

Testing Suite for Characterization of Articular Cartilage with Documented Repeatability

Introduction

Articular cartilage is a complex multilayer, multi-component structure. The underlying components have widely different material properties. Mechanical response of cartilage is also tied to fluid flow in the tissue. This structure provides load bearing and shock absorption capabilities. The biomechanical characteristics of the tissue depend on the multiphasic nature. Understanding of cartilage mechanics is essential for development of treatments options and preventative measures for pathologies.

Finite element analysis is being widely used to further the understanding of mechanics of biological structures and assist in development of said treatment options and measures. An important concern is whether specimen / patient specific information is needed in developing these models and to what extent and detail, depending on the question at hand. We are interested in development of finite element models of the knee joint and an important component of that is the articular cartilage. This document provides an overview of the work done so far to efficiently and effectively characterize specimen specific knee cartilage material properties with repeatability behavior documented in detail.

Current testing protocol

1. Find reference thickness/length using 10g load.
2. Ramp load to 15% strain at 20%/s strain rate.
3. Ramp unload from 15% strain at 20%/s strain rate.
4. 1000 preconditioning cycles between 10% - 15% strain
5. Ramp load to 15% strain at 20%/s strain rate.
6. Ramp unload from 15% strain at 20%/s strain rate.
7. Find reference thickness/length using 10g load.
8. Three step stress relaxation: 5-10-15 % strain at 20%/s strain rate, 30 min wait after each ramp.

Number of locations / samples / tests

Locations: Patella, patellar groove, medial and lateral tibial plateaus, medial and lateral femoral condyles.

Number of samples: 6 compression samples, 6 tensile samples.

Types of tests: Unconfined compression, confined compression, uniaxial tension

Number of tests: 6 unconfined compression sets with 3 repeatability tests in each set, 6 confined compression sets with 3 repeatability tests in each set, 6 tension sets with 3 repeatability tests in each set. **Total = 54**

Unconfined compression:

Figure 1: stress relaxation repeatability

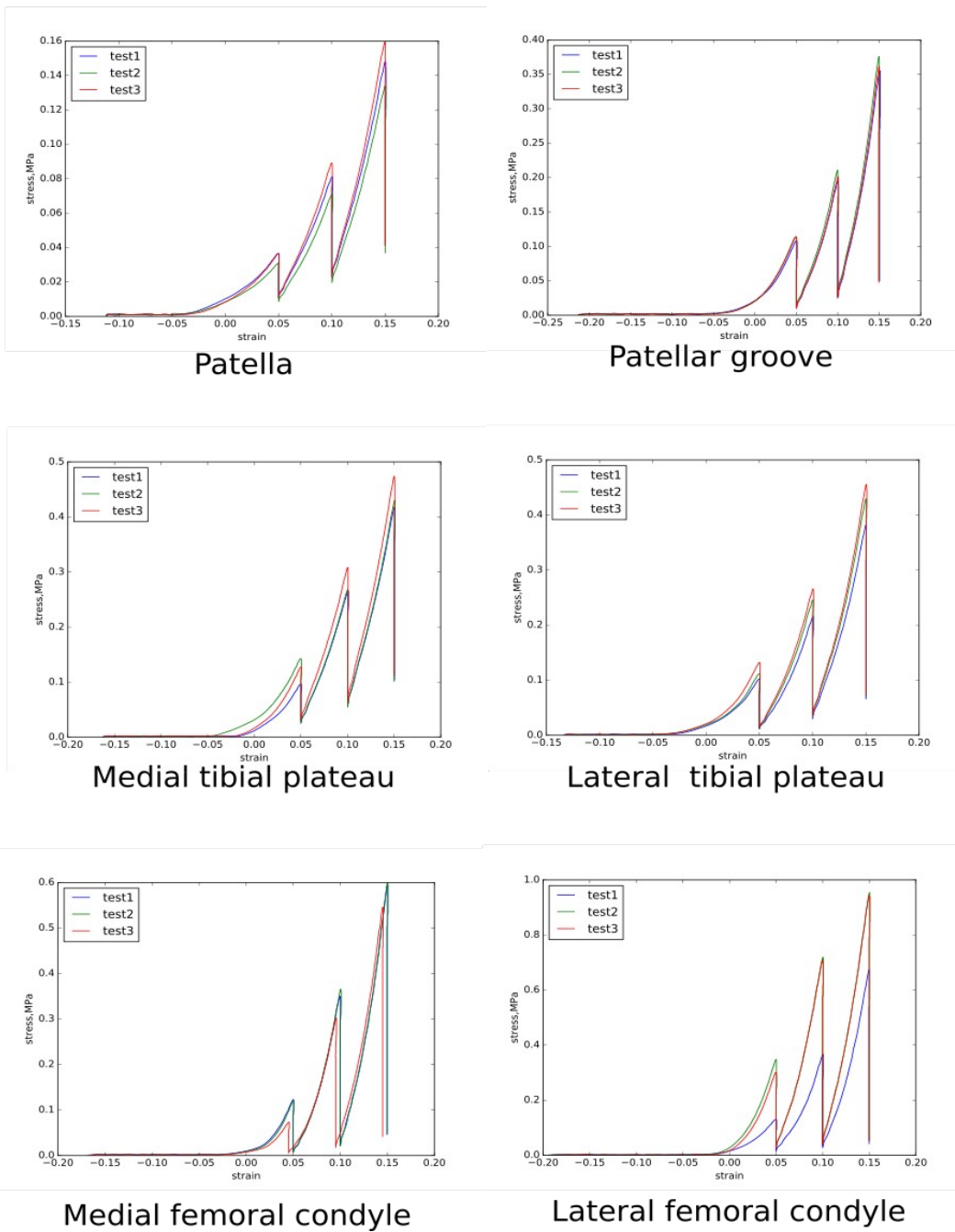


Figure 2: PC repeatability

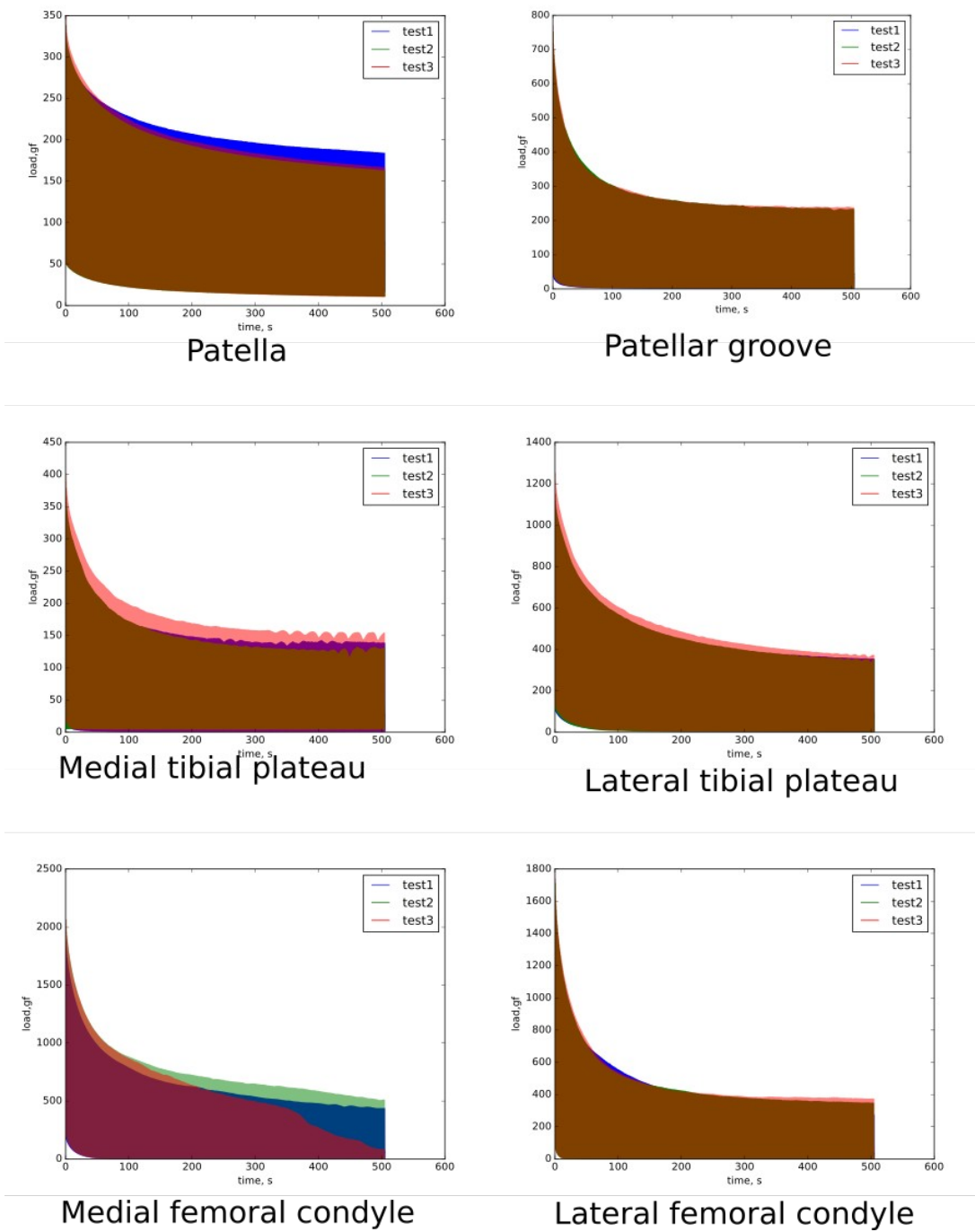
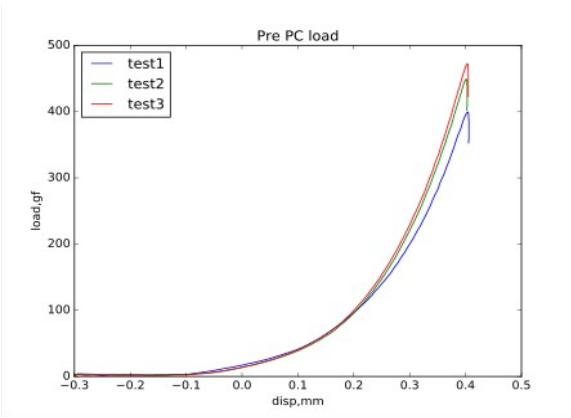
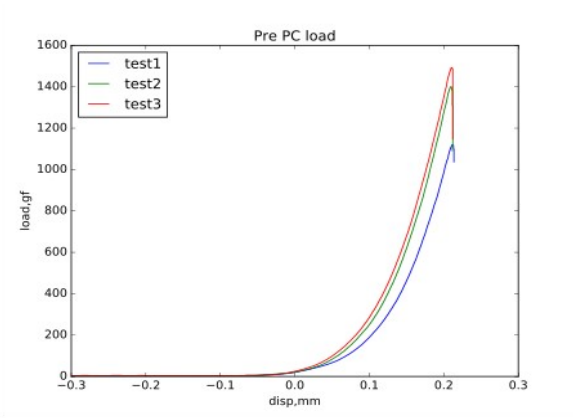


