

# Three ways of assessing the forces at the knee and ankle while cycling

EF Rios Soltero <sup>1</sup>✉ and HHCM Savelberg <sup>2</sup>

## Abstract

The analysis of the biomechanics of the leg while cycling is based on assumptions that make the calculations easier or faster. Most of the models and optimisations based on the dynamic chains introduced by Gonzalez & Hull (Hull & Gonzalez, 1988: J. Biomechanics, 21(10), 839-849) and by Papadopoulos (Papadopoulos, 1987: Biomechanics in Sport, 6, 83-92) with 5 and 4 links respectively share many of these assumptions. For instance, a fixed or no distance from the seat to the centre of rotation of the hip, a constant length of the segments of the leg (thigh, shank and foot) or a constant angular speed of the crank. Previous work (Rios Soltero et al., 2014: Procedia Engineering, in press) has shown that these assumptions may have an influence on the inertial forces of the system.

The present study shows that the generalised forces at the knee and ankle would also be different. As it was done before (Rios Soltero et al, 2014), the dynamic chain consisted of three leg segments (thigh, shank and foot), a crank and a grounding element. Also, three motion models were used to calculate the forces at each instant of the pedalling cycle in the sagittal plane at the knee and ankle (Figure 1.a). Here, the analysis was based on the force data at the pedal reported by Boyd et al. (1996, J. Biomechanics, 29(8), 1105-1110), and the motion capture of markers located at the leg and pedal from Rios Soltero et al. (2014). The crank speed was calculated from the pedal marker. To get the orientation angle of each segment, the first two models used a linear regression of their markers. One of them (Inters; intersections method) intersected each line of contiguous segments (thigh with shank and seat-tube, shank with foot and thigh, foot with crank and shank, and crank with seat-tube and foot) to create a dynamic chain at each instant. This allowed a change in length of the segments and the motion of the hip. The second method (Proj; projections method) only uses the orientation of the linear regression for each segment, while their lengths were constant as measured directly from the person. In this way, neither the hip nor the length of the segments were fixed. The third method (Kin; kinematics method) reproduced the assumptions of other studies: a hip fixed at the seat and unvarying length of the leg segments. The length of the leg segments was calculated according to anatomical tables (Winter, 2004: Biomechanics and motor control of human movement (3d ed.). John Wiley & Sons). To calculate the position of the thigh at each instant, an 8th-degree polynomial regression was calculated between the angle of the crank and that of the thigh. In all cases, the centre of mass and mass-moment of inertia of the thigh and shank were calculated using an analytical equation based on the geometry proposed by Durkin Teague et al. (2005: J. Biomechanical Engineering 127, 455-464) and Durkin and Dowling (2006: Annals of Biomedical Engineering 34, pp. 1483-1493). An elliptical frustum was used for the foot.

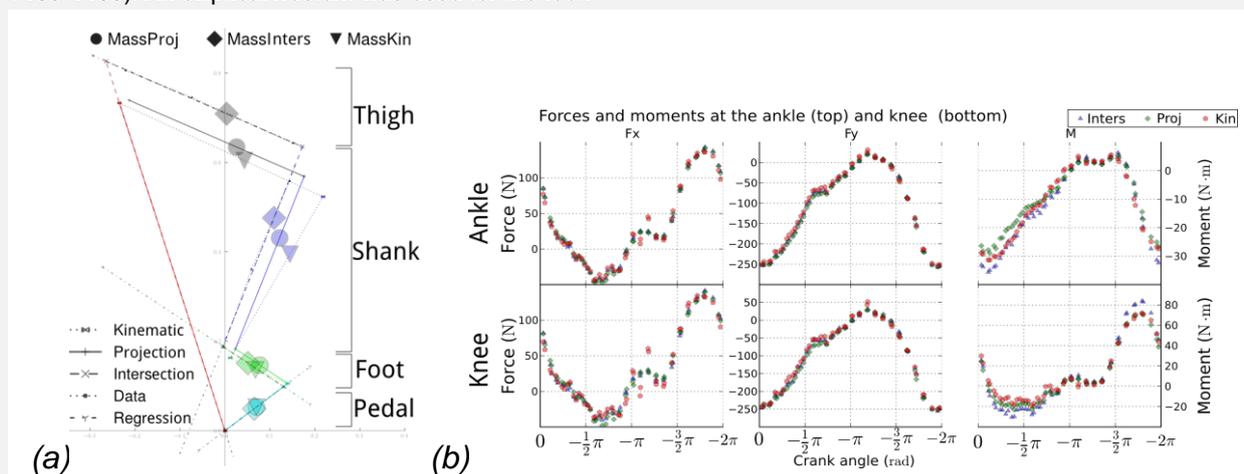


Figure 1: A graphical depiction of the dynamic chain formed by the three methods (a), and the resulting generalised forces at the ankle and knee (b)

The results of the analysis show a slight difference in the moments at the ankle and the knee for the first half of the cycle (Figure 1.b). The maximum absolute difference in the case of the knee is 15.4 N·m (between Inters and Kin) which is around 13% of the values' range. As for the ankle, it is 7.79 N·m (between Inters and Proj) with a 19% of the values' range. It is clear that there is no qualitative difference between the models. However, further analysis is needed to determine if there is a significant effect.

✉ **Contact email:** [e.f.riossiltero@tudelft.nl](mailto:e.f.riossiltero@tudelft.nl) (EF. Rios)

<sup>1</sup> TU Delft, Delft, The Netherlands

<sup>2</sup> Maastricht University, Maastricht, The Netherlands

---

*Received: 1 May 2014. Accepted: 1 June 2014.*

