Knee torque estimation in sit to stand transfer

S Bhardwaj$^{1,2}$, A A Khan$^1$ and M Muzammil$^1$

$^1$Department of Mechanical Engineering, Aligarh Muslim University, Aligarh, India.
$^2$Corresponding author: siddharth.bhardwaj@live.com

Abstract. Multi-body formulations of human body has been a major approach in biomechanics to study the kinematics and dynamics of human movements. This paper discuss an inverse dynamics model of human body for the estimation of knee torque requirement during a sit to stand (STS) transfer. The study was carried out in two parts. In the first part of the study, angular deviations of trunk and knee were recorded in the sagittal plane, while one participant performed STS transfer. In the second part of the study, a five segment human model was designed in SolidWorks and later analysed in MSC/ADAMS for computation of knee torque in STS transfer. The maximum knee torque was found to be 1.34 Nm/kg at 59.2° knee extension.

1. Introduction
Multi-body modelling approach has been significantly used in past many researches for studying the motion dynamics. Simulation approaches have been used for the development of human models and the application of motion kinematics to study joint dynamics [1]. Computer models for human body are helpful in creating and studying different motions by considering the subject characteristics followed by changes in model parameters. Various human movements have been analysed using such computer models for estimating the dynamic forces on the joints [2,3].

In recent times, with the increase in health care requirements, more emphasis has been given to robotic devices for rehabilitation and assistive needs [4–6]. These devices must be capable of determining the assistance ratio and provide required torque at the joints to complete the assisted motion [7]. Inverse dynamic approaches have vastly followed in studying joint loadings [8–10]. In biomechanical studies these approaches requires quantification of kinematics data for motion.

Evaluation of kinematics and dynamics of human movement plays a key role in patient diagnosis and enables formulation of rehabilitation strategies. In the present study, knee torque was estimated during sit to stand (STS) transfer using multi-body modelling based approach. Standing from a sitting posture is a basic activity of daily life that requires significant effort from the lower limbs. STS transfer have also been used to measure lower extremity strength and as well as serves as a rehabilitation exercise [11]. The modelling approach and results from the study might be used for designing patient-tailored rehabilitation programs and assistive aids for supporting knee movement.

2. Methods
The study was conducted in two parts. In the first part knee flexion/extension ($K_{FE}$) and trunk flexion/extension ($T_{FE}$) was recorded from the participant performing a STS transfer. In the second part of the study, offline multi-body modelling was performed to evaluate the knee dynamics during STS transfer.
2.1. Data acquisition
Trunk and knee angular deflections were recorded from a healthy participant (Male, height = 1.58 m and weight = 58 kg) with no record of knee injury. Before conducting the experiment, the participant was informed about the procedure and signed consent was taken as approved by the University ethics board.

2.1.1. STS transfer. The experimented STS trial consisted of standing from a sitting posture. The seat height was fixed to the knee height of the participant. While seated, the participant was asked to maintain a neutral posture (T_{FE} = 0^\circ (\pm 5^\circ), K_{FE} = 90^\circ (\pm 5^\circ)) from which the participant initiated the STS transfer at his own natural pace.

2.1.2. Instrumentation. During the experimental trial, real-time and synchronized data for T_{FE} and K_{FE} were recorded in a custom build LabVIEW program (National Instruments Ltd.). Inertial measurement unit (IMU), MPU6050, was used to measure of T_{FE}. Time-weighted complementary filter was used in IMU to measure sagittal deflection of the trunk. The IMU was interfaced with LabVIEW through ATmega328 based Arduino board and sampled at 100 Hz. 

K_{FE} was measured using rotary potentiometer. The potentiometer was attached to the lateral epicondyle of the femur, forming a hinge with metal strips attached to the upper and lower leg. The potentiometer was pre-calibrated and interfaced with LabVIEW program via NI-myDAQ (National Instruments Ltd.) data acquisition unit and sampled at 1000 Hz. Figure 1 shows the experimental setup for the study.

![Experimental setup for data acquisition](image1.jpg)

Figure 1. Experimental setup for data acquisition

2.1.3. Procedure. Participant falling in 50th percentile anthropometry data for Indian population was recruited for the study. Anthropometry data for the upper and lower limb of the participant was measured. The participant was asked to perform practice STS trails to gain confidence. IMU was secured at the mid chest of the participant using a stretchable belt while the potentiometer was secured at the knees, after which the recording of the data was done. Three consecutive trials were made with a rest period comfortable to the participant.

3. Multi-body modelling
With the acquired anthropometry data, a 5 segment Human CAD model was modelled in SolidWorks (version 2013). Figure 2 shows the designed Human CAD model for the analysis. The model was later imported in ADAMS (MSC Corp.) for inverse dynamics computations.
3.1. **ADAMS modelling/setup**

Degree of freedom at the knee and trunk was considered in sagittal plane only for the purpose of dynamic analysis. Lower leg were given fixed constrain in the model while the joint between lower leg and upper leg, and the joints between upper leg and trunk were modelled to form revolute pairs. The acquired data form the experiment was used to form time variant functions at the knees and trunk joints to simulate STS transfer. Figure 3 shows the ADAMS model and constrain for the study.

4. **Results and discussion**

Figure 4 shows the time variation of $T_{FE}$ and $K_{FE}$ during the progression of STS transfer motion. Trunk flexion started at 13.4% before the knee extension started with STS transfer progress. An earlier start of trunk flexion indicates body coordination to reduce the knee torque requirement and improve stability by aligning the center of gravity of the upper body between the feet.
Figure 4. Knee and trunk deflection in sagittal plane during STS transfer.

Figure 5 shows the result of multibody simulation in ADAMS. From the simulation, the maximum knee torque was found to be 1.34 Nm/kg (normalised with respect to body weight) at 44.9% of the progression of the STS movement. The knee and trunk deviations at maximum torque were found to be 59.2° and -23.8° respectively.

Figure 5. Estimated Knee torque (body weight normalized) for STS transfer multi-body simulation.

*P1, P2 and P3 shows the local maxima (peaks) in the torque curve.

Unlike the knee that only passes through the extension phase, changes to the $T_{FE}$ during STS progression can be divided into two parts: the flexion phase that marks the initiation of the STS transfer, followed by the extension phase that begins with knee extension until the completion of the STS transfer. The peak P1 (0.56 Nm/kg) was observed in the torque curve corresponds to the flexion of trunk that poses a slight moment at the knee. While the peak P3 (0.64 Nm/kg) corresponds to the stabilizing torque at the knee just before the completion of STS transfer. The human model considered in the study consisted of five segments, with the hip and torso considered as one segment. The peak P3 observed in the model might be attributed to this reason. Peak knee torque from present study is in similitude to the
past studies which have reported peak knee torque in STS transfer as high as 2.2 Nm/kg and as low as 0.92 Nm/kg for able bodied person [12–14].

In the current model approach, the motion hypothesis has been assumed to be confined to the sagittal plane. However, to model the movements of people with disabilities and the elderly, these assumptions need to be reconsidered. In case of disability, the muscular coordination ensuring the movement torque changes, thus modifying the axis of the moments at the level of the articulation.

5. Conclusions
The paper presents a simulation based multi-body inverse dynamics approach for the evaluation of knee torque in STS transfer. The maximum knee torque from the model was found to be 1.34 Nm/kg, which is consistent with other studies. Such an off-line body dynamics assessment approach can be used to tailor patient-specific rehabilitation therapies.

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