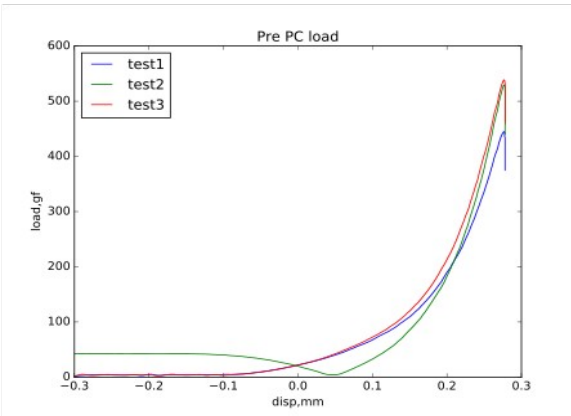
Figure 3: Pre pc load



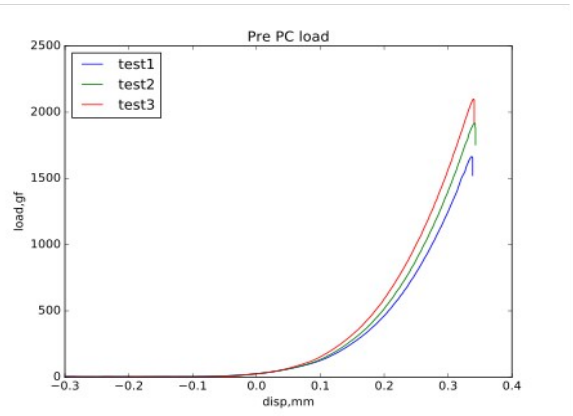
Patella



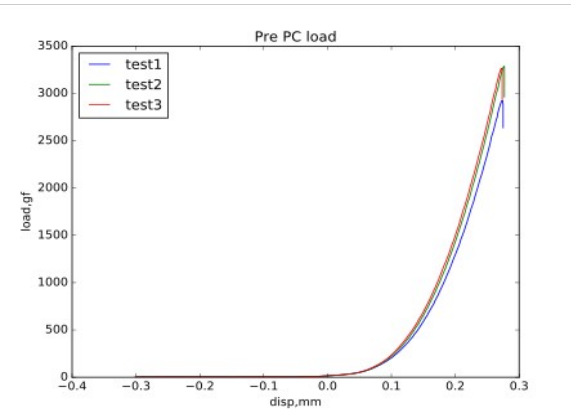
Patellar groove



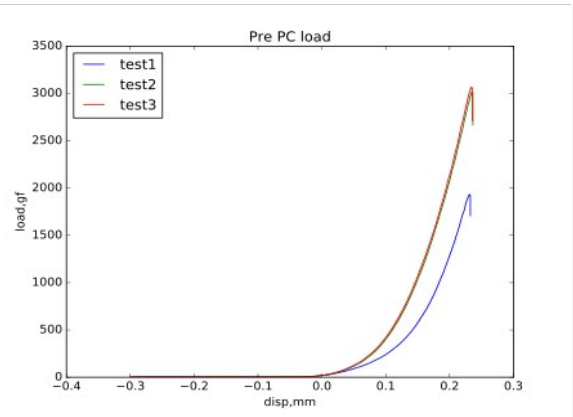
Medial tibial plateau



Lateral tibial plateau



Medial femoral condyle



Lateral femoral condyle

Figure 4: Pre pc unload

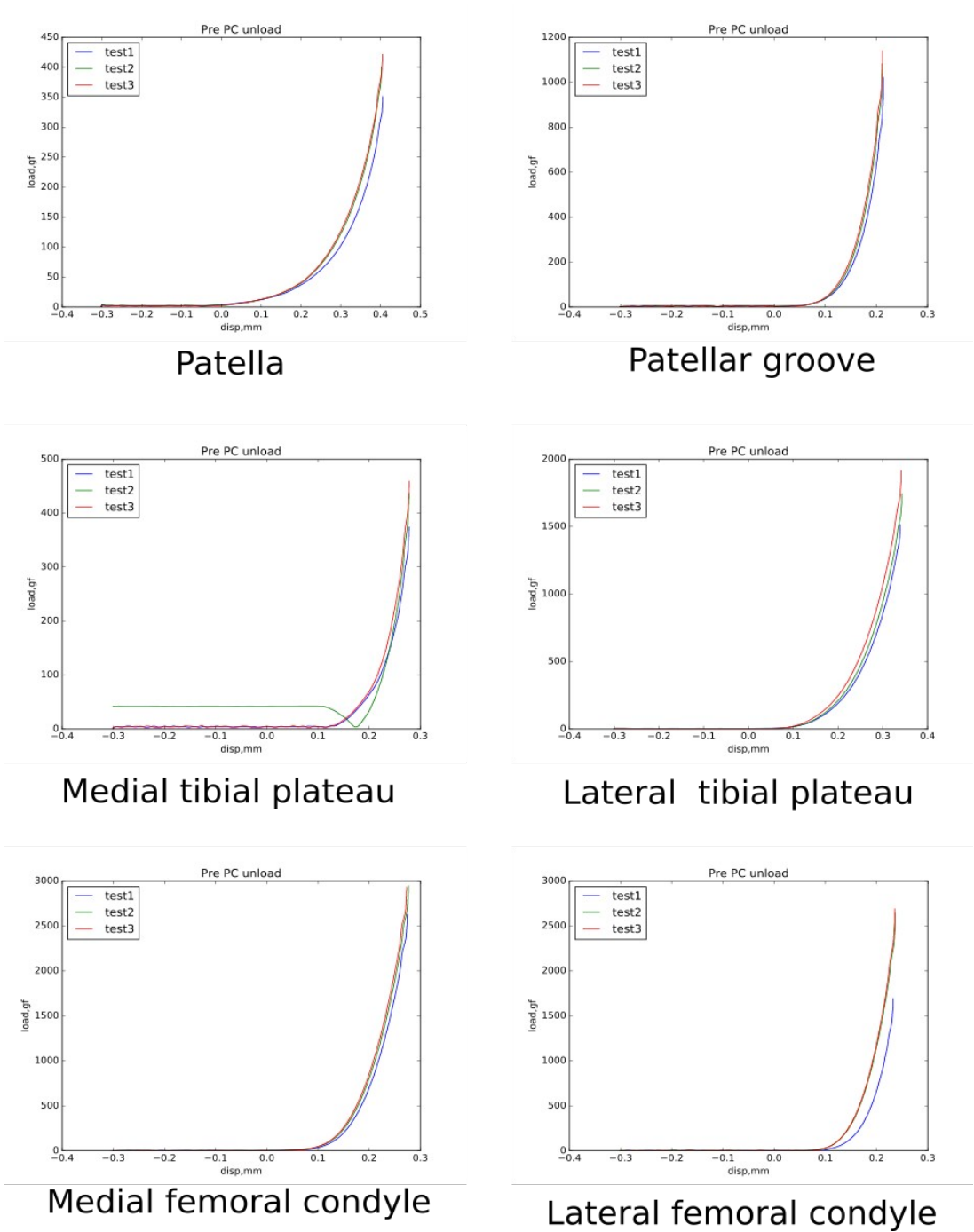
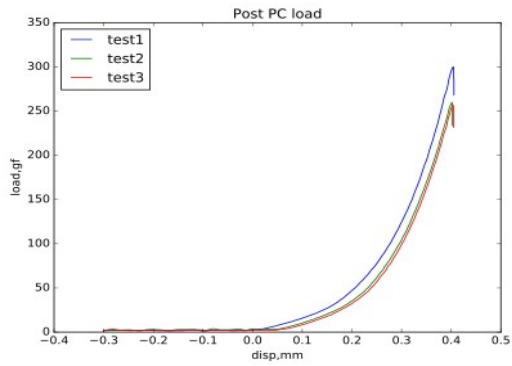
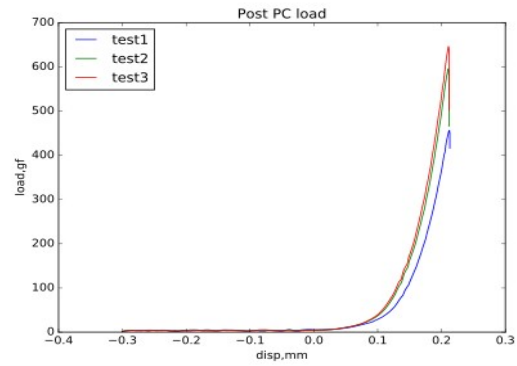


