

Electrode Placement Affects Clinical Outcome in Transcutaneous Electrical Nerve Stimulation for Knee Osteoarthritis: A Combined Cadaver Study and Randomized Controlled Trial

Yu Xu ¹, Yanfu Bai ², Meimin Deng ², Xuyi Hu ³, Manqin Lian ², Zhisheng Huang ²,
Lingling Su ^{2*}

¹ Department of Musculoskeletal Oncology, The First Affiliated Hospital of Sun Yat-sen University, Guangzhou, Guangdong, China

² Department of Rehabilitation Medicine, Guangzhou Hospital of Integrated Traditional and Western Medicine, Guangzhou, Guangdong, China

³ Health Science Center, Shenzhen University, Shenzhen, Guangdong, China

Corresponding author :

Lingling Su, MD,

Department of Rehabilitation Medicine, Guangzhou Hospital of Integrated Traditional and Western Medicine, Guangzhou, Guangdong, China, 510800,

Email: su653903983@163.com

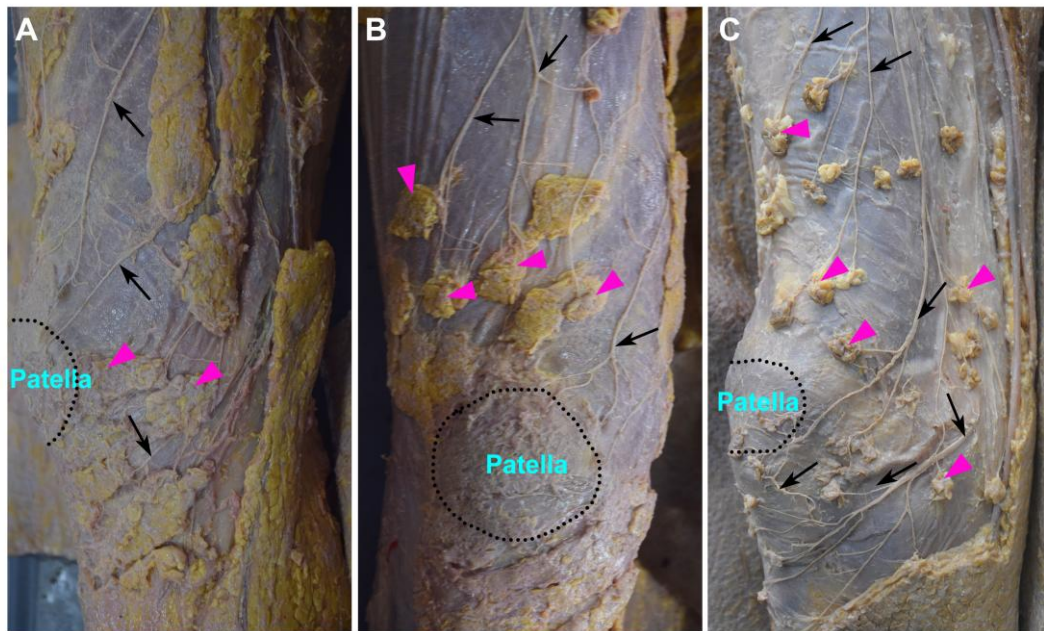
Supplementary figure 1: Anatomical process

Supplementary figure 2: Step-by-step guide for patella-informed electrode placement

