

Supplementary Data

for

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Implication of region-dependent material properties of articular cartilage in the contact mechanics of porcine knee joint

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Table S1 Mesh information of all tissues. C3D8P: 8-node hexahedral element with pore pressure; R3D3(4): 3(4)-node 3D rigid triangular(quadrilateral) element (ABAQUS element library).

Tissues		Element type	Number of elements	Average aspect ratio
Bones	Femur	Discrete rigid (R3D3 / R3D4)	110 / 6100	1.26 / 1.32
	Tibia/fibula		162 / 6629	1.59 / 1.39
Cartilages	Femoral	3D Solid with fluid pressure (C3D8P)	6158	1.76
	Lateral tibial		1878	1.57
	Medial tibial		1600	2.10
Menisci	Lateral		1316	2.13
	Medial		1104	1.91
Ligaments	ACL	3D Solid (C3D8)	444	2.53
	PCL		300	1.97
	LCL		1710	1.98
	MCL		2109	2.49

Table S2 Comparison of the peak mechanical responses (at 12 s, **100 $\mu\text{m/s}$** compression rate) of each region between Benchmarks I and II, determined using the reference material properties (Table 1) for the **meniscectomized knee**. The ratios R (%), as per Eq. (1), with an absolute value of 15% or greater are shown in bold. A positive/negative ratio implies a higher/lower Benchmark II value. The non-contact region was denoted with N/A. Fluid velocity in 10^{-4} mm/s; pressure and stress in MPa.

100 $\mu\text{m/s}$		Fluid velocity		Fluid pressure		Contact pressure		Maximum principal stress		Maximum principal strain	
Region		v_{fluid}	R	p_{fluid}	R	p_{contact}	R	σ_1	R	ϵ_1	R
LFC	05	40	21	1.76	13	1.48	6	2.28	7	0.42	3
	06	4	-4.6	0.117	-3.5	0.04	-8	0.11	-2.3	0.08	-6
	07	9	39	0.39	12	0.29	-19	0.64	14	0.13	37
MFC	08	42	-20	2.08	-13	1.89	-15	2.2	-16	0.38	-4
	09	43	-20	2.43	-16	1.59	-16	2	-22	0.35	-1
	10	34	10	1.76	-17	1.83	-15	2.24	-17	0.27	-3
LTC	11	22	9	1.06	2	0.95	-1	0.76	7	0.3	2
	12	88	-34	1.89	0.6	1.5	7	2.36	-7	0.4	-10
	13	1.6	-9	0.1	-5	1e-3	-6	0.1	15	0.038	1
MTC	14	1.3	-5	0.084	-26	N/A		0.12	-32	0.071	3
	15	77	-18	2.03	-23	1.88	-15	1.64	-27	0.34	-13
	16	0.2	-20	6e-3	-21	N/A		6.6e-3	-21	7.4e-3	-11
	17	60	60	1.74	-17	1.72	-17	1.79	-24	0.31	-9

Table S3 Comparison of the peak mechanical responses (at 120 s, **10 $\mu\text{m/s}$** compression rate) of each region between Benchmarks I and II, determined using the reference material properties (Table 1) for the **meniscectomized knee**. Fluid velocity in 10^{-4} mm/s; pressure and stress in MPa; ratio R in % (Eq. 1).

10 $\mu\text{m/s}$		Fluid velocity		Fluid pressure		Contact pressure		Maximum principal stress		Maximum principal strain	
Region		v_{fluid}	R	p_{fluid}	R	p_{contact}	R	σ_1	R	ε_1	R
LFC	05	10	31	0.63	18	0.57	12	0.62	26	0.16	18
	06	0.6	3	0.023	1	0.031	5	0.022	10	0.041	1
	07	2.1	32	0.192	1	0.22	-7	0.255	17	0.089	49
MFC	08	12	6	0.82	1	0.672	3	0.62	2	0.22	2
	09	10	-2	0.762	-2	0.62	2	0.491	-5	0.271	2
	10	11	23	0.78	-8	0.672	-2	0.59	-24	0.177	1
LTC	11	13	2	0.65	3	0.52	1	0.323	4	0.2	10
	12	23	-39	0.64	8	0.57	13	0.57	-5	0.28	-19
	13	1	1	0.062	-5	0.001	-26	0.064	11	0.03	2
MTC	14	0.6	-8	0.058	-33	N/A		0.081	-38	0.05	-4
	15	22	-26	0.86	-13	0.67	3	0.48	-26	0.21	-7
	16	0.1	-47	0.002	-41	N/A		2.2e-3	-41	0.004	-31
	17	20	28	0.786	-27	0.648	-12	0.61	-39	0.21	-3

Table S4 Calculated p-values for assessing significant differences in mechanical responses as functions of time between benchmarks I and II in each region (comparing complete compression-relaxation curves obtained from the **meniscectomized knee compressed at 100 $\mu\text{m/s}$** , and Table 1 material properties).