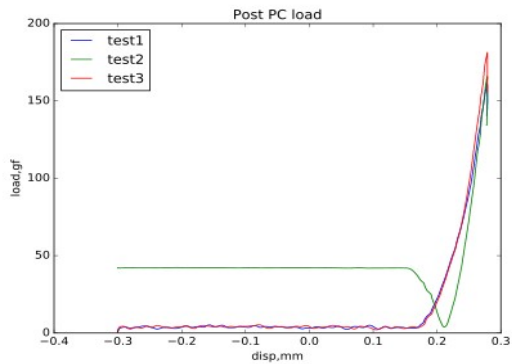
Figure 5: Post pc load



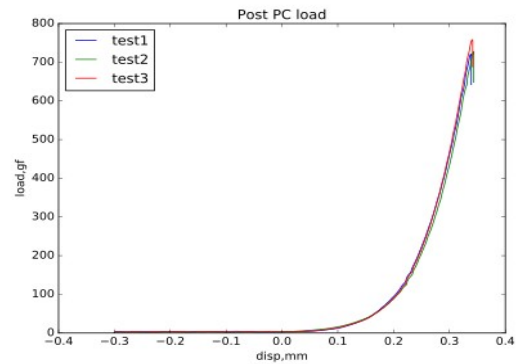
Patella



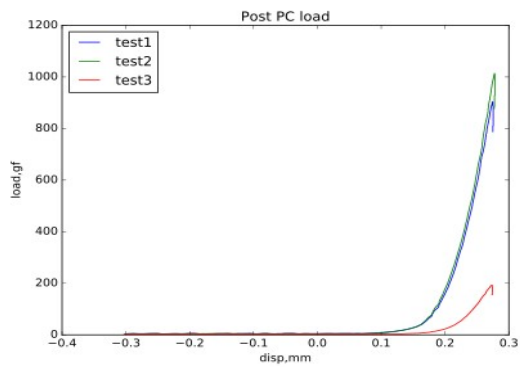
Patellar groove



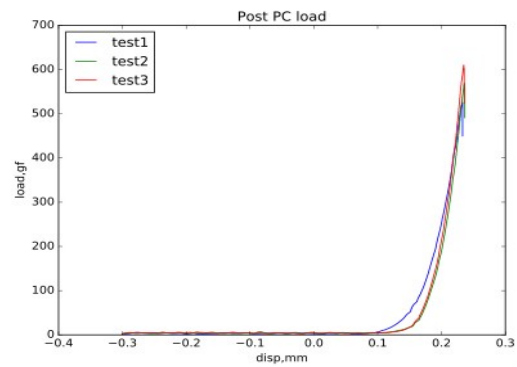
Medial tibial plateau



Lateral tibial plateau



Medial femoral condyle



Lateral femoral condyle

Figure 6: Post pc unload

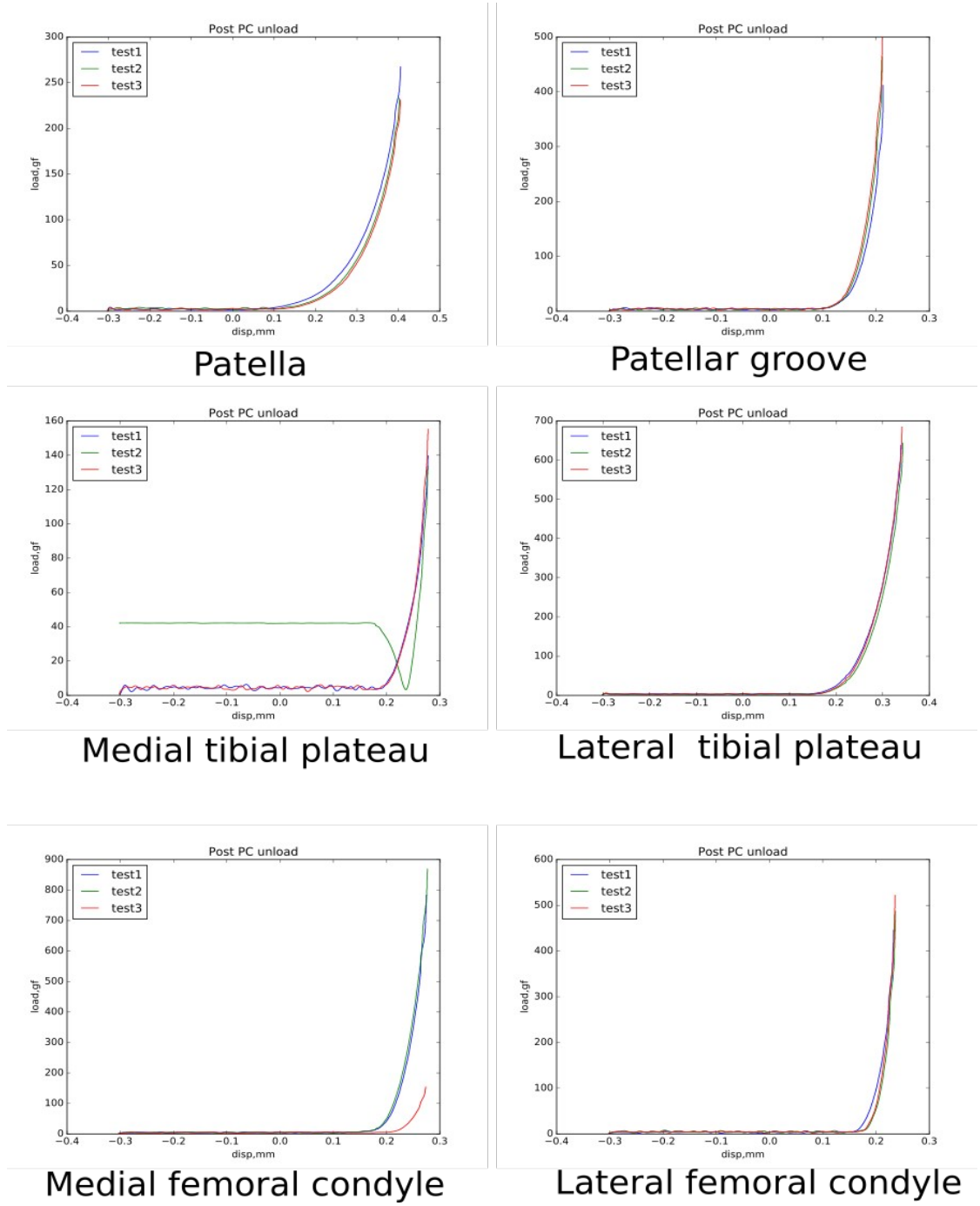


Table 1a:

Sample	Thickness % diff	Diameter (mm)	Peak load % diff	High strain inst mod % diff	High strain eqbm mod % diff
oks003-PTC-MCXX-01	0.74	5	19.13	15.87	1.52
oks003-FMC-ACXX-01	0.77	5	4.7	4.11	20.74
oks003-TBC-MCXX-03	0.27	5	12.39	4.11	7.37
oks003-TBC-LCXX-01	1.28	5	16.25	10.46	1.7
oks003-FMC-MCXX-01	0.49	5	8.89	6.14	38.32
oks003-FMC-LCXX-01	1.67	5	33.3	31.8	neg

Table 1b:

Sample	Thickness, mm (mean, SD)	Peak load , g (mean, SD)	High strain inst mod MPa (mean, SD)	High strain eqbm mod, MPa (mean, SD)
oks003-PTC-MCXX-01	2.688, 0.011	289.552, 27.714	1.3, 0.10	0.28, 0.002
oks003-FMC-ACXX-01	1.408, 0.006	725.815, 17.509	3.36, 0.06	0.39, 0.04
oks003-TBC-MCXX-03	1.847, 0.002	873.373, 55.80	3.10, 0.14	0.78,0.02
oks003-TBC-LCXX-01	2.264, 0.014	837.608, 69.1806	3.54, 0.2	0.62, 0.007
oks003-FMC-MCXX-01	1.832, 0.007	1158.578, 58.24	4.87, 0.15	0.289, 0.05
oks003-FMC-LCXX-01	1.558, 0.013	1701.304, 309.805	5.14,0.89	-

Confined compression:

Figure 1: stress relaxation repeatability

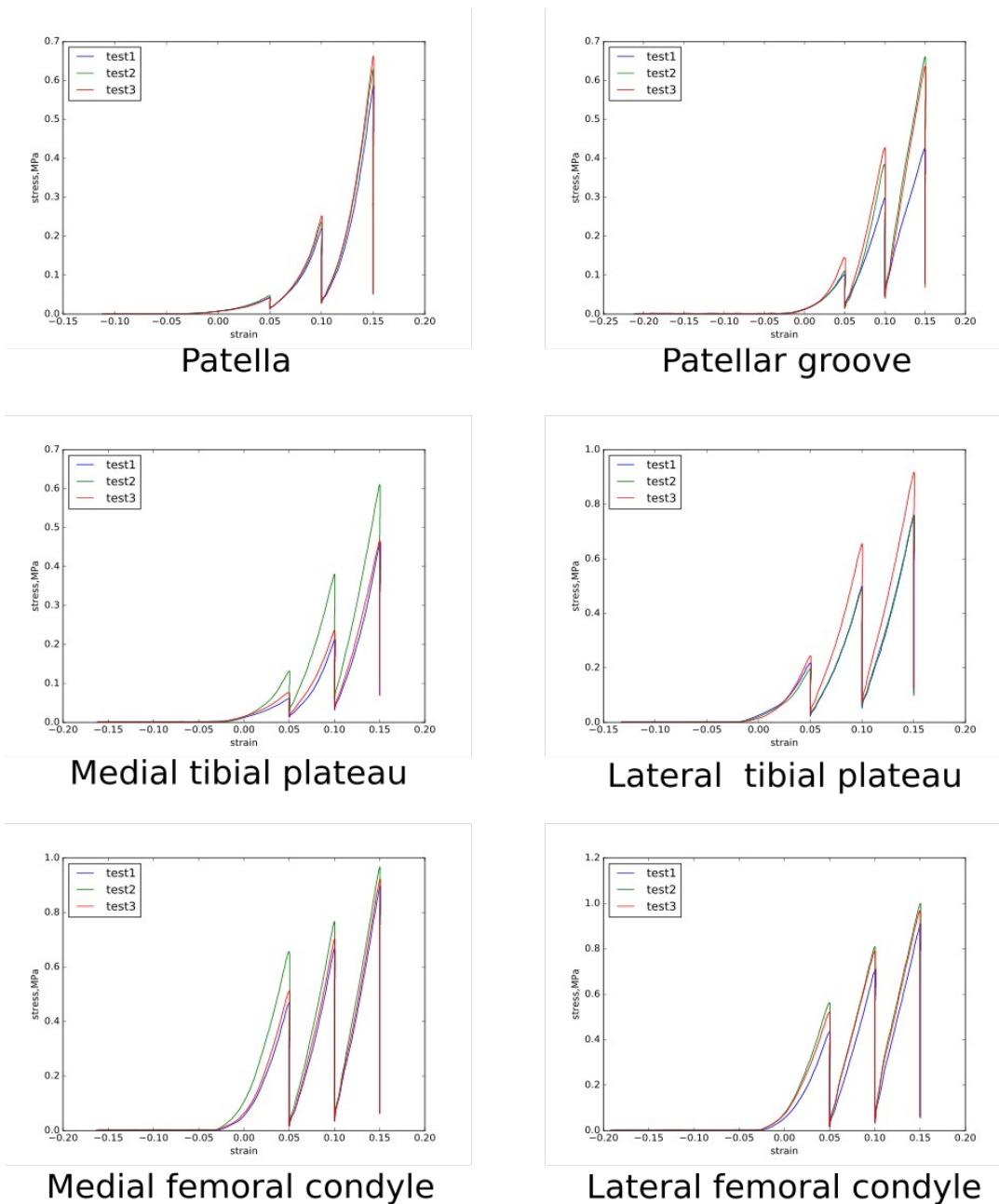


Figure 2: PC repeatability

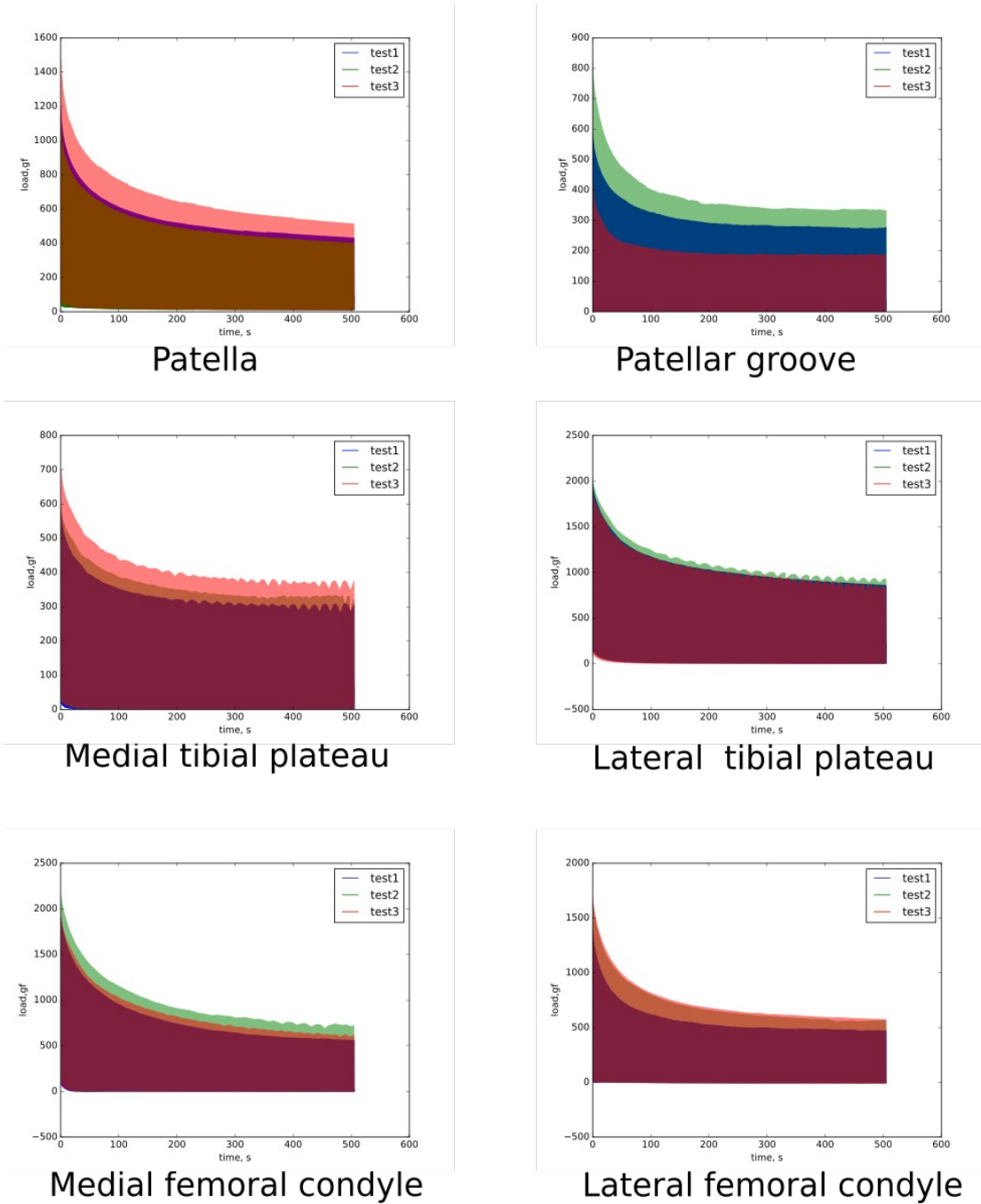
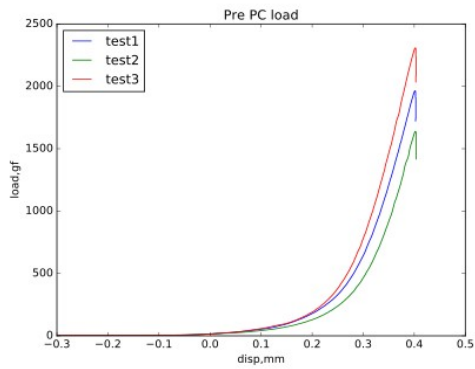
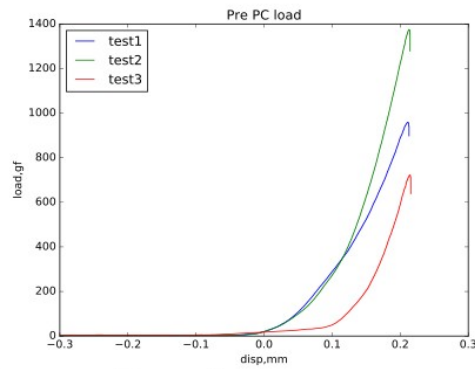