Supplementary table 1. Electrode placement

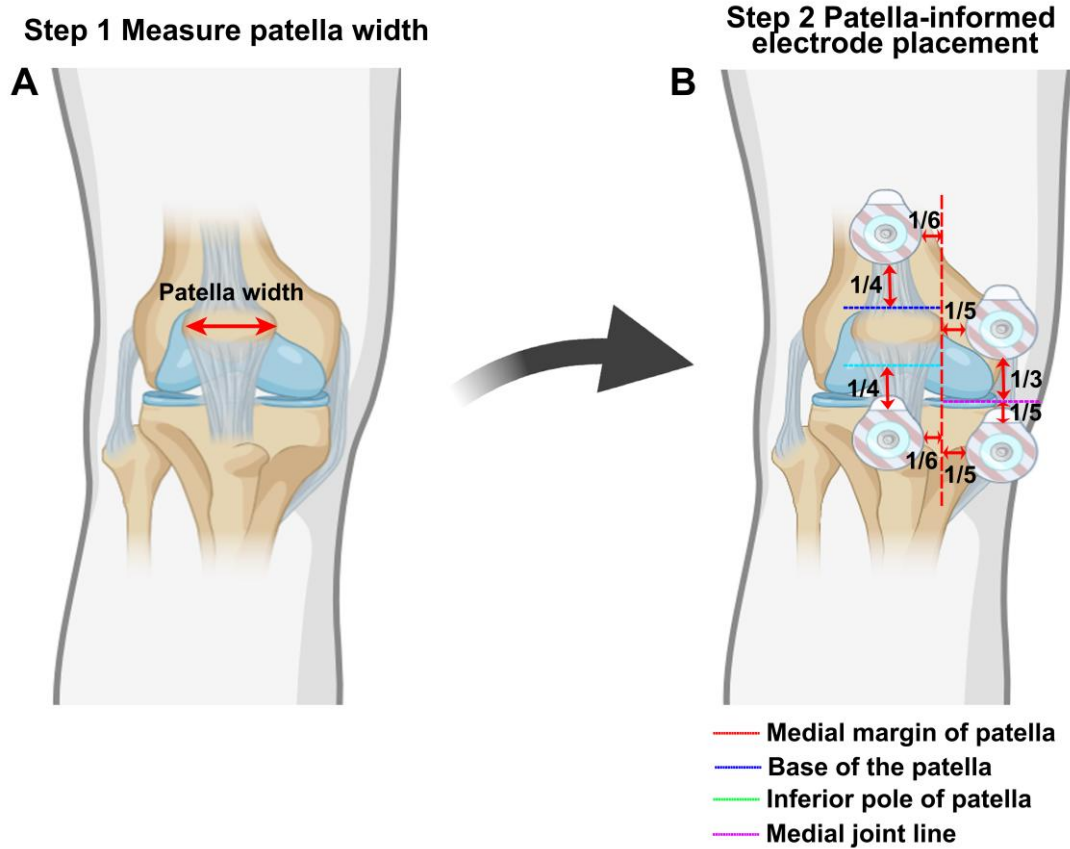
Supplementary table 2. Individual patient characteristics of clinical trial

Supplementary figure 1: Anatomical process



A. Systematic anatomical dissection was performed. B. The skin and subcutaneous tissue were carefully dissected to expose the cutaneous nerves, which pass between the skin and the superficial fascia. C. To ensure that the location of the cutaneous nerve branches was maintained *in situ*, the adipose tissue attached to the endings of the cutaneous nerve was retained. Black arrow indicates cutaneous nerves; Pink triangle indicates adipose tissue attached to the endings of the cutaneous nerve.

Supplementary figure 2: Step-by-step guide for patella-informed electrode placement



A. Patellar width is first measured; B. Electrodes are placed at positions corresponding proportionally to the measured patellar width.