Region		Fluid velocity	Fluid pressure	Contact pressure	Stress	Strain
LFC	5	<0.001	0.001	0.053	0.004	0.002
	6	0.659	0.596	<0.001	0.684	0.201
	7	<0.001	0.018	<0.001	0.03	<0.001
MFC	8	0.001	0.010	0.008	0.007	0.064
	9	<0.001	0.002	0.001	<0.001	0.845
	10	0.004	<0.001	<0.001	<0.001	0.259
LTC	11	0.609	0.146	0.151	0.744	0.948
	12	<0.001	0.737	0.053	0.131	<0.001
	13	0.004	0.007	<0.001	0.442	0.495
MTC	14	0.016	<0.001	N/A	<0.001	0.217
	15	<0.001	<0.001	0.004	<0.001	<0.001
	16	<0.001	<0.001	N/A	<0.001	<0.001
	17	<0.001	<0.001	<0.001	<0.001	<0.001

Table S5 Calculated p-values for assessing significant differences in mechanical responses as functions of time between benchmarks I and II in each region (comparing complete compression-relaxation curves obtained from the **meniscectomized knee compressed at 10 $\mu\text{m/s}$** , and Table 1 material properties).

Region		Fluid velocity	Fluid pressure	Contact pressure	Stress	Strain
LFC	5	0.390	0.720	0.399	0.233	0.077
	6	0.384	0.752	0.018	0.018	0.061
	7	0.362	0.037	<0.001	0.664	<0.001
MFC	8	0.135	0.051	0.335	0.098	0.971
	9	0.021	0.024	0.217	0.007	0.522
	10	0.500	<0.001	0.010	<0.001	<0.001
LTC	11	0.026	0.022	0.014	0.026	0.165
	12	<0.001	0.147	0.391	<0.001	<0.001
	13	0.011	0.001	<0.001	0.039	0.017
MTC	14	<0.001	<0.001	N/A	<0.001	<0.001
	15	<0.001	<0.001	0.259	<0.001	<0.001
	16	<0.001	<0.001	N/A	<0.001	<0.001
	17	0.832	<0.001	<0.001	<0.001	<0.001

Table S6 Comparison of the peak mechanical responses (at 1.2 s, **1000 $\mu\text{m/s}$** compression rate) of each region between Benchmarks I and II, determined using the reference material properties (Table 1) for the **intact knee**. The ratios R (%), as per Eq. (1), with an absolute value of 15% or greater are shown in bold. A positive/negative ratio implies a higher/lower Benchmark II value. Fluid velocity in 10^{-4} mm/s; pressure and stress in MPa.

1000 μm/s		Fluid velocity		Fluid pressure		Contact pressure		Maximum principal stress		Maximum principal strain	
Region		v_{fluid}	R	p_{fluid}	R	p_{contact}	R	σ_1	R	ϵ_1	R
LFC	05	59	15	2.393	6	2.4	-1	3.14	3	0.463	1
	06	6.4	-9	0.224	1	0.18	1	0.18	-7	0.089	-3
	07	17.2	34	0.67	8	0.52	-10	0.986	7	0.3	38
MFC	08	60	-20	2.74	-17	2.55	-22	3.51	-23	0.43	-4
	09	74	-30	3.53	-24	2.1	-23	3.01	-30	0.397	-1
	10	51	24	2.37	-11	2.43	-19	3.8	-15	0.313	-4
LTC	11	36	-3	1.62	-2	1.16	-1	1.215	9	0.295	-1
	12	0.011	-31	2.62	-5	2.32	-2	3.69	-16	0.415	-3
	13	8.7	12	0.36	-2	0.45	-3	0.248	6	0.163	15
MTC	14	4.3	20	0.28	-10	0.276	-8	0.22	-17	0.116	14
	15	98	-20	2.68	-24	2.53	-22	2.41	-35	0.378	-9
	16	1.6	-6	0.044	-7	0.011	38	0.047	-2	0.034	3
	17	74.6	72	2.62	-31	2.32	-19	3.692	-44	0.411	-18

Table S7 Comparison of the peak mechanical responses (at 12 s, **100 $\mu\text{m/s}$** compression rate) of each region between Benchmarks I and II, determined using the reference material properties (Table 1) for the **intact knee**. Fluid velocity in 10^{-4} mm/s; pressure and stress in MPa; ratio R in % (Eq. 1).

