

Supplementary Data

Effects of geometric individualisation of a human spine model on load sharing: neuro-musculoskeletal simulation reveals significant differences in ligament and muscle contribution

Biomechanics and Modeling in Mechanobiology

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1 Generic muscle parameters

Table 1: Generic muscle parameters

	activation	m [s ⁻¹]	ϖ []	ν []	q_0 []
	dynamics	15.0*	8.0	3.0	0.001
CE	force-length	ΔW_{asc} []	$\nu_{\text{CE,asc}}$ []	ΔW_{des} []	$\nu_{\text{CE,des}}$ []
	relation	0.35	3.0	0.35*	1.5*
	force-velocity	$A_{\text{rel},0}$ []	$B_{\text{rel},0}$ [s ⁻¹]	$\mathcal{F}_{\text{max,ecc}}$ []	$\mathcal{S}_{\text{ecc}}$ []
	relation	0.2	2.0	1.8*	2.0*
PEE		$\mathcal{L}_{\text{PEE},0}$ []	ν_{PEE} []	$\mathcal{F}_{\text{max,PEE}}$ []	
		0.95	4.0	0.2	
SEE		$\Delta U_{\text{SEE,nll}}$ []	$\Delta U_{\text{SEE,l}}$ []	$\Delta F_{\text{SEE},0}$ [N]	
		0.06	0.02	$F_{\text{max}}/3$	
SDE		D_{SDE} []	R_{SDE} []		
		0.3	0.01		

Generic muscle parameters as used in our recently published model (Mörl et al., 2020). Note, that parameter values with an asterisk were inadvertently misstated in Table 5 of Mörl et al. (2020) and corrected here using the values from Mörl et al. (2012). A comprehensive parameter description can be found in Günther et al. (2007) and Haeufle et al. (2014). Parameters for the activation dynamics of the contractile element (CE) (Hatzel, 1977) are implemented according to Rockenfeller et al. (2015) in its recently revised form (Rockenfeller and Günther, 2018)

2 Muscle-specific parameters

Table 2: Muscle-specific parameters of abdominal muscles

Muscle name	PCSA[cm ²]	$F_{\max}$ [N]	m_{ratio} []
<i>Rectus abdominis</i>			
M_rectus_abdominis_1	1.42	[C]/4	[C]
M_rectus_abdominis_2	1.42	32.60	0.788
M_rectus_abdominis_3	1.42	32.60	0.788
M_rectus_abdominis_4	1.42	32.60	0.788
<i>Externus oblique</i>			
M_externus_oblique_1	1.96	[C]	[C]
M_externus_oblique_2	2.32	45.080	0.389
M_externus_oblique_3	2.43	53.360	0.410
M_externus_oblique_4	2.34	55.890	0.455
M_externus_oblique_5	2.73	53.820	0.470
M_externus_oblique_6	3.97	62.790	0.480
<i>Internus oblique</i>			
M_internus_oblique_1	1.85	91.310	0.50
M_internus_oblique_2	2.24	[C]	[C]
M_internus_oblique_3	2.26	42.550	0.40
M_internus_oblique_4	2.68	51.520	0.40
M_internus_oblique_5	2.35	51.980	0.40
M_internus_oblique_6	2.07	61.640	0.60
<i>Psoas major</i>			
M_psoas_major_L1L2Pelvis_IVD	1.20	54.050	0.60
M_psoas_major_L1Pelvis_TP	0.61	47.610	0.60
M_psoas_major_L1Pelvis_VB	2.11	[C]	[C]
M_psoas_major_L2L3Pelvis_IVD	1.19	27.600	0.800
M_psoas_major_L2Pelvis_TP	2.11	14.030	0.800
M_psoas_major_L3L4Pelvis_IVD	0.36	48.530	0.800
M_psoas_major_L3Pelvis_TP	1.01	27.370	0.800
M_psoas_major_L4L5Pelvis_IVD	0.79	48.530	0.800
M_psoas_major_L4Pelvis_TP	1.61	8.280	0.800
M_psoas_major_L5Pelvis_TP	1.73	23.230	0.800
M_psoas_major_L5Pelvis_VB	1.91	18.170	0.800