Supplementary table 1. Electrode placement

Sample	Patellar width (Three measurements) [cm]			Average patellar width [cm]	A* (Three measurements) [cm]			Average A [cm]	A to patellar width (AP) [% patellar width]	B# (Three measurements) [cm]			Average B [cm]	B to patellar width (BP) [% patellar width]	C^ (Three measurements) [cm]			Average C [cm]	C to patellar width (CP) [% patellar width]	D* (Three measurements) [cm]			Average D [cm]	D to patellar width (DP) [% patellar width]	E† (Three measurements) [cm]			Average E [cm]	E to patellar width (EP) [% patellar width]	F†† (Three measurements) [cm]			Average F [cm]	F to patellar width (FP) [% patellar width]	G††† (Three measurements) [cm]			Average G [cm]	G to patellar width (GP) [% patellar width]	H†††† (Three measurements) [cm]			Average H [cm]	H to patellar width (HP) [% patellar width]
Sample 01	46.46	46.26	46.50	46.41	12.77	13.16	12.82	12.92	0.28	6.97	7.04	7.46	7.16	0.16	13.68	13.66	13.72	13.69	0.29	7.48	7.44	7.31	7.41	0.16	17.81	18.01	18.15	17.99	0.39	11.86	11.90	11.92	11.89	0.25	6.56	6.49	6.37	6.47	0.14	10.46	10.35	10.40	10.40	0.22
Sample 02	46.74	46.89	46.66	46.76	11.02	11.43	11.34	11.26	0.25	8.50	8.70	9.28	8.83	0.19	9.18	9.36	9.52	9.35	0.20	5.11	5.01	5.07	5.06	0.11	22.75	22.71	22.25	22.57	0.39	5.86	5.91	6.38	6.05	0.13	5.37	5.34	5.26	5.32	0.12	10.47	10.53	10.66	10.55	0.22
Sample 03	48.84	48.21	48.50	48.52	18.85	19.14	18.77	18.92	0.40	14.62	14.39	15.00	14.67	0.29	12.34	12.68	12.83	12.62	0.26	9.89	9.90	10.01	9.93	0.17	16.88	16.16	16.98	16.67	0.34	5.28	5.25	5.10	5.21	0.11	13.90	13.69	13.92	13.84	0.29	3.98	4.12	3.99	4.03	0.09
Sample 04	45.35	45.81	45.68	45.61	10.85	10.65	11.48	10.99	0.26	7.32	7.14	7.36	7.27	0.15	10.75	10.61	10.89	10.75	0.24	7.97	7.69	7.71	7.79	0.17	18.69	18.32	18.02	18.34	0.40	9.17	9.13	9.32	9.21	0.20	7.48	7.30	7.38	7.39	0.14	6.39	6.30	6.41	6.37	0.16
Sample 05	49.96	49.70	49.93	49.86	15.96	15.55	14.86	15.46	0.29	9.93	9.76	9.53	9.74	0.19	12.95	13.05	13.13	13.04	0.26	10.02	10.20	9.67	9.96	0.20	21.31	21.14	21.29	21.25	0.42	10.94	10.77	10.89	10.87	0.22	11.78	11.87	11.80	11.82	0.26	7.08	6.96	7.17	7.07	0.13
Sample 06	52.58	52.36	52.51	52.48	15.87	15.15	15.45	15.49	0.30	9.44	9.26	9.40	9.37	0.18	20.86	20.82	20.62	20.77	0.38	9.08	8.86	8.96	8.97	0.18	23.45	23.32	23.83	23.53	0.45	12.36	12.62	12.85	12.61	0.24	12.90	12.68	13.00	12.86	0.25	9.61	9.64	9.27	9.51	0.19
Sample 07	45.15	45.47	45.16	45.26	12.37	11.74	11.99	12.03	0.26	3.64	3.44	3.82	3.63	0.10	12.37	12.08	12.48	12.31	0.27	8.94	8.69	8.76	8.80	0.15	19.21	18.72	19.10	19.01	0.40	15.38	15.32	15.01	15.24	0.30	8.70	8.50	8.54	8.58	0.19	10.26	10.11	10.23	10.20	0.23
Sample 08	51.10	51.06	51.06	51.07	15.32	15.20	14.95	15.16	0.30	10.10	1.08	9.93	7.04	0.17	14.14	13.89	13.98	14.00	0.27	7.34	7.28	7.49	7.37	0.15	20.96	20.36	21.53	20.95	0.41	13.31	13.22	13.23	13.25	0.26	11.81	11.92	11.95	11.89	0.23	12.16	12.27	12.06	12.16	0.24
