Sensitivity study: Find the influence of differences in Prestretch values and Young's modulus on points of rotation and ligament moment arms

Methods

- Used the four best calibrated models (from Chapter 7) (Figure 1).
- The simulations performed are described in Table 1.
- 17 simulations per model: Best optimized prestretch and Young's modulus values +/- 0.1 for the prestretch values and +/- 10 for the Young's modulus values.
- The prestretch and Young's modulus values used as input for the simulations are given in Table 2.
- Best calibrated values used from calibration:

Model oks006	Calibration 7 - TNC 2
Model oks003	Calibration 8 - L-BFGS-B 4
Model oks001	Calibration 7 - TNC 5
Model du02	Calibration 8 - L-BFGS-B 2

- Look at differences in points of rotation and calculated ligament moment arms.

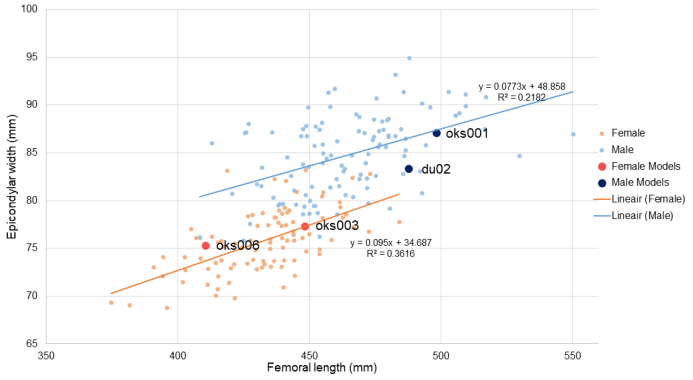

Figure 1: Epicondylar width over femoral length of a population of femurs (Zhang et al., 2016) and the four best calibrated models.

Table 1: Performed simulations to obtain the ligament moment arms.

Simulation	Timesteps	Description	
1	0.0 - 0.1	Prestretch application	
	0.1 - 0.5 (oks)	Rotate to robot data flexion angle	
	0.5 - 1.0 (oks)	Apply -20N axial load	*Create .dmp file 1*
	0.1 - 1.0 (du02)	Rotate to robot data flexion angle	*Create .dmp file 1*
2	1.0 - 1.5	Rotate to 0 degrees flexion	*Restart from .dmp file 1* *Create .dmp file 2*
3	1.5 - 2.0	Apply axial load (½ body weight)	*Restart from .dmp file 2* *Create .dmp file 3*
4	2.0 - 3.0	Simulate varus rotation (-40000 Nmm applied)	*Restart from .dmp file 3*
	2.0 - 3.0	Simulate valgus rotation (40000 Nmm applied)	*Restart from .dmp file 3*

Table 2: Prestretch (PS) and Young's modulus (YM) input values for the sensitivity simulations.

Simulation	Description	PS ACL	PS PCL	PS MCL	PS LCL	YM ACL	YM PCL	YM MCL	YM LCL
0	*Best calibration*	A	P	M	L	a	p	m	l
1	*ACL PS up*	A + 0.1	P	M	L	a	p	m	l
2	*ACL PS down*	A - 0.1	P	M	L	a	p	m	l
3	*PCL PS up*	A	P + 0.1	M	L	a	p	m	l
4	*PCL PS down*	A	P - 0.1	M	L	a	p	m	l
5	*MCL PS up*	A	P	M + 0.1	L	a	p	m	l
6	*MCL PS down*	A	P	M - 0.1	L	a	p	m	l
7	*LCL PS up*	A	P	M	L + 0.1	a	p	m	l
8	*LCL PS down*	A	P	M	L - 0.1	a	p	m	l
9	*ACL YM up*	A	P	M	L	a + 10	p	m	l
10	*ACL YM down*	A	P	M	L	a - 10	p	m	l
11	*PCL YM up*	A	P	M	L	a	p + 10	m	l
12	*PCL YM down*	A	P	M	L	a	p - 10	m	l
13	*MCL YM up*	A	P	M	L	a	p	m + 10	l
14	*MCL YM down*	A	P	M	L	a	p	m - 10	l
15	*LCL YM up*	A	P	M	L	a	p	m	l + 10
16	*LCL YM down*	A	P	M	L	a	p	m	l - 10