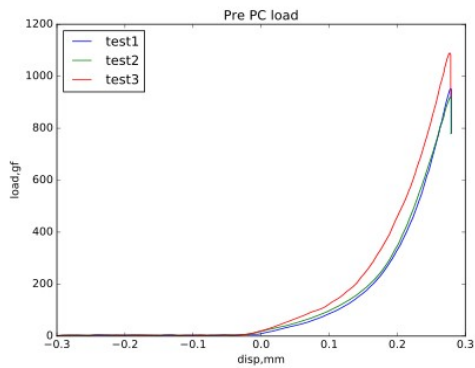
Figure 3: Pre pc load



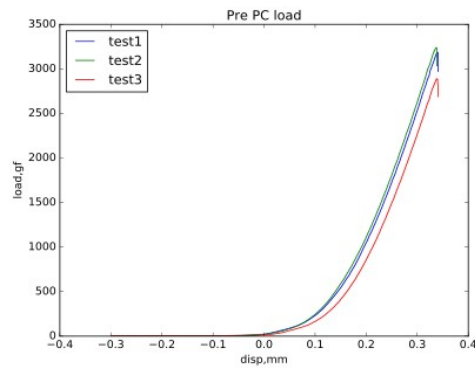
Patella



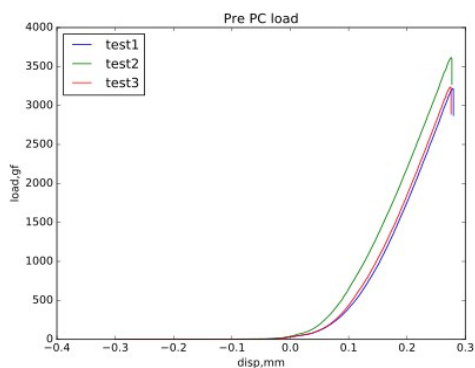
Patellar groove



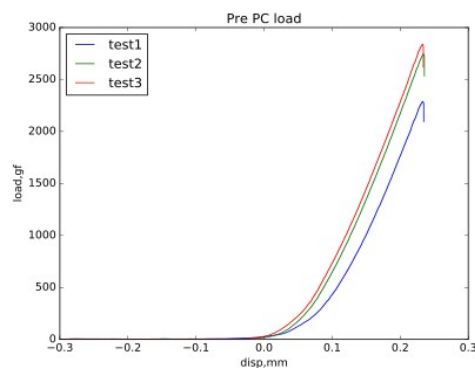
Medial tibial plateau



Lateral tibial plateau



Medial femoral condyle



Lateral femoral condyle

Figure 4: Pre pc unload

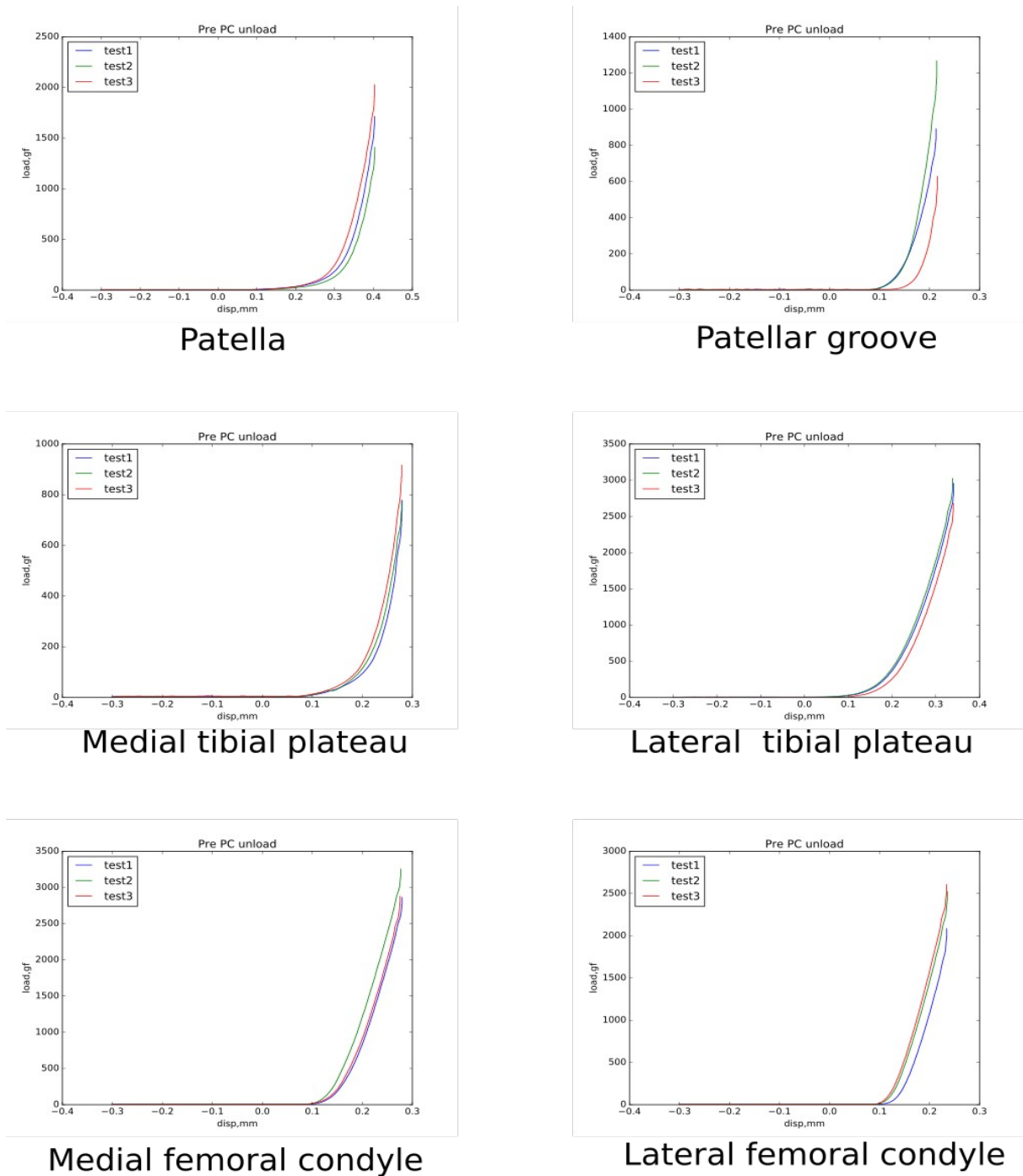
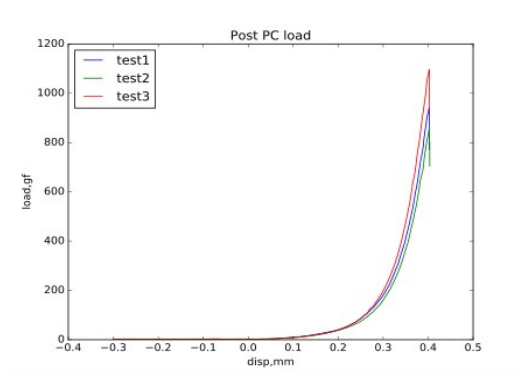
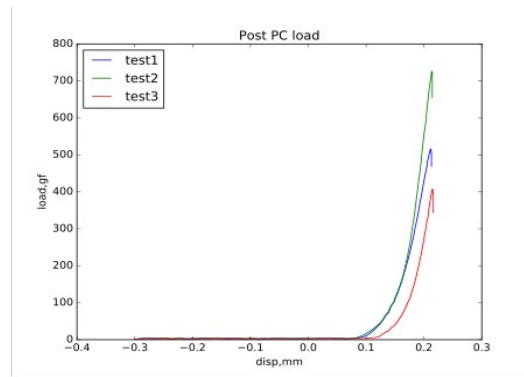


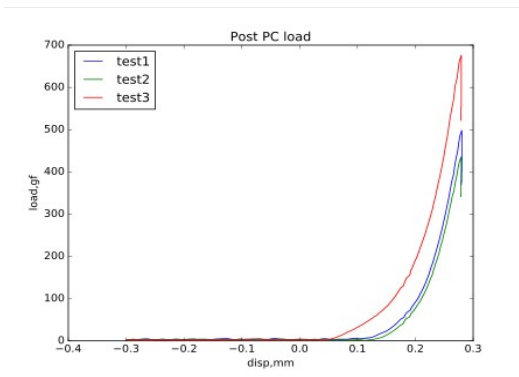
Figure 5: Post pc load



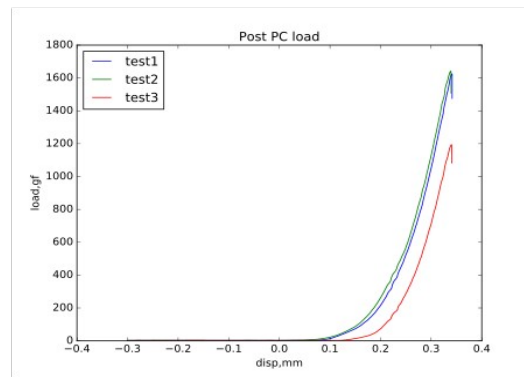
Patella



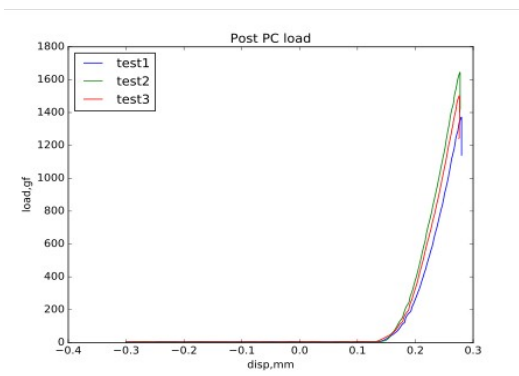
Patellar groove



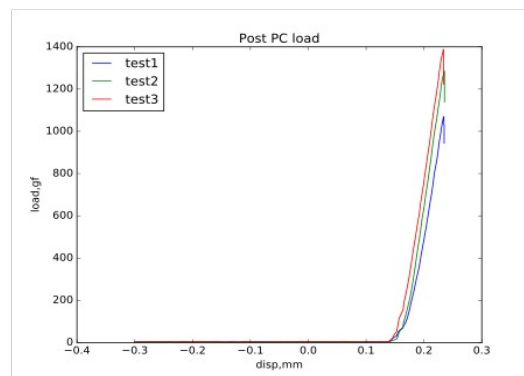
Medial tibial plateau



Lateral tibial plateau



Medial femoral condyle



Lateral femoral condyle

Figure 6: Post pc unload

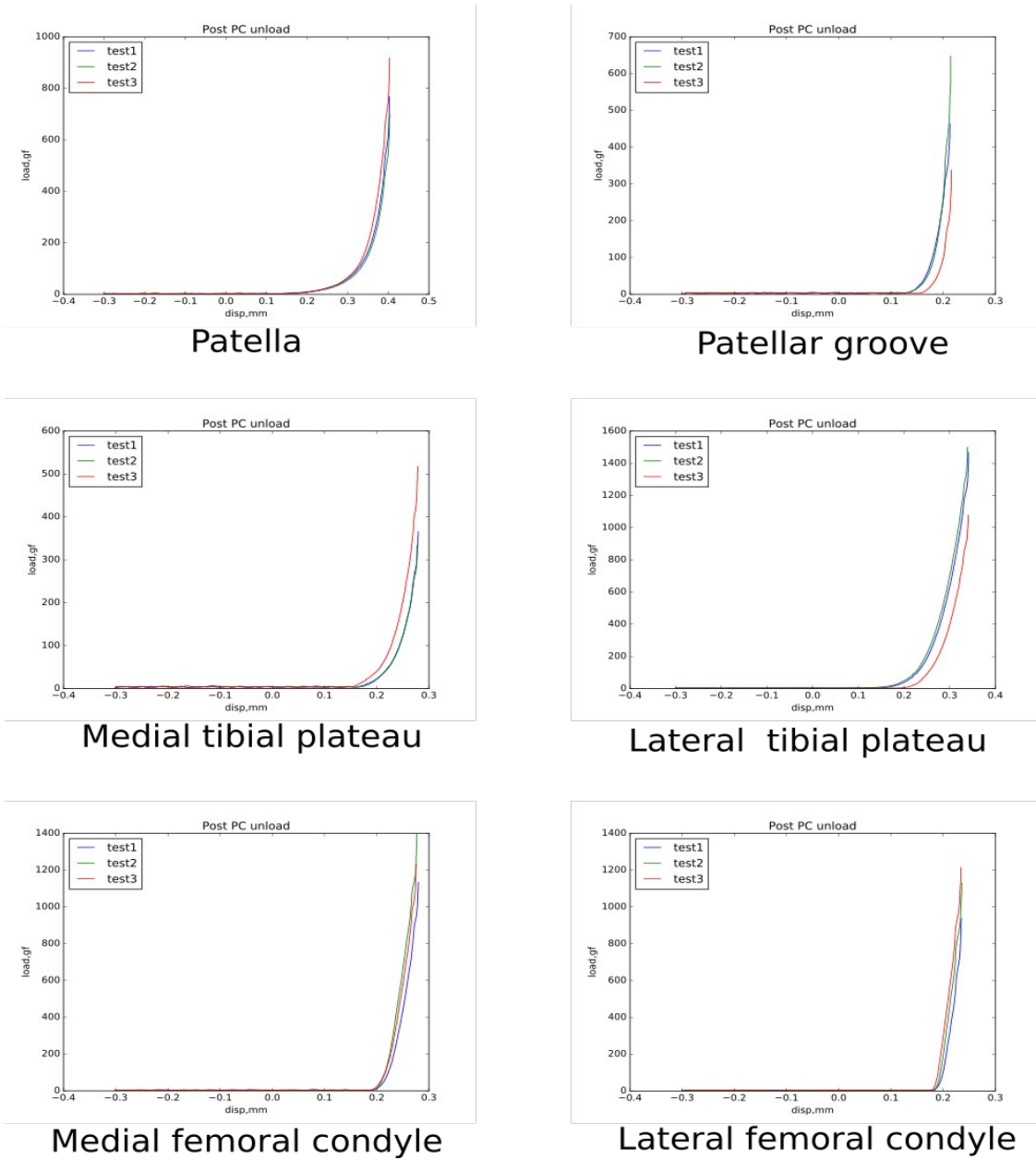


Table 1a:

Sample	Thickness % diff	Diameter (mm)	Peak load (g) % diff	High strain inst mod % diff	High strain eqbm mod % diff
oks003-PTC-MCXX-01	0.33	5	11.3	29.8	26.61
oks003-FMC-ACXX-01	1.12	5	43.54	75.6	46.12
oks003-TBC-MCXX-03	0.37	5	28.61	6.75	21.14
oks003-TBC-LCXX-01	0.7	5	19.17	3.76	41.29
oks003-FMC-MCXX-01	1.51	5	7.68	11.9	34.91
oks003-FMC-LCXX-01	0.51	5	8.78	19.47	neg

Table 1b:

Sample	Thickness, mm mean, SD	Peak load, g mean, SD	High strain inst mod, MPa mean, SD	High strain eqbm mod, MPa mean, SD
oks003-PTC-MCXX-01	2.68, 0.33	1240.71, 70.09	7.254, 1.127	0.282, 0.038
oks003-FMC-ACXX-01	1.42, 0.008	1135.786, 252.669	4.11, 1.53	0.392, 0.09
oks003-TBC-MCXX-03	1.85, 0.004	1017.94, 168.07	4.72, 0.17	0.645, 0.070
oks003-TBC-LCXX-01	2.25, 0.008	1620.311, 181.981	5.30, 0.10	0.552, 0.120
oks003-FMC-MCXX-01	1.84, 0.01	1857.95, 72.511	4.37, 0.26	0.324, 0.057
oks003-FMC-LCXX-01	1.55, 0.004	1911.652, 83.99	3.74, 0.36	-

Uniaxial tension:

Figure 1: stress relaxation repeatability

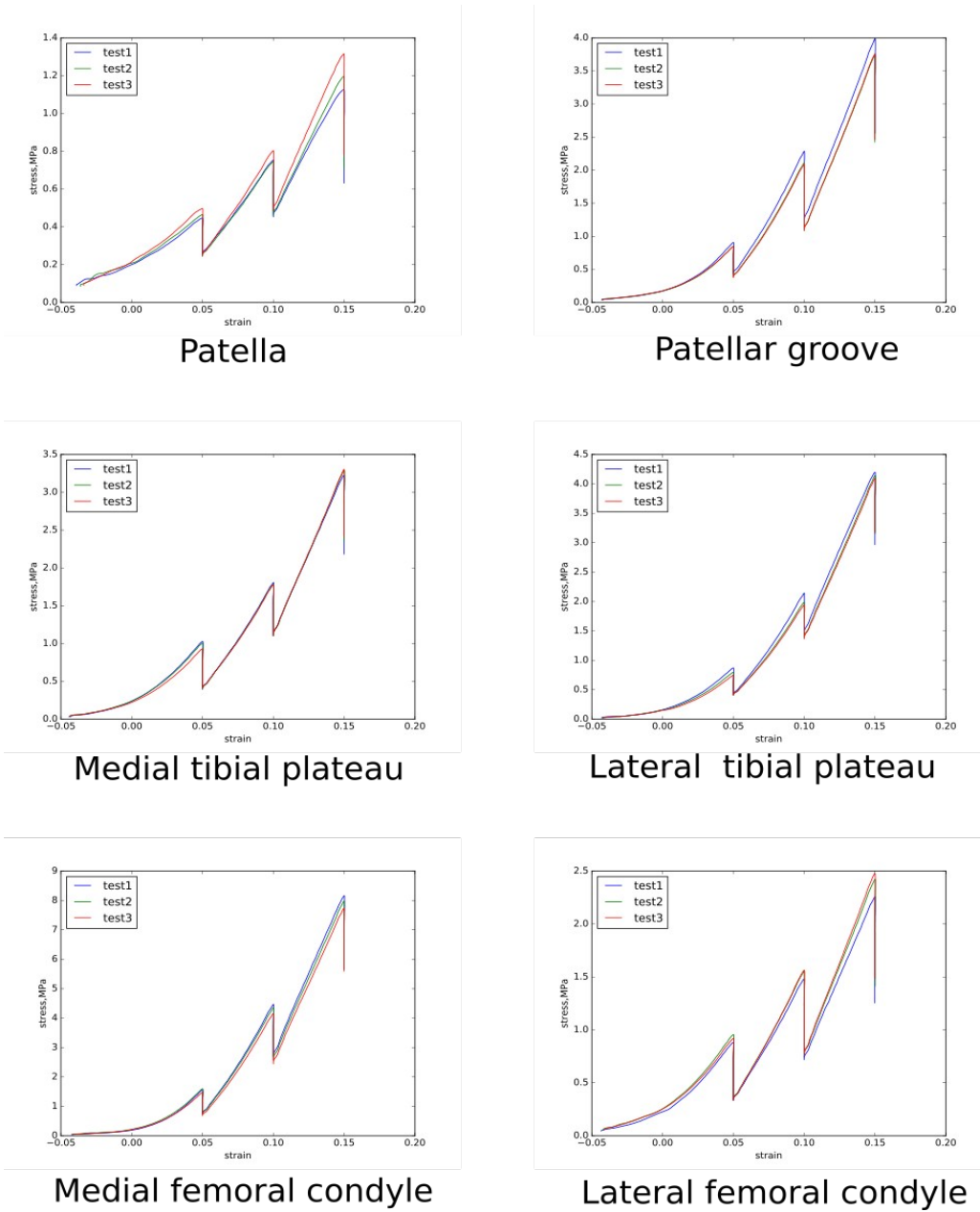
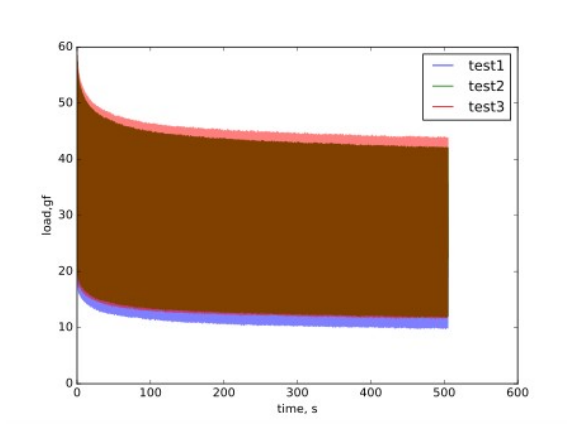
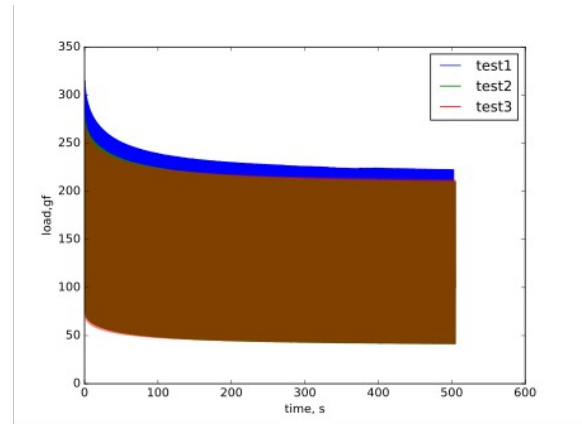