Sample 09	45.47	45.59	45.53	45.53	10.19	10.37	10.20	10.25	0.22	8.81	8.66	8.90	8.79	0.17	10.86	10.97	10.77	10.87	0.24	8.40	8.38	8.47	8.42	0.19	18.73	18.95	18.81	18.83	0.41	4.53	4.79	4.59	4.64	0.11	10.69	10.68	10.59	10.65	0.23	10.35	10.24	10.20	10.26	0.22
Sample 10	47.13	47.96	47.12	47.40	8.14	8.12	8.99	8.42	0.18	7.12	6.88	7.29	7.10	0.16	11.46	11.54	11.49	11.50	0.25	5.18	5.31	5.14	5.21	0.11	5.56	5.88	5.85	5.76	0.13	12.22	12.06	12.17	12.15	0.25	4.47	4.68	4.73	4.63	0.10	11.55	11.50	11.51	11.52	0.24
Sample 11	44.78	44.63	45.40	44.94	11.63	10.94	11.68	11.42	0.24	9.25	8.56	8.86	8.89	0.20	10.84	10.73	10.99	10.85	0.24	6.37	6.28	6.35	6.33	0.14	13.23	13.02	13.11	13.12	0.29	9.98	10.09	10.12	10.06	0.23	14.55	14.50	14.33	14.46	0.32	8.65	9.03	8.97	8.88	0.23
Sample 12	44.62	44.85	44.06	44.51	11.74	11.24	11.07	11.35	0.25	8.92	8.75	8.88	8.85	0.19	9.46	9.42	9.60	9.49	0.24	10.34	10.09	10.92	10.45	0.24	4.60	4.49	4.66	4.58	0.12	9.61	9.68	9.53	9.61	0.22	8.47	8.37	8.45	8.43	0.18	10.67	10.61	10.48	10.59	0.24
Sample 13	52.99	52.65	51.88	52.51	13.68	13.02	13.43	13.38	0.27	9.61	9.58	9.54	9.58	0.16	14.58	14.68	14.87	14.71	0.29	9.08	9.02	9.03	9.04	0.18	18.97	18.71	18.92	18.87	0.36	11.96	11.76	11.83	11.85	0.24	7.70	7.91	7.96	7.86	0.15	14.15	14.00	13.97	14.04	0.28
Sample 14	52.96	50.83	51.02	51.60	11.63	11.27	11.45	11.45	0.27	6.68	6.81	6.72	6.74	0.16	11.68	11.54	11.65	11.62	0.23	6.73	6.85	6.80	6.79	0.13	20.01	19.54	19.65	19.73	0.39	14.70	14.62	14.80	14.71	0.29	8.07	8.05	7.93	8.02	0.15	11.81	11.46	11.51	11.59	0.22
Sample 15	52.73	52.41	52.38	52.51	14.88	15.05	14.58	14.84	0.29	10.42	10.55	10.20	10.39	0.19	14.23	14.47	14.42	14.37	0.28	9.48	9.61	9.72	9.60	0.18	23.57	23.95	23.87	23.80	0.45	12.23	12.40	12.45	12.36	0.24	8.62	8.81	8.89	8.77	0.20	7.63	7.77	7.94	7.78	0.19
Sample 16	45.74	45.48	45.40	45.54	11.51	11.55	11.63	11.56	0.26	9.24	8.80	8.90	8.98	0.19	11.48	11.42	11.32	11.41	0.25	9.46	9.21	9.74	9.47	0.16	16.74	16.76	17.07	16.86	0.31	10.98	11.03	11.00	11.00	0.25	8.03	8.13	8.30	8.15	0.18	10.05	10.06	10.18	10.10	0.22
Sample 17	49.13	48.97	48.98	49.03	13.15	12.60	12.92	12.89	0.26	8.29	7.92	8.34	8.18	0.17	8.23	8.13	8.29	8.22	0.19	9.10	9.28	8.97	9.12	0.18	18.41	18.25	18.34	18.33	0.36	6.95	7.12	7.04	7.04	0.13	8.54	8.70	8.87	8.70	0.17	10.22	10.04	10.21	10.16	0.20
Sample 18	44.02	44.26	45.80	44.69	11.56	11.84	11.51	11.64	0.25	9.18	9.46	9.87	9.50	0.21	5.48	5.23	5.57	5.43	0.12	7.02	6.93	6.97	6.97	0.16	18.73	18.77	18.91	18.80	0.42	10.17	10.20	10.26	10.21	0.23	7.03	6.96	6.93	6.97	0.16	11.64	11.56	11.62	11.61	0.25
Sample 19	48.33	48.32	47.86	48.17	9.61	9.45	9.52	9.53	0.22	7.96	8.29	8.14	8.13	0.17	11.85	11.91	11.89	11.88	0.26	3.11	3.18	3.70	3.33	0.06	18.14	18.06	18.21	18.14	0.38	11.36	11.08	11.05	11.16	0.22	6.03	6.19	6.14	6.12	0.13	11.63	11.77	11.75	11.72	0.25
Sample 20	52.28	55.06	54.97	54.10	11.77	11.95	11.90	11.87	0.22	10.71	10.76	10.60	10.69	0.20	10.81	10.95	11.73	11.16	0.21	10.39	10.55	10.48	10.47	0.19	23.59	23.79	23.99	23.79	0.43	12.22	12.38	12.28	12.29	0.22	10.45	10.33	10.55	10.44	0.19	13.18	13.15	13.22	13.18	0.24