Results

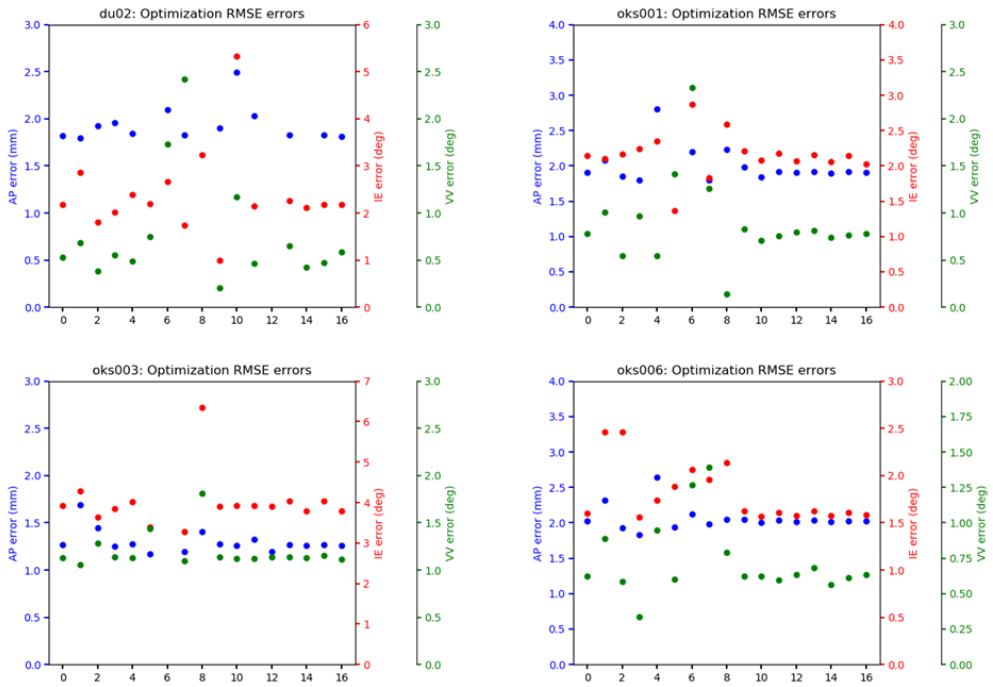

Figure 2: AP, IE and VV simulation RMSE errors for the du02, oks001, oks003 and oks006 model, for all 17 runs per model.