Muscle-specific parameters (physiological cross-sectional area PCSA, ratio of the muscle fibre length to the length of the muscle tendon unit m_{ratio}) were taken from literature (Key: [C]: [Christophy et al. \(2012\)](#)) and used to derive the three modelling parameters: Maximum isometric force $F_{\max}$, optimal fibre length $l_{\text{CE,opt}}$ and tendon slack length $l_{\text{SEE},0}$. For the calculation of $F_{\max}$ we assumed a maximum isometric stress of $\sigma = 23 \text{ N/cm}^2$

Table 3: Muscle-specific parameters of back muscles

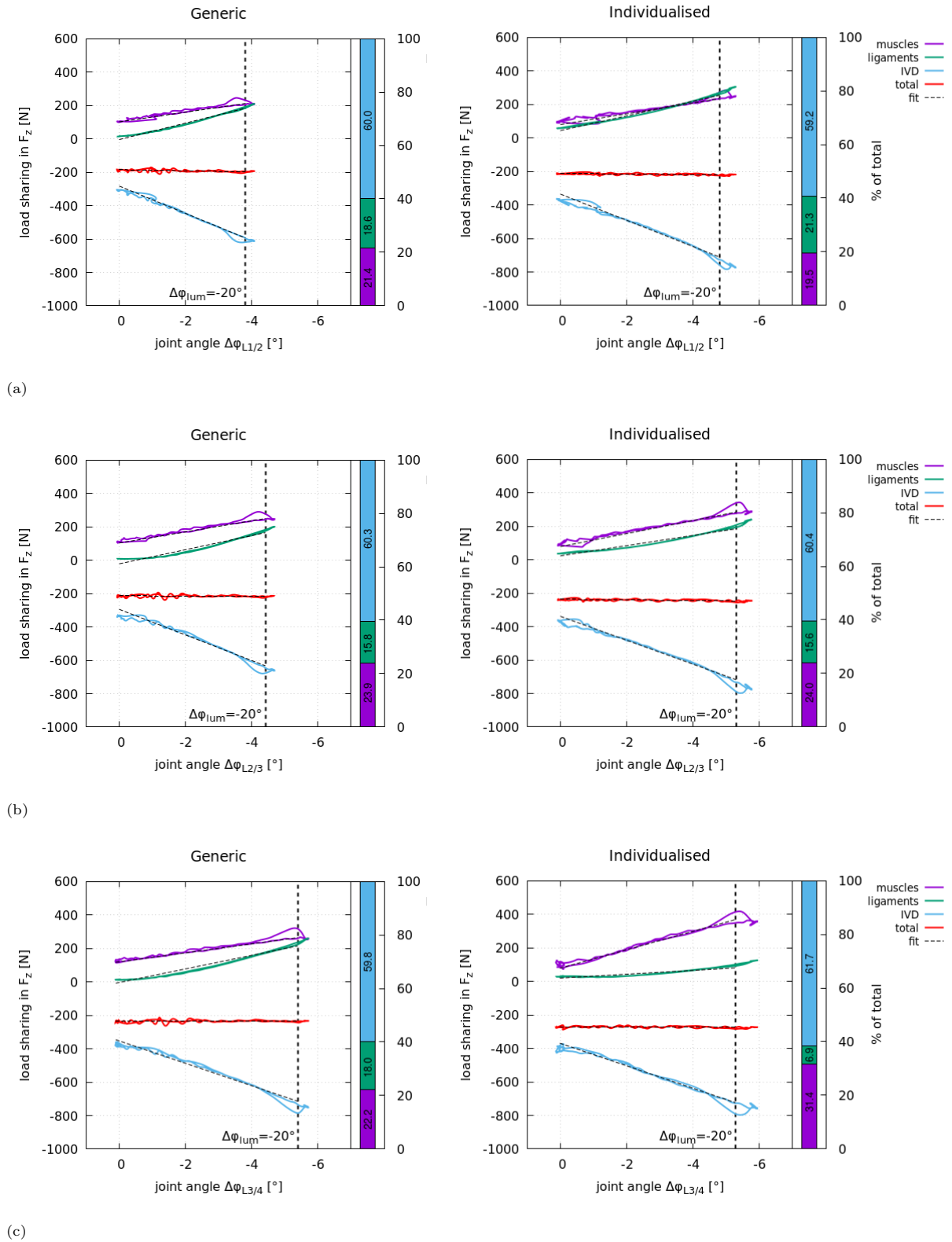
Muscle name	PCSA[cm ²]	$F_{\max}$ [N]	m_{ratio} []
<i>Erectus spinae</i>	[C]		[C]
M.longissimus.thoracis.pars.lumborum.L1S1	0.79	18.170	0.419
M.longissimus.thoracis.pars.lumborum.L2S1	0.91	20.930	0.433
M.longissimus.thoracis.pars.lumborum.L3S1	1.03	23.690	0.436
M.longissimus.thoracis.pars.lumborum.L4S1	1.10	25.300	0.438
M.longissimus.thoracis.pars.lumborum.L5S1	1.16	26.680	0.440
M.longissimus.thoracis.pars.thoracis.R4L4	0.23	5.290	0.330
M.longissimus.thoracis.pars.thoracis.R5L5	0.22	5.060	0.330
M.longissimus.thoracis.pars.thoracis.R6Pelvis	0.32	7.360	0.353
M.longissimus.thoracis.pars.thoracis.R7Pelvis	0.39	8.970	0.333
M.longissimus.thoracis.pars.thoracis.R8Pelvis	0.63	14.490	0.290
M.longissimus.thoracis.pars.thoracis.R9Pelvis	0.73	16.790	0.254
M.longissimus.thoracis.pars.thoracis.R10Pelvis	0.80	18.400	0.327
M.longissimus.thoracis.pars.thoracis.R11Pelvis	0.84	19.320	0.370
M.longissimus.thoracis.pars.thoracis.R12Pelvis	0.69	15.870	0.300
M.longissimus.thoracis.pars.thoracis.T1L1	0.29	6.670	0.260
M.longissimus.thoracis.pars.thoracis.T2L2	0.57	13.110	0.257
M.longissimus.thoracis.pars.thoracis.T3L3	0.56	12.880	0.257
M.longissimus.thoracis.pars.thoracis.T4L4	0.23	5.290	0.257
M.longissimus.thoracis.pars.thoracis.T5L5	0.22	5.060	0.257
M.longissimus.thoracis.pars.thoracis.T6Pelvis	0.32	7.360	0.267
M.longissimus.thoracis.pars.thoracis.T7Pelvis	0.39	8.970	0.306
M.longissimus.thoracis.pars.thoracis.T8Pelvis	0.63	14.490	0.346