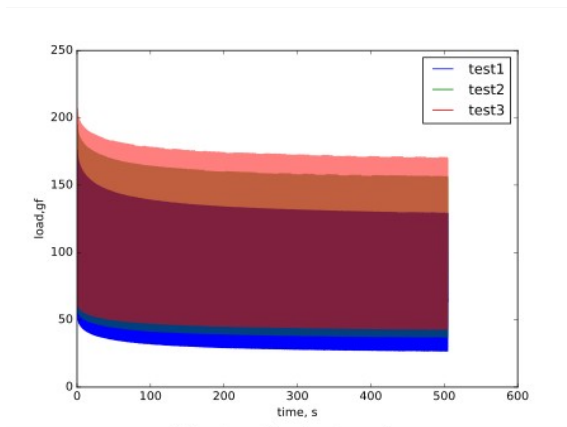
Figure 2: PC repeatability



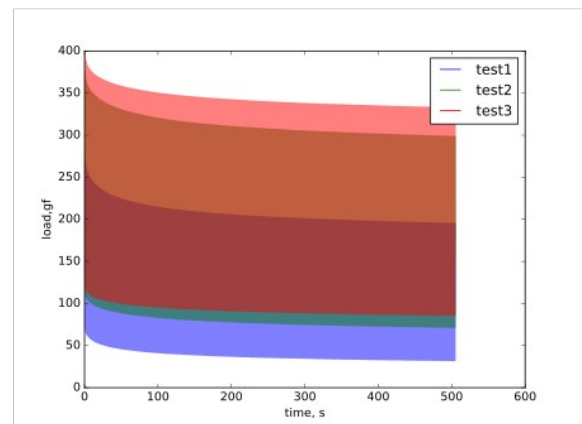
Patella



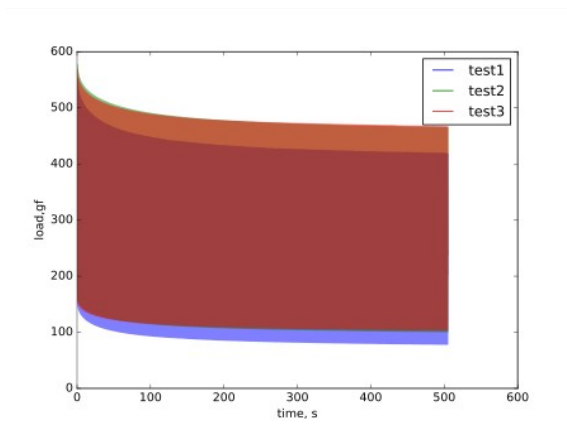
Patellar groove



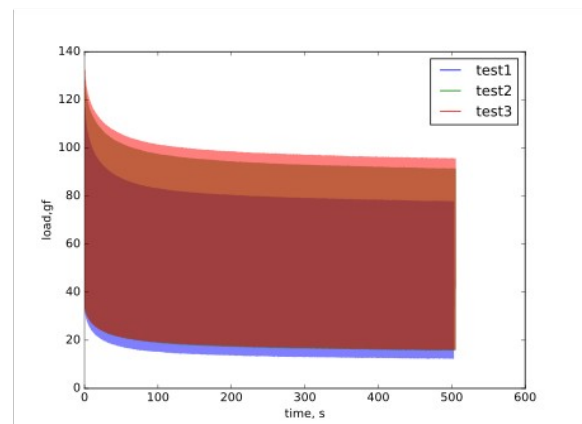
Medial tibial plateau



Lateral tibial plateau

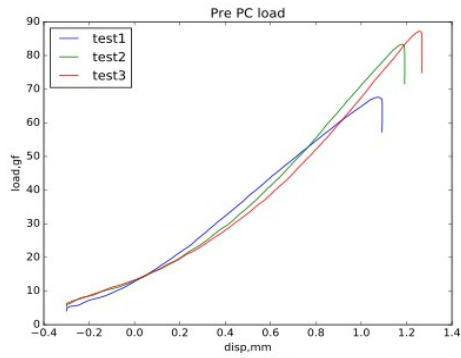


Medial femoral condyle

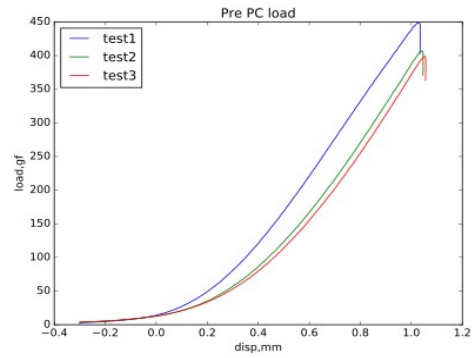


Lateral femoral condyle

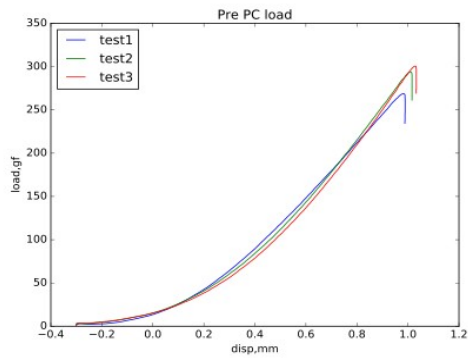
Figure 3: Pre pc load



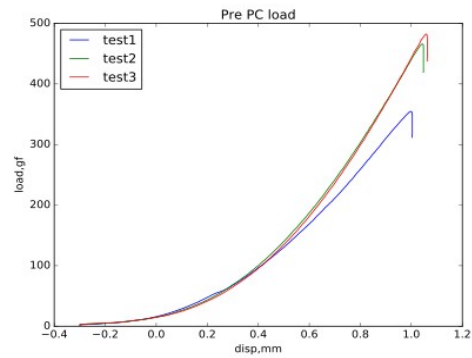
Patella



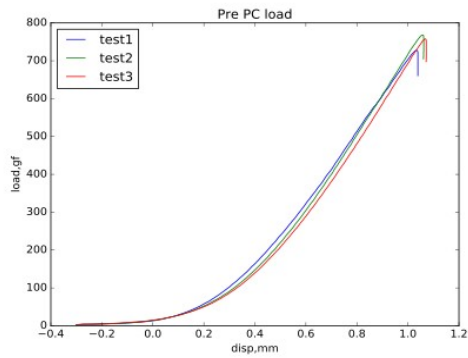
Patellar groove



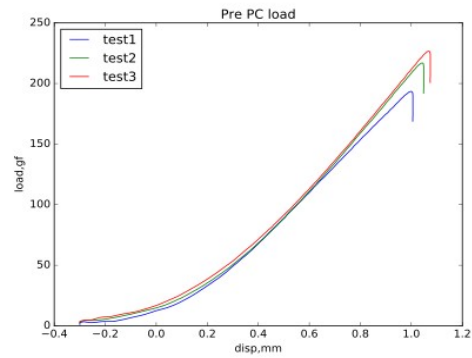
Medial tibial plateau



Lateral tibial plateau



Medial femoral condyle



Lateral femoral condyle

Figure 4: Pre pc unload

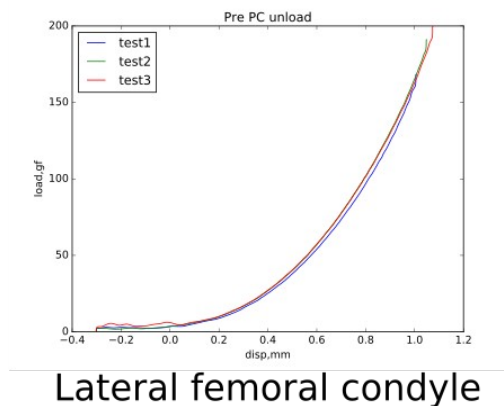
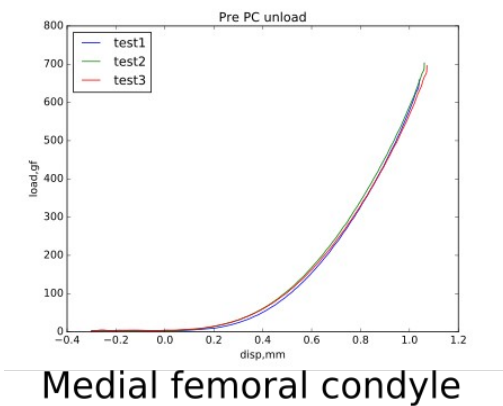
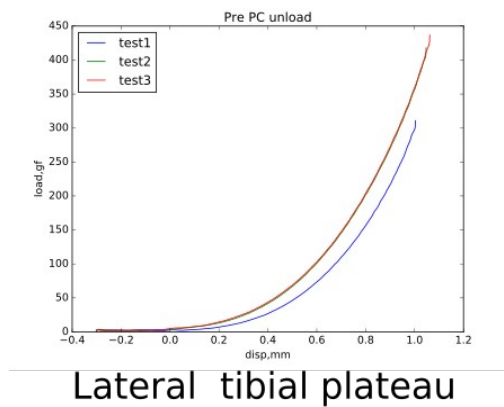
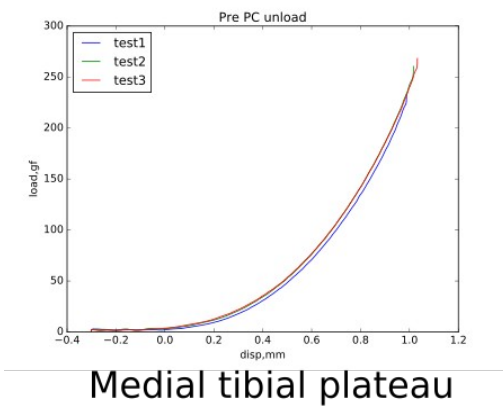
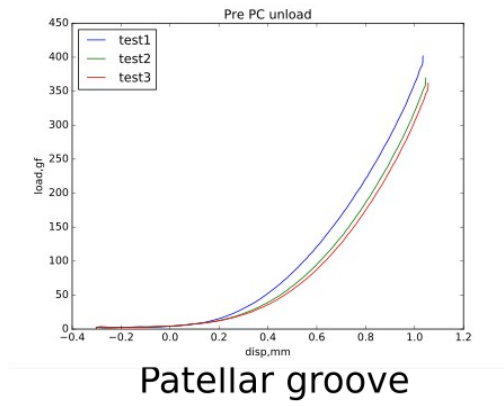
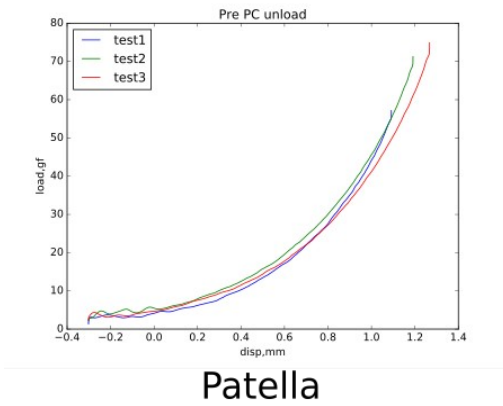
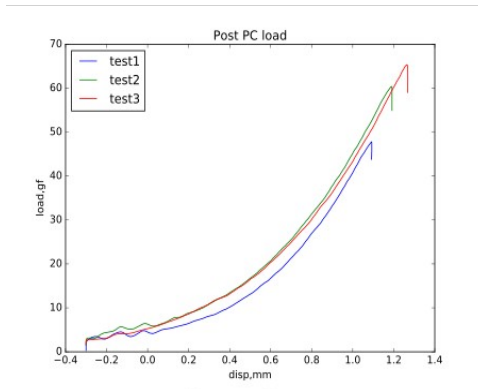
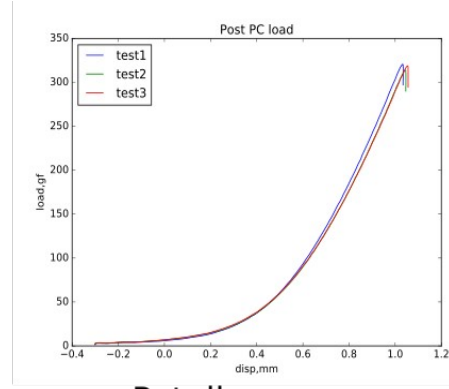