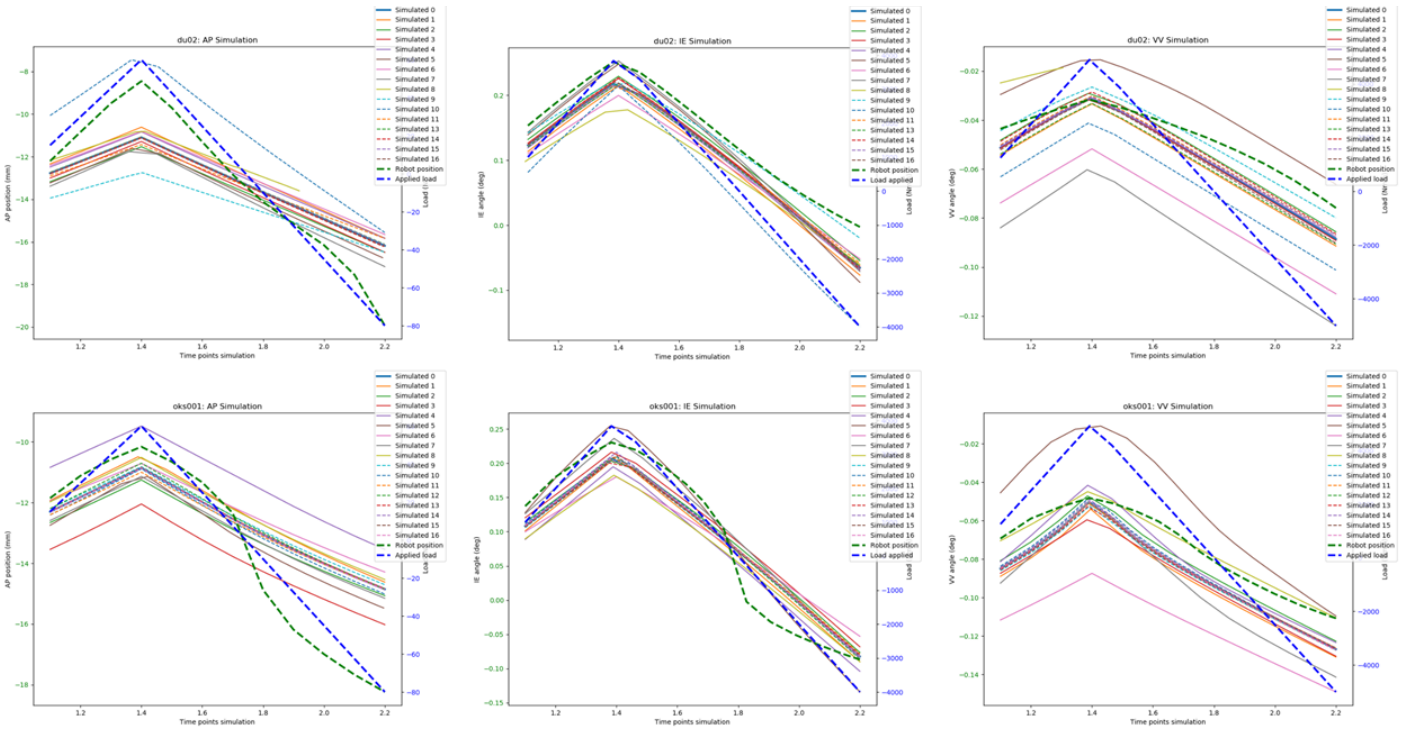

Figure 3: AP, IE and VV simulated positions compared to robot positions for model DU02 and oks001.

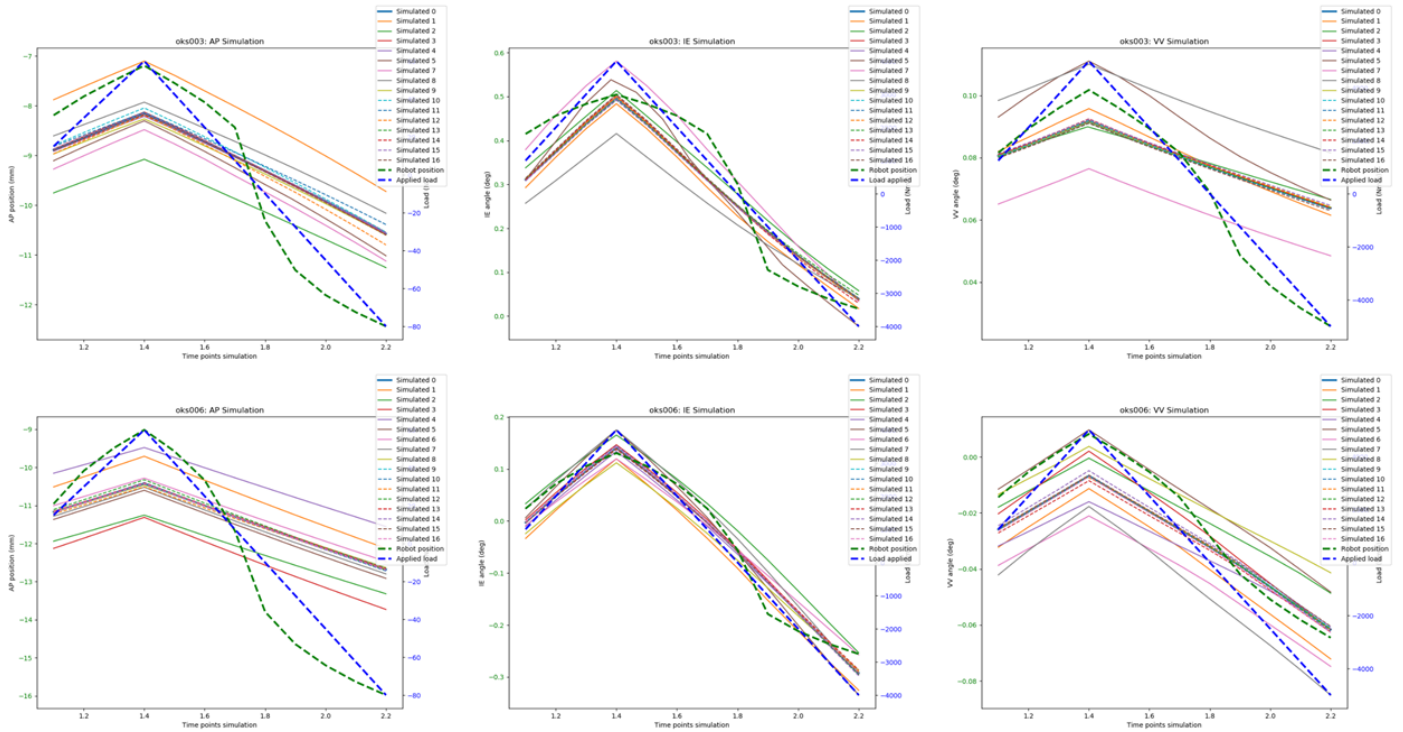

Figure 4: (Placeholder) AP, IE and VV simulated positions compared to robot positions model oks003 and oks006.