M.longissimus.thoracis.pars.thoracis.T9Pelvis	0.73	16.790	0.330
M.longissimus.thoracis.pars.thoracis.T10Pelvis	0.80	18.400	0.330
M.longissimus.thoracis.pars.thoracis.T11Pelvis	0.84	19.320	0.330
M.longissimus.thoracis.pars.thoracis.T12Pelvis	0.69	15.870	0.330
M.iliocostalis.lumborum.pars.lumborum.L1S1	1.08	24.840	0.274
M.iliocostalis.lumborum.pars.lumborum.L2S1	1.54	35.420	0.274
M.iliocostalis.lumborum.pars.lumborum.L3S1	1.82	41.860	0.274
M.iliocostalis.lumborum.pars.lumborum.L4S1	1.89	43.470	0.274
M.iliocostalis.lumborum.pars.thoracis.R10Pelvis	1.00	23.000	0.600
M.iliocostalis.lumborum.pars.thoracis.R11Pelvis	1.23	28.290	0.640
M.iliocostalis.lumborum.pars.thoracis.R12Pelvis	1.47	33.810	0.640
M.iliocostalis.lumborum.pars.thoracis.R5Pelvis	0.23	5.290	0.381
M.iliocostalis.lumborum.pars.thoracis.R6Pelvis	0.31	7.130	0.417
M.iliocostalis.lumborum.pars.thoracis.R7Pelvis	0.39	8.970	0.452
M.iliocostalis.lumborum.pars.thoracis.R8Pelvis	0.34	7.820	0.462
M.iliocostalis.lumborum.pars.thoracis.R9Pelvis	0.50	11.500	0.600
<i>Intertransversarii</i>		[M]	[M]
M.intertransversarii.mediales.L1L2	-	21.420	0.500
M.intertransversarii.mediales.L2L3	-	21.420	0.500
M.intertransversarii.mediales.L3L4	-	21.420	0.500
M.intertransversarii.mediales.L4L5	-	21.420	0.500
<i>Multifidus</i>	[C]		[C]
M.multifidus.multifascicle.L1L5	0.42	9.660	0.730
M.multifidus.multifascicle.L1S1	0.36	8.280	0.730
M.multifidus.multifascicle.L1S1caudal	0.60	13.800	0.730
M.multifidus.multifascicle.L2S1	0.50	11.390	0.727
M.multifidus.multifascicle.L2S1caudal	0.50	11.390	0.727
M.multifidus.multifascicle.L2S1cranial	0.39	8.970	0.727
M.multifidus.multifascicle.L3S1	0.52	11.960	0.709
M.multifidus.multifascicle.L3S1caudal	0.52	11.960	0.709
M.multifidus.multifascicle.L3S1cranial	0.52	11.960	0.709
M.multifidus.multifascicle.L4S1	0.47	10.810	0.667
M.multifidus.multifascicle.L4S1caudal	0.47	10.810	0.667
M.multifidus.multifascicle.L4S1cranial	0.47	10.810	0.667
M.multifidus.multifascicle.L5S1	0.23	5.290	0.667
M.multifidus.multifascicle.L5S1caudal	0.23	5.290	0.667