A* : Vertical distance between the base of the patella and the inferior margin of the electrode **covering the high-density nerve area at quadriceps tendon.**

B# : Horizontal distance between the medial margin of the patella and the medial margin of the electrode **covering the high-density nerve area at quadriceps tendon.**

C^ : Vertical distance between the inferior pole of the patella and the superior border of electrode **covering the high-density nerve area at the patellar ligament.**

D* : Horizontal distance between the medial border of the patellar ligament and the medial edge of the electrode **covering the high-density nerve area at the patellar ligament.**

E† : Vertical distance between the medial joint line and the inferior margin of the electrode **covering the high-density nerve area at superior medial region.**

F†† : Horizontal distance between the medial margin of the patella and the lateral border of the electrode **covering the high-density nerve area at superior medial region.**

G††† : Vertical distance from the medial joint line to the superior border of the electrode **at the medial join line area.**

H†††† : Horizontal distance between the medial margin of the patella and the lateral border of the electrode **at the medial join line area.**

Supplementary table 2. Individual patient characteristics of clinical trial

Group	Patient	Sex	Age(years)	Weight(kg)	Height(cm)	Body mass index (BMI)	Kellgren-Lawrence grade	VAS			WOMAC (Baseline)				WOMAC (1-week follow-up)				WOMAC (2-week follow-up)			
								Baseline	1-week follow-up	2-week follow-up	Pain score	Stiffness score	Function score	Total score	Pain score	Stiffness score	Function score	Total score	pain score	Stiffness score	Function score	Total score
Study cohort	S-P01	Female	74	75	165	27.55	2	7.8	4.1	3.1	12	4	39	55	8	4	31	43	7	2	29	38
Study cohort	S-P02	Male	51	65	175	21.22	2	7.3	3.2	3.9	12	5	46	63	8	4	32	44	7	3	29	39
Study cohort	S-P03	Female	74	56	158	22.43	3	8.4	4.2	4.9	13	4	37	54	7	4	30	41	6	2	31	39
Study cohort	S-P04	Female	63	61	164	22.68	2	6.7	4	4.1	12	5	46	63	11	1	35	47	8	2	31	41
Study cohort	S-P05	Female	72	53	160	20.70	3	8.3	4.1	4.9	8	3	38	49	6	3	29	38	5	3	27	35
Study cohort	S-P06	Female	75	58	161	22.38	3	7.5	3	3.3	12	4	46	62	10	4	31	45	8	4	30	42
Study cohort	S-P07	Female	68	68	155	28.30	2	6.5	3.5	3.5	11	4	38	53	8	2	33	43	8	4	27	39
Study cohort	S-P08	Male	75	85	160	33.20	2	6.3	3.6	3.9	13	4	41	58	8	2	30	40	7	3	32	42
Study cohort	S-P09	Male	75	70	155	29.14	3	8	4.3	4.7	10	5	38	53	9	2	32	43	6	2	33	41