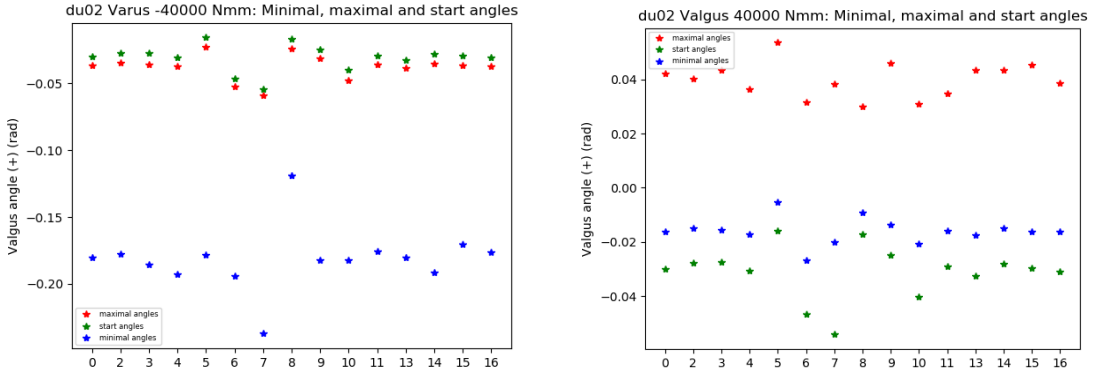

Figure 5: Model du02, Varus (left) and valgus (right) simulated varus and valgus angles after applying -40000 and 40000 Nmm, respectively.

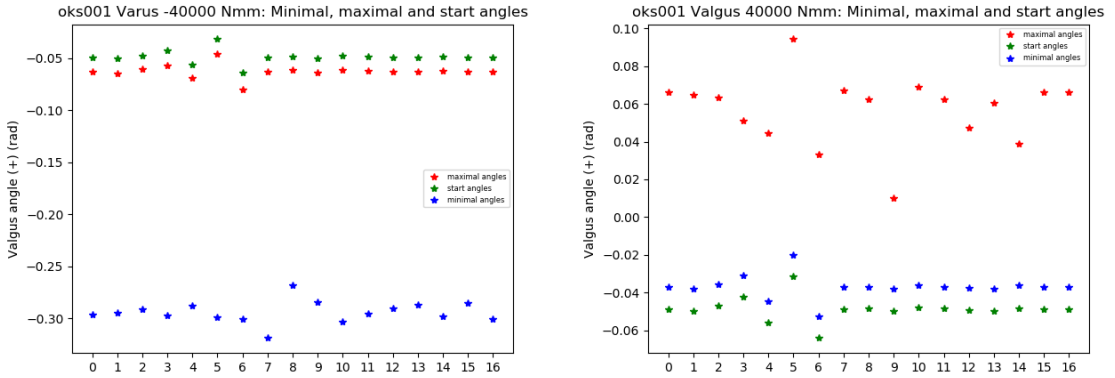

Figure 6: Model oks001, Varus (left) and valgus (right) simulated varus and valgus angles after applying -40000 and 40000 Nmm, respectively.

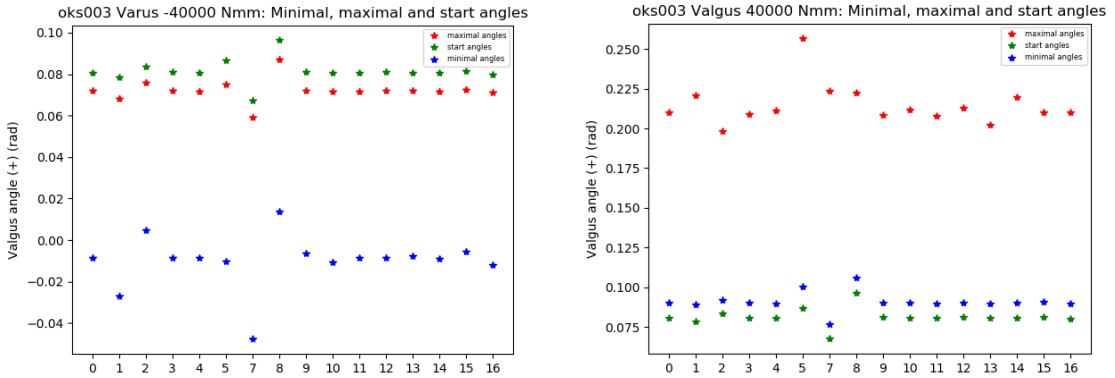

Figure 7: Model oks003, Varus (left) and valgus (right) simulated varus and valgus angles after applying -40000 and 40000 Nmm, respectively.