100 $\mu\text{m/s}$		Fluid velocity		Fluid pressure		Contact pressure		Maximum principal stress		Maximum principal strain	
Region		v_{fluid}	R	p_{fluid}	R	p_{contact}	R	σ_1	R	ε_1	R
LFC	05	40.2	15	1.8	11	1.49	5	2.307	8	0.423	2
	06	4.9	-17	0.177	-7	0.172	-1	0.131	-17	0.08	-7
	07	12.3	29	0.493	8	0.46	-11	0.706	15	0.275	41
MFC	08	42.8	-21	2.114	-13	1.913	-15	2.296	-16	0.385	-4
	09	44.2	-20	2.487	-16	1.625	-16	2.038	-22	0.356	-1
	10	35.5	11	1.807	-16	1.874	-15	2.436	-20	0.273	-1
LTC	11	22.3	9	1.11	5	0.972	-1	0.793	12	0.299	1
	12	89.5	-33	1.895	-5	1.512	5	2.336	-13	0.405	-6
	13	6.8	11	0.295	-4	0.367	-3	0.186	4	0.143	17
MTC	14	3.7	21	0.239	-8	0.233	-6	0.182	-19	0.111	15
	15	80	-17	2.06	-22	1.91	-15	1.66	-27	0.335	-12
	16	1.2	-8	0.035	-11	0.016	11	0.039	-4	0.034	1
	17	63	61	1.76	-17	1.76	-17	1.777	-23	0.314	-9

Table S8 Comparison of the peak mechanical responses (at 120 s, **10 $\mu\text{m/s}$** compression rate) of each region between Benchmarks I and II, determined using the reference material properties (Table 1) for the **intact knee**. Fluid velocity in 10^{-4} mm/s; pressure and stress in MPa; ratio R in % (Eq. 1).

10 $\mu\text{m/s}$		Fluid velocity		Fluid pressure		Contact pressure		Maximum principal stress		Maximum principal strain	
Region		v_{fluid}	R	p_{fluid}	R	p_{contact}	R	σ_1	R	ε_1	R
LFC	05	9.9	33	0.643	17	0.576	11	0.644	27	0.163	18
	06	1.66	-8	0.109	2	0.125	3	0.078	-4	0.055	-4
	07	5.6	42	0.325	5	0.263	-8	0.312	19	0.158	68
MFC	08	12.4	6	0.838	1	0.685	3	0.642	3	0.227	2
	09	10	-2	0.782	-2	0.632	2	0.506	-4	0.275	2
	10	11.2	25	0.792	-7	0.684	-2	0.638	-25	0.172	5
LTC	11	14	2	0.663	2	0.528	-1	0.528	-1	0.197	13
	12	23.6	-39	0.652	7	0.58	12	0.574	-4	0.28	-19
	13	3.5	17	0.22	3	0.25	-6	0.112	10	0.095	11
MTC	14	2.1	22	0.175	-6	0.144	-5	0.0838	-24	0.093	15
	15	22.2	-26	0.875	-14	0.679	3	0.487	-23	0.208	-8
	16	0.32	-13	0.024	-12	0.016	13	0.032	-12	0.032	4
	17	20.4	-37	0.807	-27	0.66	-11	0.588	-37	0.206	-5

Table S9 Comparison of load sharing asymmetry, *i.e.*, the difference between the forces borne by the medial and lateral compartments, for benchmarks I and II (Table 1 material properties were used). The contact forces were calculated for the end of ramp compression prior to relaxation.

Knee model	Compression rate ($\mu\text{m/s}$)	Benchmark	Contact force (N)		
			Medial compartment	Lateral compartment	Load sharing difference
Meniscectomized	1000	I	102.9	81.4	21.5
		II	85.5	80.5	4.9
	100	I	81.7	62.8	18.9
		II	69.6	64.8	4.8
	10	I	34.9	28.4	6.5
		II	32.4	30.2	2.2
Intact	1000	I	125.5	108.4	17.1
		II	107.8	107.6	0.2
	100	I	102.9	88.1	14.8
		II	90.5	89.0	1.5
	10	I	52.6	49.0	3.6
		II	51.1	50.3	0.8