Study cohort	S-P10	Female	52	55	177	17.56	3	8.2	4	4.5	10	5	37	52	9	3	29	41	7	2	30	39
Study cohort	S-P11	Female	59	46	176	14.85	2	7.6	3.1	3.9	9	5	39	53	6	4	27	37	6	1	25	32
Study cohort	S-P12	Male	58	75	161	28.93	2	9	4.3	4.5	11	4	48	63	10	6	29	45	9	4	29	42
Study cohort	S-P13	Female	61	68	168	24.09	2	6.8	3.2	3.9	15	6	51	72	10	5	32	47	9	4	28	41
Study cohort	S-P14	Female	53	56	156	23.01	2	7	2.5	2.9	11	3	39	53	8	4	31	43	8	5	27	40
Study cohort	S-P15	Female	73	60	171	20.52	3	6	3	3.1	12	4	38	54	9	2	32	43	5	1	30	36
Study cohort	S-P16	Female	73	55	166	19.96	3	6	3.4	2.9	10	5	40	55	6	4	32	42	6	1	35	42
Study cohort	S-P17	Female	56	63	168	22.32	2	7.4	3	3.4	12	4	41	57	9	3	32	44	7	2	29	38
Study cohort	S-P18	Female	64	65	175	21.22	3	7.8	2.3	2.9	11	3	37	51	8	2	30	40	7	3	26	36
Study cohort	S-P19	Female	71	56	159	22.15	2	8.2	4	3.9	8	2	36	46	5	5	29	39	6	1	29	36
Study cohort	S-P20	Female	75	75	155	31.22	2	7.6	3.1	3.9	11	4	41	56	9	2	32	43	8	3	26	37
Study cohort	S-P21	Female	57	62	170	21.45	2	7.7	4.1	4.9	12	4	38	54	8	2	34	44	8	3	25	36
Study cohort	S-P22	Female	60	76	171	25.99	3	7.4	3	3.3	9	3	36	48	5	7	25	37	6	2	27	35
Study cohort	S-P23	Female	72	50	157	20.28	3	6	3.1	3.4	15	6	42	63	9	5	33	47	8	2	31	41
Study cohort	S-P24	Male	59	80	156	32.87	2	6.4	3.4	3.1	10	4	35	49	5	4	27	36	6	1	26	33
Study cohort	S-P25	Female	69	55	168	19.49	2	7.8	2.4	2.9	10	3	36	49	7	2	30	39	7	2	26	35
Study cohort	S-P26	Female	72	55	161	21.22	3	8.6	5	5.1	11	4	37	52	7	2	32	41	7	2	30	39
Study cohort	S-P27	Male	67	60	168	21.26	2	6.7	2.1	2.6	9	3	36	48	8	2	30	40	6	3	28	37
Study cohort	S-P28	Female	68	48	160	18.75	2	7.2	3.9	3.4	11	5	43	59	8	2	32	42	5	1	32	38
Study cohort	S-P29	Female	73	55	168	19.49	3	9	5.1	4.9	12	4	40	56	9	2	33	44	7	3	29	39
Study cohort	S-P30	Female	64	57	157	23.12	2	6.9	3.5	4.1	10	3	41	54	9	5	30	44	8	3	29	40
Study cohort	S-P31	Female	59	90	161	34.72	3	7.9	2.8	2.9	12	5	44	61	10	1	36	47	10	6	23	39
Study cohort	S-P32	Female	56	60	155	24.97	2	6.9	3.5	3.1	10	3	38	51	5	5	30	40	9	4	24	37
Study cohort	S-P33	Female	56	48	163	18.07	3	8.2	2.8	3.7	8	3	37	48	7	4	28	39	9	3	25	37
Study cohort	S-P34	Female	74	69	170	23.88	3	7.6	3	3.1	14	5	42	61	12	4	34	50	10	5	29	44
Study cohort	S-P35	Female	64	66	168	23.38	3	9	4	4.9	9	3	37	49	8	3	28	39	5	2	29	36
Study cohort	S-P36	Male	67	76	175	24.81	3	8.1	4.4	3.1	14	3	43	60	10	4	32	46	6	2	32	40
Study cohort	S-P37	Female	63	80	160	31.25	2	8.3	4.2	3	13	4	41	58	9	2	34	45	7	1	31	39
Study cohort	S-P38	Female	56	75	152	32.46	2	7.5	3.6	3	11	2	39	52	8	3	31	42	5	1	33	39