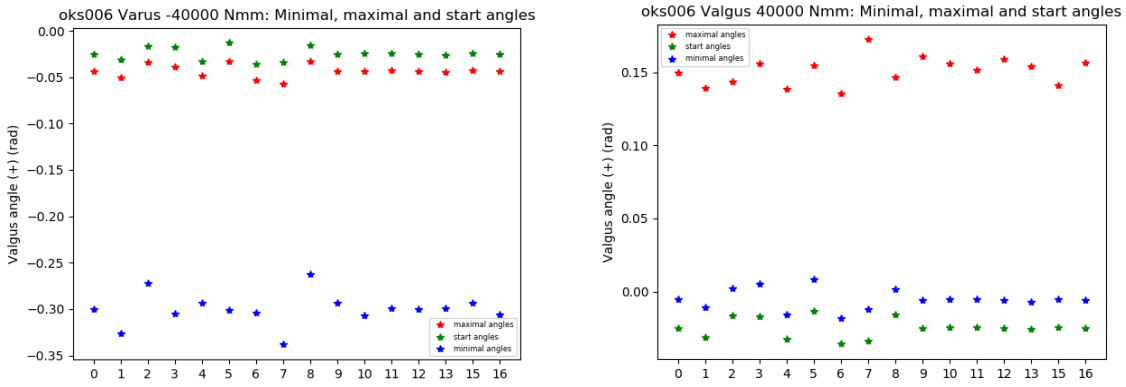

Figure 8: Model oks006, Varus (left) and valgus (right) simulated varus and valgus angles after applying -40000 and 40000 Nmm, respectively.

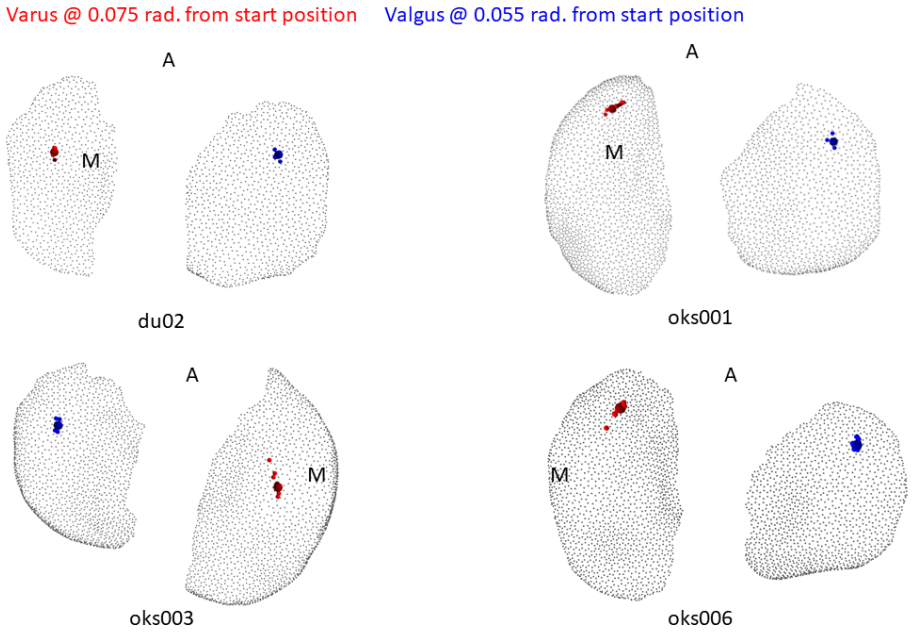

Figure 9: Point of rotation for all 17 varus and valgus rotation simulations per model. The larger dot indicates the point of rotation from the simulation using the best calibrated prestretch and Young's moduli values.

