibration method described by List et al., (2017).
  - **Tz_lab_IfB**; corrected free vertical torque (in Nm) acting on the foot and presented in the CS_{Lab}. This torque was calculated after correction of the CoP based on the calibration method described by List et al., (2017) (i.e. corresponding to COPx_lab_IfB, COPy_lab_IfB and COPz_lab_IfB).

- ***EMG data***
  - Sixteen columns reporting the output of 16 EMG sensors used during the measurements (see Taylor et al. 2017 for more details about placement of the sensors on the target muscles).
  - EMG signals are reported without any post processing.

- ***In-vivo joint loads***
  - All force data was synchronised with the motion data
  - **Fx, Fy, Fz, and Fres**; three components and the resultant contact force (in N) measured by the instrumented implant and reported in the coordinate system of the tibial component as described by Kutzner et al. 2010.
  - **Mx, My, Mz, and Mres**; three components and the resultant contact moment (in Nm) measured by the instrumented implant and reported in the coordinate system of the tibial component as described by Kutzner et al. 2010.
  - For transforming forces and moments from the implant-based system (IBS) to the bone-based system (BBS) for this subject using the follows transformation matrices:

$$\begin{bmatrix} a11 & \cdots & a13 \\ \vdots & \ddots & \vdots \\ a31 & \cdots & a33 \end{bmatrix} \times \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} \qquad T_{BBS\_K8L} = \begin{bmatrix} 0.9780 & -0.2071 & 0.0247 \\ 0.2079 & 0.9578 & -0.1986 \\ 0.0175 & 0.1993 & 0.9798 \end{bmatrix}$$

- **Transformation matrix of the tibial component**
  - $T_{11\_tib\text{-}lab}$ … $T_{44\_tib\text{-}lab}$; the sixteen elements of a 4x4 transformation matrix describe the translation and rotation from the tibial component CS (coinciding with the CS of the STL file of the tibial component) into the CS_{Lab}:

$$T_{tib-lab} = \begin{bmatrix} T_{11\_tib-lab} & \cdots & T_{14\_tib-lab} \\ \vdots & \ddots & \vdots \\ T_{41\_tib-lab} & \cdots & T_{44\_tib-lab} \end{bmatrix}$$

- **Transformation matrix of the femoral component**
  - $T_{11\_fem\text{-}lab}$ … $T_{44\_fem\text{-}lab}$; sixteen elements of a 4x4 transformation matrix describe the translation and rotation from the femoral component CS (coinciding with the coordinate system of the STL file of the femoral component) into the CS_{Lab}.

$$T_{fem-lab} = \begin{bmatrix} T_{11\_fem-lab} & \cdots & T_{14\_fem-lab} \\ \vdots & \ddots & \vdots \\ T_{41\_fem-lab} & \cdots & T_{44\_fem-lab} \end{bmatrix}$$

- **SYNC_fluoro**
  - Is a binary signal, where a '1' indicates the time point when the fluoroscope captures images.

3.3. fluoro_reg_img

The folder 'CAMS_Knee_Sample\K8L**task***\fluoro_reg_img\' contains fluoroscopic captured images/video including the 3D implant components, registered according to the process described in Burckhardt et al., (2005). In addition, there is a video of the fluoroscopic image series.

3.4. video_images

This directory contains video and image overview data. The image shows the data at the instant of maximum vertical force (Fz) on the force plate.

References:

Burckhardt, K., et al. "Submillimeter measurement of cup migration in clinical standard radiographs." IEEE Trans. Med. Imaging. 24 (2015): 676–688.

Kutzner, I., et al. "Loading of the knee joint during activities of daily living measured in vivo in five subjects." *Journal of biomechanics* 43.11 (2010): 2164-2173.

List, R., et al. "In-situ force plate calibration: 12 years' experience with an approach for correcting the point of force application." Gait & Posture 58 (2017): 98-102.

Taylor, W.R., et al. "A Comprehensive Assessment of the Musculoskeletal System: The CAMS-Knee Data Set. Journal of Biomechanics (2017), pre-print: DOI: 10.1016/j.jbiomech.2017.09.022

Terms and conditions:

1. The data may be used only for scientific purposes without any commercial benefit
2. The data may be used only at the registered institute or facility and may not be passed on to third parties
3. In any scientific publication (e.g. journals, conference abstracts, poster, or oral presentation) reporting use of the data, the CAMS-Knee database must be cited as follows: CAMS-Knee (2017): 'filename', retrieved from https://CAMS-Knee.orthoload.com, 'Date of access (day, month, and year)'

and

Taylor W.R., Schütz P., Bergmann G., List R., Postolka B., Hitz M., Dymke J., Damm P., Duda G., Gerber H., Schwachmeyer V., Hamed Hosseini Nasab S., Trepczynski A., Kutzner I.; "A Comprehensive Assessment of the Musculoskeletal System: The CAMS-Knee Data Set"; Journal of Biomechanics 2017; http://dx.doi.org/10.1016/j.jbiomech.2017.09.022; https://cams-knee.orthoload.com/

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