M_multifidus_multifascicle_L5S1cranial	0.23	5.290	0.667
M_multifidus_laminarfibres_L1L3	0.19	4.370	0.681
M_multifidus_laminarfibres_L2L4	0.22	5.060	0.681
M_multifidus_laminarfibres_L3L5	0.23	5.290	0.681
M_multifidus_laminarfibres_L4S1	0.17	3.910	0.681
M_multifidus_laminarfibres_L5S1	0.36	8.280	0.681
M_multifidus_singlefascicle_L1L4	0.40	9.200	0.661
M_multifidus_singlefascicle_L2L5	0.39	8.970	0.677
M_multifidus_singlefascicle_L3S1	0.54	12.420	0.661
M_multifidus_singlefascicle_L4S1	0.47	10.810	0.562
M_multifidus_singlefascicle_L5S1	0.23	5.290	0.562
	[S]		av.[Ba]
M_multifidus_laminarfibres_T1T3	0.40	9.200	0.797
M_multifidus_laminarfibres_T2T4	0.40	9.200	0.797
M_multifidus_laminarfibres_T3T5	0.40	9.200	0.797
M_multifidus_laminarfibres_T4T6	0.40	9.200	0.797
M_multifidus_laminarfibres_T5T7	0.40	9.200	0.797
M_multifidus_laminarfibres_T6T8	0.40	9.200	0.797
M_multifidus_laminarfibres_T7T9	0.40	9.200	0.797
M_multifidus_laminarfibres_T8T10	0.40	9.200	0.797
M_multifidus_laminarfibres_T9T11	0.40	9.200	0.797
M_multifidus_laminarfibres_T10T12	0.40	9.200	0.797
M_multifidus_laminarfibres_T11L1	0.40	9.200	0.797
M_multifidus_laminarfibres_T12L2	0.40	9.200	0.797
M_multifidus_singlefascicle_T1T4	0.40	9.200	0.797
M_multifidus_singlefascicle_T2T5	0.40	9.200	0.797
M_multifidus_singlefascicle_T3T6	0.40	9.200	0.797
M_multifidus_singlefascicle_T4T7	0.40	9.200	0.797
M_multifidus_singlefascicle_T5T8	0.40	9.200	0.797
M_multifidus_singlefascicle_T6T9	0.40	9.200	0.797
M_multifidus_singlefascicle_T7T10	0.40	9.200	0.797
M_multifidus_singlefascicle_T8T11	0.40	9.200	0.797
M_multifidus_singlefascicle_T9T12	0.40	9.200	0.797
M_multifidus_singlefascicle_T10L1	0.40	9.200	0.797
M_multifidus_singlefascicle_T11L2	0.40	9.200	0.797
M_multifidus_singlefascicle_T12L3	0.40	9.200	0.797
<i>Semispinalis</i>	[Ba]		av.[Ba]
M_semisपालis_T1T8_s	0.160	3.680	0.597
M_semisपालis_T2T9_s	0.160	3.680	0.597
M_semisपालis_T3T10_s	0.160	3.680	0.597
M_semisपालis_T4T11_s	0.160	3.680	0.597
M_semisपालis_T5T12_s	0.160	3.680	0.597
<i>Interspinalis</i>	[M]		[M]
M_interspinalis_L1L2	-	13.430	0.500
M_interspinalis_L2L3	-	13.430	0.500
M_interspinalis_L3L4	-	13.430	0.500
M_interspinalis_L4L5	-	13.430	0.500
	est.[Br]		est.[CD]
M_interspinalis_T10T11	0.50	11.500	0.530
M_interspinalis_T11T12	0.50	11.500	0.530
M_interspinalis_T12L1	0.50	11.500	0.530
M_interspinalis_T1T2	0.50	11.500	0.530
M_interspinalis_T2T3	0.50	11.500	0.530
M_interspinalis_T3T4	0.50	11.500	0.530
M_interspinalis_T4T5	0.50	11.500	0.530
M_interspinalis_T5T6	0.50	11.500	0.530
M_interspinalis_T6T7	0.50	11.500	0.530
M_interspinalis_T7T8	0.50	11.500	0.530
M_interspinalis_T8T9	0.50	11.500	0.530
M_interspinalis_T9T10	0.50	11.500	0.530