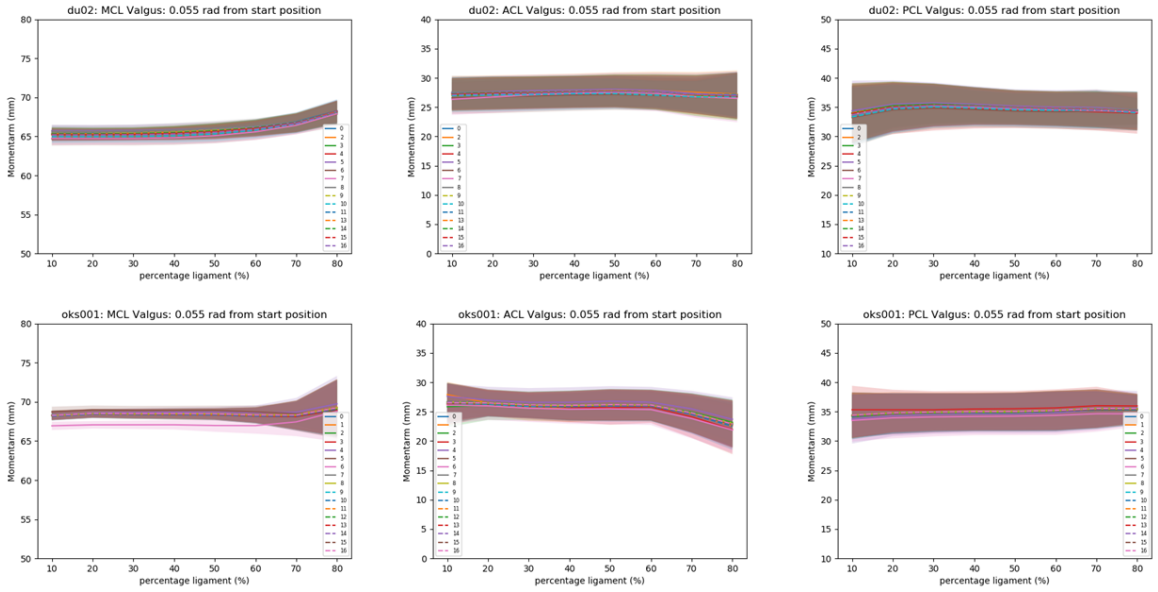

Figure 10: Ligament moment arms over the length of the ligaments (mean +/-SD over 5 lines of action per ligament), Valgus simulation (0.055 rad from starting position) for model du02 and oks001.

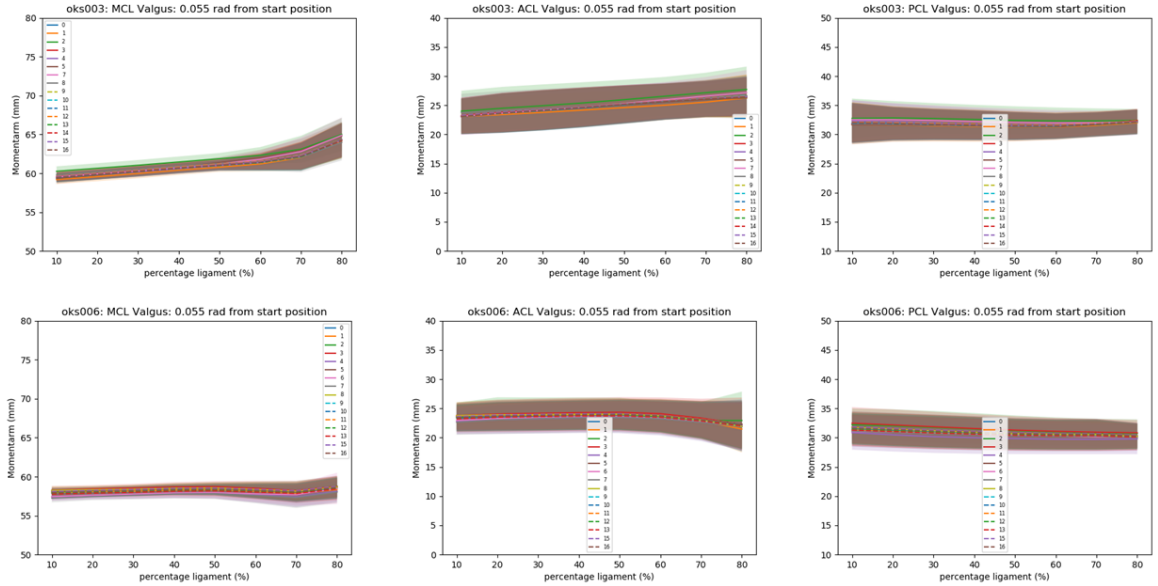

Figure 11: Ligament moment arms over the length of the ligaments (mean +/-SD over 5 lines of action per ligament), Valgus simulation (0.055 rad from starting position) for model oks003 and oks006.