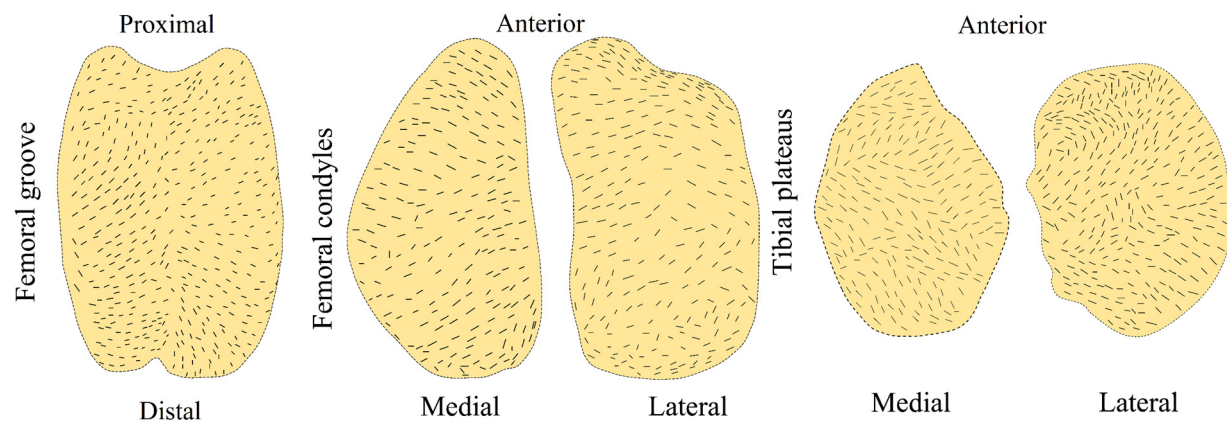


Fig. S1 Maps of split-line pattern of porcine knee cartilages traced from the raw images that were provided by an independent research group (Kakavand R *et al.*, 2023, A numerical model for fibril remodeling in articular cartilage. *Knee* **41**, 83–96.

<https://doi.org/10.1016/J.KNEE.2022.12.009>). These maps were used to implement collagen fiber orientation in the present study.

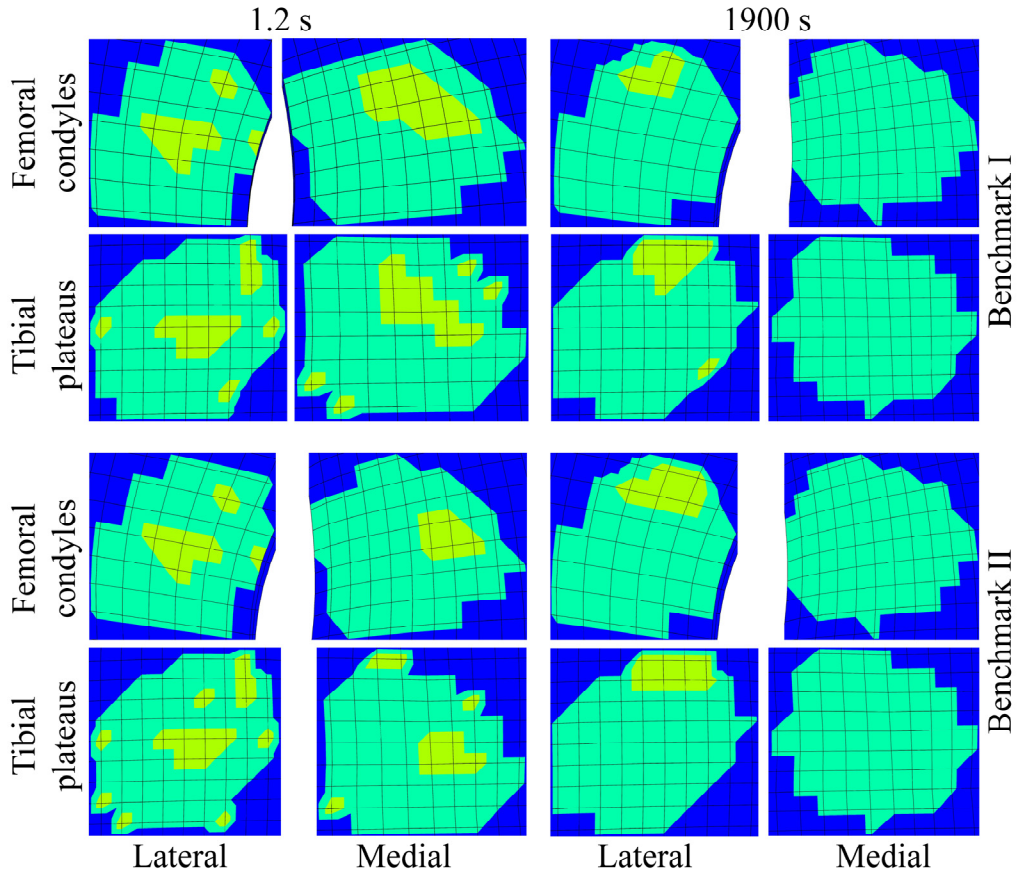


Fig. S2 Contact areas on femoral condyles and tibial plateaus at peak compression (1.2 s) and late relaxation (1900 s) for both benchmarks. Sticking and slipping elements were shown using yellow and green colors, respectively (determined using the meniscectomized joint compressed under 1000 $\mu\text{m/s}$ and Table 1 material properties).