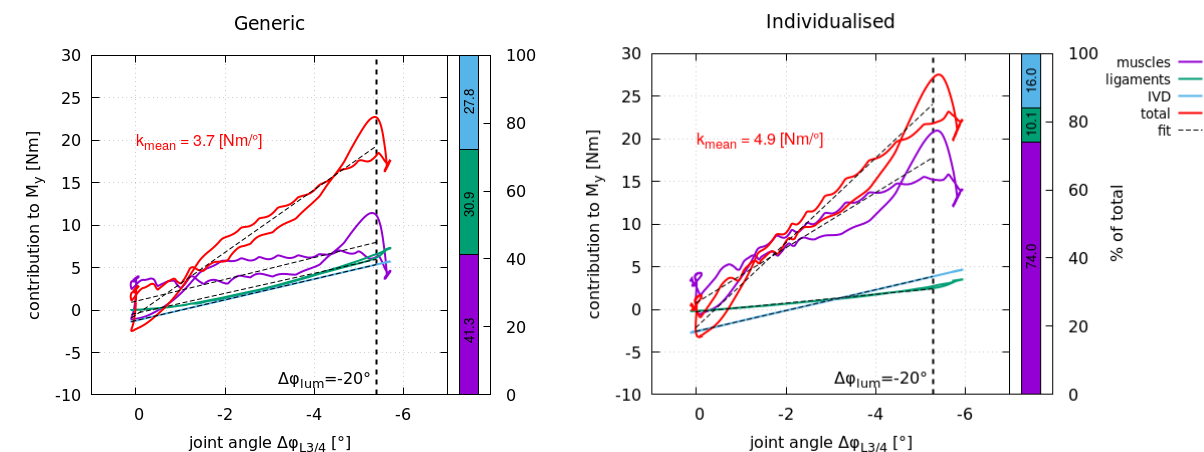
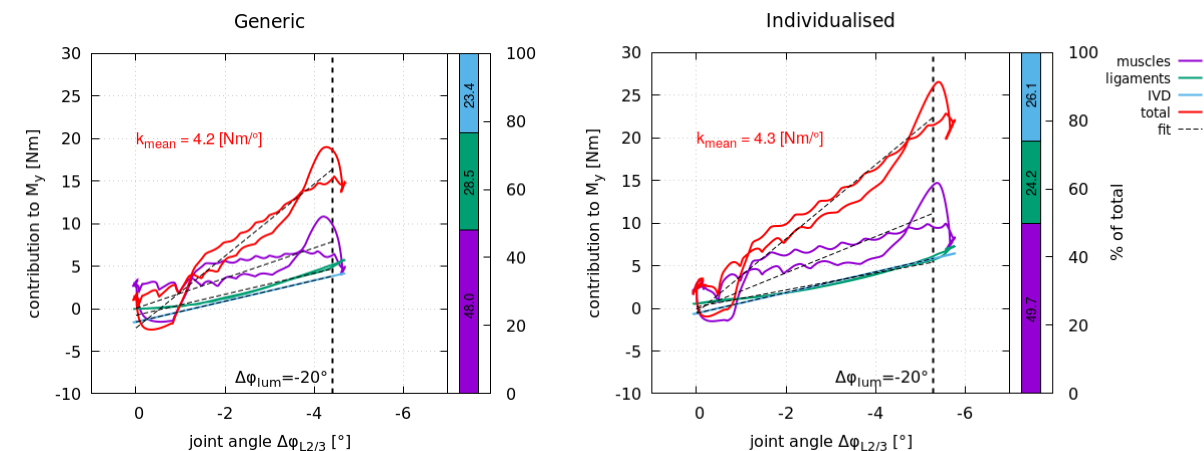
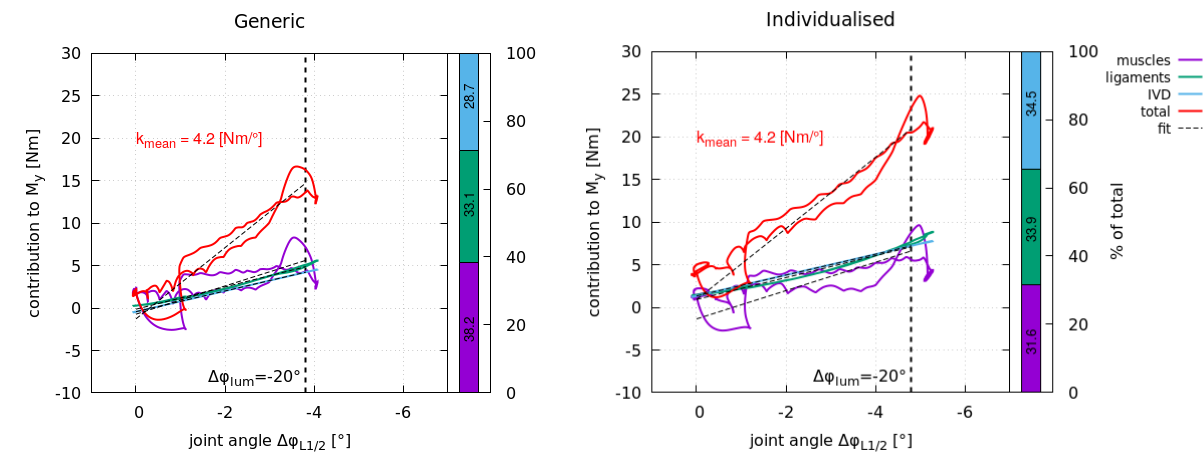
<i>Spinalis</i>	[D]		[D]
M_spinalis_T1L5	0.20	4.600	0.259
M_spinalis_T2L4	0.20	4.600	0.259
M_spinalis_T3L3	0.20	4.600	0.259
M_spinalis_T4L2	0.20	4.600	0.259
M_spinalis_T5L1	0.20	4.600	0.259
M_spinalis_T6T12	0.20	4.600	0.259
M_spinalis_T7T11	0.20	4.600	0.259
M_spinalis_T8T10	0.20	4.600	0.259