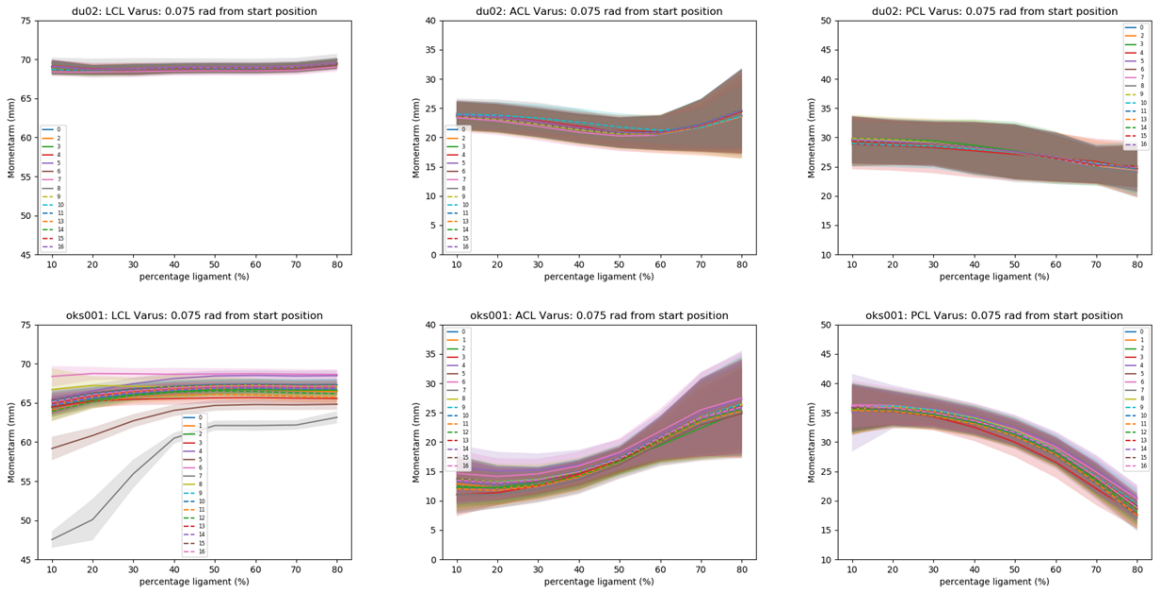

Figure 12: Ligament moment arms over the length of the ligaments (mean +/-SD over 5 lines of action per ligament), Varus simulation (0.075 rad from starting position) for model du02 and oks001.

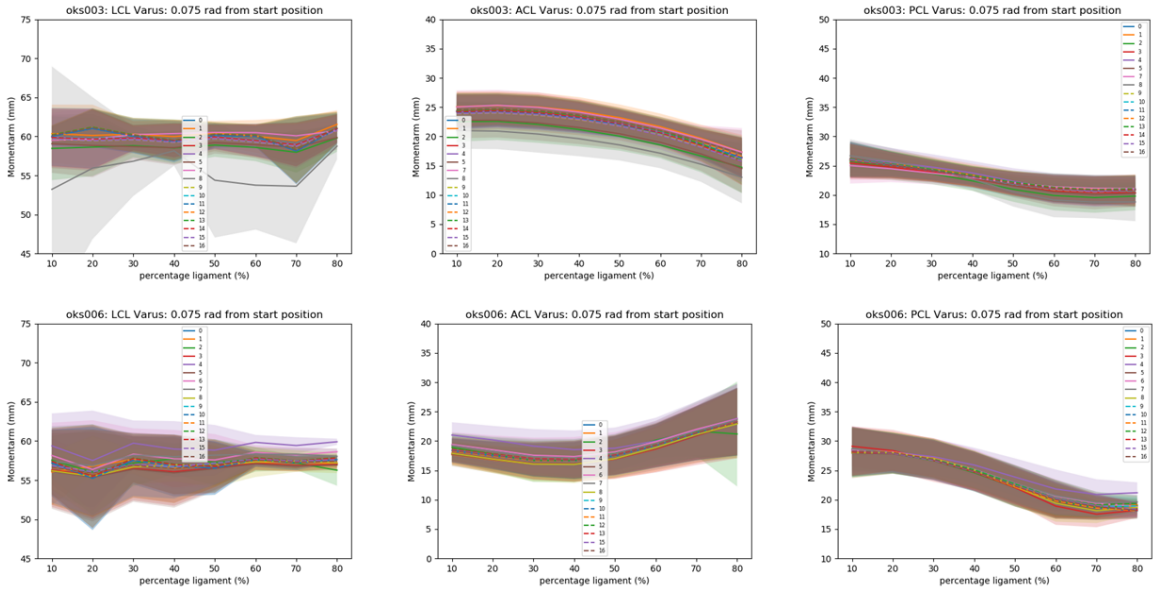

Figure 13: Ligament moment arms over the length of the ligaments (mean +/-SD over 5 lines of action per ligament), Varus simulation (0.075 rad from starting position) for model oks003 and oks006.