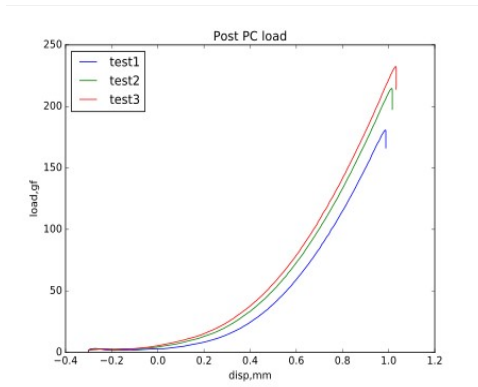
Figure 5: Post pc load



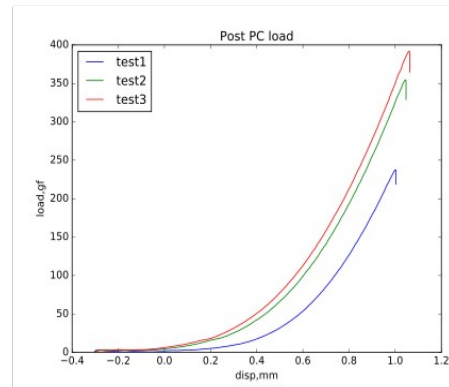
Patella



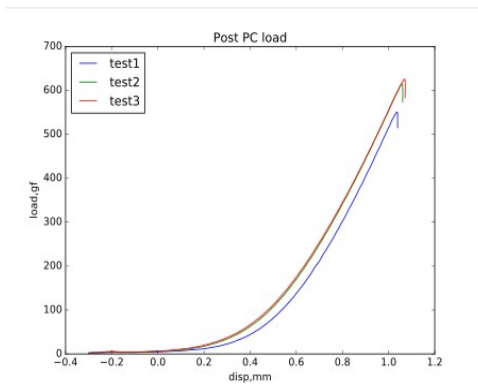
Patellar groove



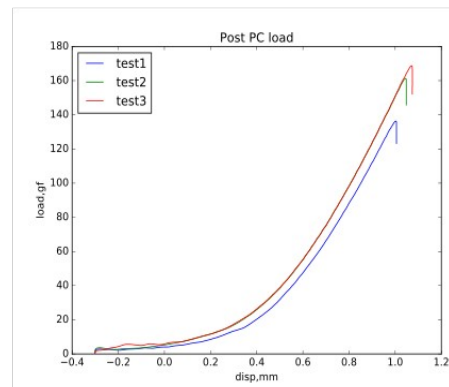
Medial tibial plateau



Lateral tibial plateau



Medial femoral condyle



Lateral femoral condyle

Figure 6: Post pc unload

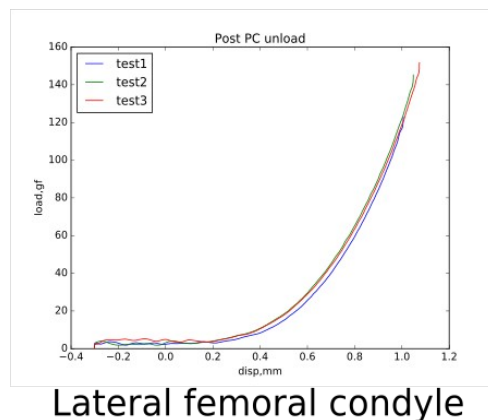
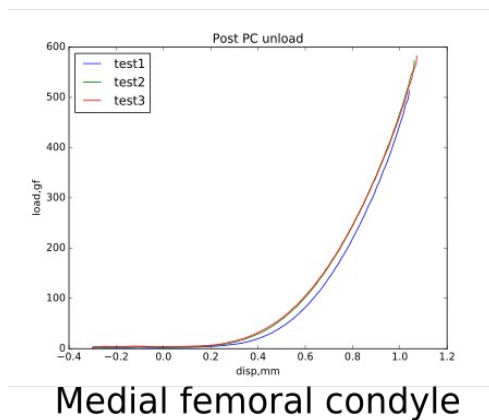
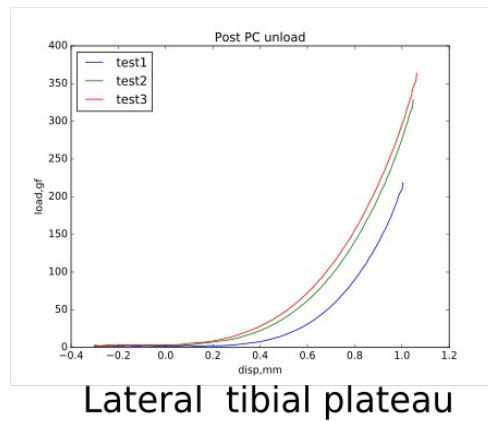
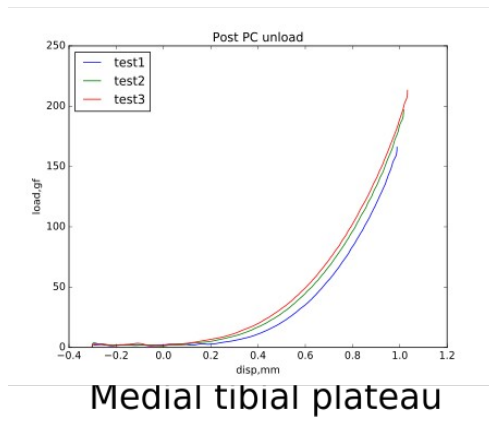
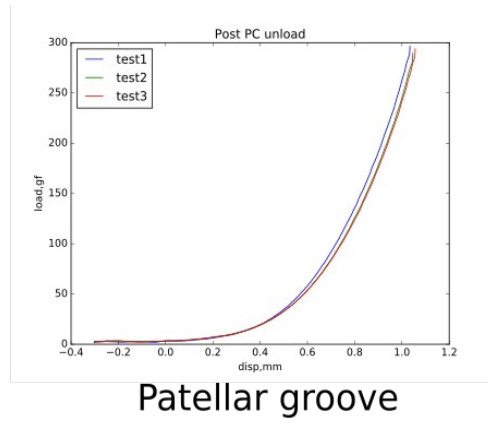
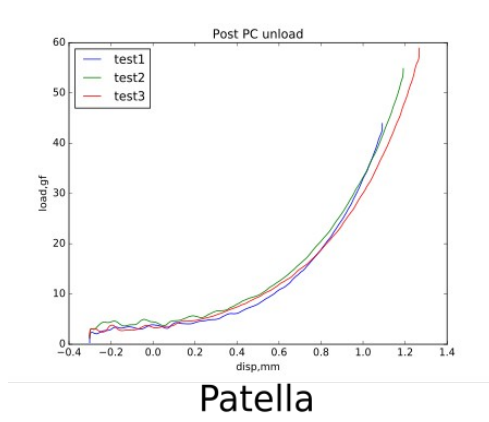


Table 1a:

Sample	Thickness (mm)	Width (mm)	Length % diff	Peak load (g) % diff	High strain inst mod % diff	High strain eqbm mod % diff
oks003-PTC-LcuX-01	0.622	1	13.7	15.14	31.08	57.13
oks003-FMC-AcuX-01	0.796	1	0.8	5.35	3.02	5.09
oks003-TBC-McuX-01	0.69	1	2.4	3.2	9.18	21.4
oks003-TBC-LcuX-01	1.03	1	2.16	2.7	4.6	21.54
oks003-FMC-McuX-01	0.772	1	1.69	5.94	3.13	6.6
oks003-FMC-LcuX-01	0.636	1	5.15	8.75	13.52	8.75

Table 1b:

Sample	Length mean, SD	Peak load, g mean SD	High strain inst mod MPa mean, SD	High strain eqbm mod MPa mean, SD
oks003-PTC-LcuX-01	8.24 0.56	76.47 5.882	8.809 1.364	4.18 1.18
oks003-FMC-AcuX-01	7.045 0.056	309.28 9.2148	33.17 0.55	25.9 0.704
oks003-TBC-McuX-01	6.87 0.08	227.8 3.7491	28.9 1.34	23.25 2.552
oks003-TBC-LcuX-01	7.06 0.078	434.045 6.03	42.16 1.021	32.76 3.68
oks003-FMC-McuX-01	7.136 0.06	625.224 18.664	72.65 1.145	59.5 2.208
oks003-FMC-LcuX-01	7.131 0.18	153.93 7.123	16.97 1.184	11.996 1.804

Table 2: Average instantaneous and equilibrium moduli with coefficient of variation. U C: unconfined compression, C: confined compression, T: uniaxial tension, AIM: average instantaneous modulus, AEM: average equilibrium modulus.

Sample Location	Test type	Thickness (mean, SD)	Length (mean, SD)	AIM, MPa (mean, SD)	AEM, MPa (mean, SD)	Coeff. of var(%) AIM	Coeff of variation AEM
Patella	U C	2.688, 0.011	-	0.81,0.08	0.226,0.022	9.97	9.74
Groove	U C	1.408, 0.006	-	2.17,0.06	0.27,0.01	2.9	3.7
Medial tibia	U C	1.847, 0.002	-	2.68,0.24	0.618,0.06	9.28	9.88
Lateral tibia	U C	2.264, 0.014	-	2.47,0.244	0.35,0.028	9.87	8.11
Medial femur	U C	1.832, 0.007	-	3.13,0.26	0.205,0.01	8.52	5.15
Lateral femur	U C	1.558, 0.013	-	5.54,1.74	0.376,0.088	31.37	23.41
Patella	C C	2.68, 0.33	-	2.24,0.45	0.29,0.004	20.3	1.5
Groove	C C	1.42, 0.008	-	3.22,0.57	0.42,0.046	17.8	10.9
Medial tibia	C C	1.85, 0.004	-	2.6,0.75	0.45,0.14	29.02	31.46
Lateral tibia	C C	2.25, 0.008	-	4.99,0.64	0.63,0.10	12.9	16.01
Medial femur	C C	1.84, 0.01	-	7.89,0.96	0.38,0.02	12.21	6.7
Lateral femur	C C	1.55, 0.004	-	7.96,0.71	0.38,0.03	8.9	8.08
Patella	T	0.622	8.24, 0.56	8.3,0.46	4.85, 0.18	5.6	3.78
Groove	T	0.796	7.045, 0.05	21.32,0.79	12.09,0.63	3.73	5.21
Medial tibia	T	0.69	6.87, 0.08	19.64,0.26	11.58,0.302	1.34	2.60
Lateral tibia	T	1.03	7.06, 0.078	21.17,0.89	14.39,0.04	4.24	0.28
Medial femur	T	0.772	7.136, 0.06	41.97,1.52	26.18,0.71	3.6	2.7
Lateral femur	T	0.636	7.131, 0.18	16.38,0.6	7.9,0.36	3.7	4.59