Muscle-specific parameters (physiological cross-sectional area PCSA, ratio of the muscle fibre length to the length of the muscle tendon unit m_{ratio}) were taken or estimated from literature and used to derive the three modelling parameters: Maximum isometric force F_{max} , optimal fibre length $l_{\text{CE,opt}}$ and tendon slack length $l_{\text{SEE},0}$. For the calculation of F_{max} we assumed a maximum isometric stress of $\sigma = 23 \text{ N/cm}^2$. The source of this data is given at the top of each muscle column. Key: [C]: [Christophy et al. \(2012\)](#), [M]: [Mörl et al. \(2020\)](#), [S]: [Stokes and Gardner-Morse \(1999\)](#), [D]: [Delp et al. \(2001\)](#), [Br]: [Brolin et al. \(2005\)](#), [Ba]: [Bayoglu et al. \(2017\)](#), [CD]: [Cramer and Darby \(2005\)](#)

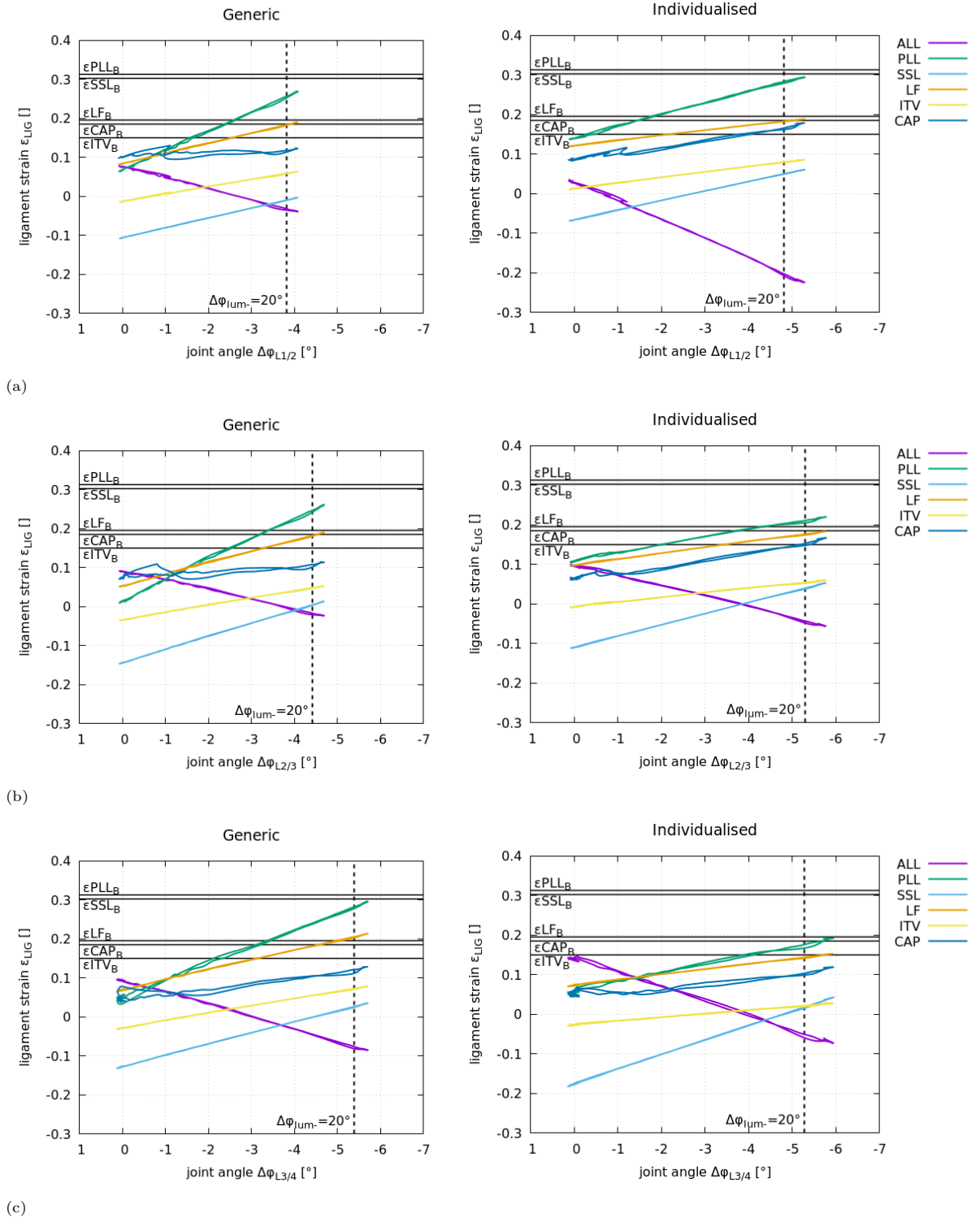
3 Model-specific structural resolution of internal forces



4 Model-specific evaluation of the FSU stiffness



5 Ligament forces and strain



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