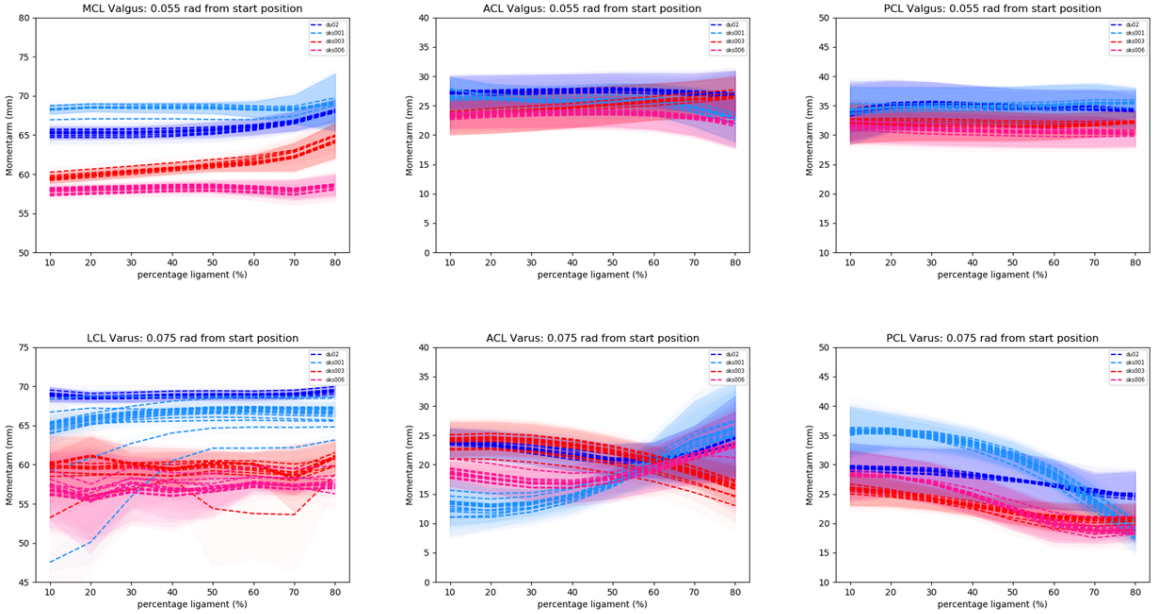

Figure 14: Ligament moment arms over the length of the ligaments (mean +/-SD over 5 lines of action per ligament), Varus (0.075 rad from starting position) and Valgus (0.055 radians from starting position) for all runs for all models .

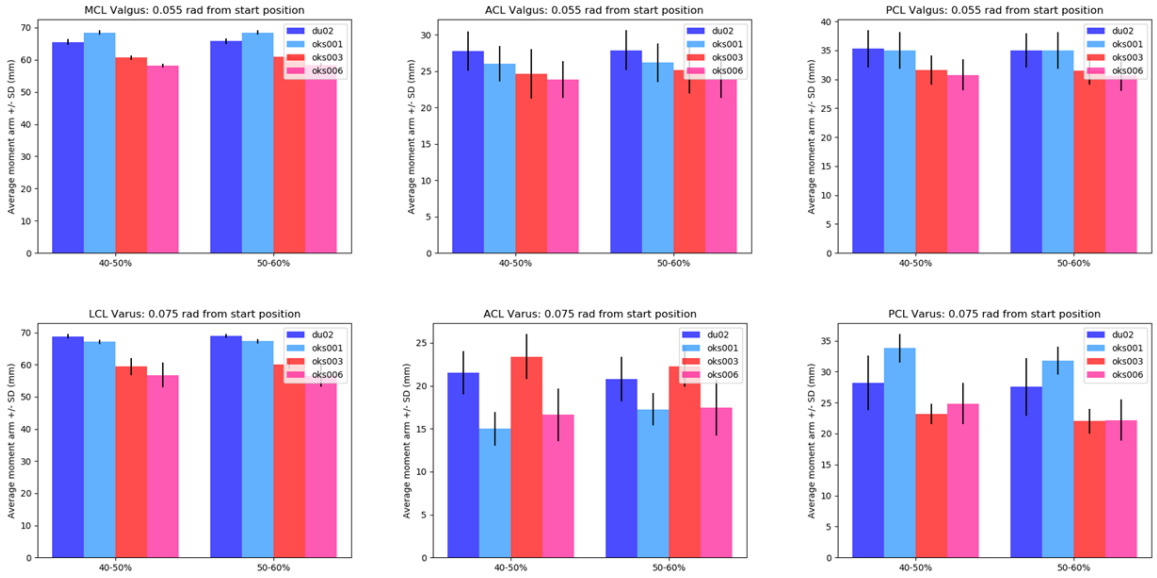

Figure 15: Mid substance moment arms of run 0 (mean +/-SD over 5 lines of action per ligament).

Conclusion

- For most simulations, the points of rotation do not vary a lot. A larger influence was seen when the prestretch was changed compared to the Young's modulus.
- Prestretch values have a clear effect on the moment arms
- Changes in Young's modulus did not change the moment arms a lot.
- We did not change the Young's modulus a lot (only 10MPa)