Control cohort	C-P01	Female	74	65	165	23.88	2	9.1	6	6	10	4	40	54	10	3	33	46	9	4	30	43
Control cohort	C-P02	Female	59	63	155	26.22	2	7.3	4.4	4.9	9	3	39	51	9	5	30	44	8	3	31	42
Control cohort	C-P03	Female	53	86	157	34.89	3	7.3	4.9	4.4	10	5	39	54	10	2	32	44	7	3	31	41
Control cohort	C-P04	Female	67	69	170	23.88	3	8	5.1	4.8	13	5	42	60	13	4	32	49	8	3	31	42
Control cohort	C-P05	Male	66	75	171	25.65	2	9.2	5	5.9	10	4	38	52	11	2	32	45	9	4	30	43
Control cohort	C-P06	Male	60	60	160	23.44	2	8	4	4.3	10	6	40	56	10	3	34	47	5	3	37	45
Control cohort	C-P07	Male	61	80	157	32.46	3	7	4.5	4.5	12	4	42	58	13	4	32	49	8	3	31	42
Control cohort	C-P08	Female	61	70	167	25.10	2	6.3	4.6	4.9	11	4	43	58	13	1	34	48	7	2	33	42
Control cohort	C-P09	Female	51	49	165	18.00	3	8	4	4.1	12	5	42	59	15	3	32	50	8	4	32	44
Control cohort	C-P10	Female	69	59	158	23.63	3	8.2	5	5.5	10	4	38	52	9	4	30	43	9	4	30	43
Control cohort	C-P11	Male	71	38	171	13.00	3	7.6	4.1	4.9	11	4	40	55	9	5	32	46	10	4	27	41
Control cohort	C-P12	Male	73	65	156	26.71	2	9	6	5.5	11	5	37	53	7	4	29	40	8	5	26	39
Control cohort	C-P13	Female	62	58	163	21.83	2	6.8	5	4.9	14	6	45	65	12	4	35	51	8	3	31	42
Control cohort	C-P14	Female	56	112	170	38.75	3	7	4.2	3.9	13	4	42	59	11	3	33	47	9	4	30	43
Control cohort	C-P15	Female	65	51	168	18.07	3	6	4	4.1	9	3	36	48	8	4	30	42	8	3	28	39
Control cohort	C-P16	Female	63	50	169	17.51	2	6.4	4.4	4.3	13	6	46	65	13	5	34	52	10	3	35	48
Control cohort	C-P17	Female	60	55	175	17.96	3	7.4	4	4.4	12	5	42	59	14	3	31	48	8	4	31	43
Control cohort	C-P18	Female	69	61	156	25.07	2	7.9	6	5.4	11	4	37	52	8	3	34	45	9	4	29	42
Control cohort	C-P19	Female	71	46	170	15.92	3	8.2	5.1	5.5	10	3	37	50	7	5	31	43	8	3	31	42
Control cohort	C-P20	Female	69	50	173	16.71	3	6.3	4	4.9	11	2	39	52	9	3	30	42	10	3	27	40
Control cohort	C-P21	Female	75	80	157	32.46	2	8	4.2	5.1	13	4	41	58	11	3	33	47	8	4	31	43
Control cohort	C-P22	Female	68	66	156	27.12	2	8	5	4.7	12	4	42	58	13	2	32	47	7	2	34	43
Control cohort	C-P23	Female	70	51	178	16.10	3	7.6	4.1	4.9	11	3	41	55	14	3	31	48	11	5	29	45
Control cohort	C-P24	Female	59	60	161	23.15	3	9	5.3	5.5	9	2	38	49	7	4	29	40	7	3	30	40
Control cohort	C-P25	Female	69	70	168	24.80	3	6.8	4.2	3.9	15	6	45	66	12	5	35	52	10	4	33	47
Control cohort	C-P26	Female	52	56	157	22.72	3	7	3.5	3.9	12	4	34	50	8	3	30	41	7	3	28	38
Control cohort	C-P27	Female	65	70	161	27.01	3	6.2	4.1	3.9	12	3	38	53	9	4	34	47	8	2	33	43
Control cohort	C-P28	Male	56	49	155	20.40	2	7.4	3.3	3.4	10	3	39	52	10	2	34	46	9	3	29	41
Control cohort	C-P29	Female	72	65	170	22.49	2	8	3.4	3.9	12	4	40	56	12	4	34	50	8	4	32	44
Control cohort	C-P30	Female	69	64	155	26.64	2	9.1	6	6	12	4	41	57	10	3	33	46	8	2	31	41
Control cohort	C-P31	Female	66	65	177	20.75	3	7.3	4.4	4.9	9	4	38	51	8	5	31	44	9	2	29	40
Control cohort	C-P32	Female	71	55	155	22.89	3	7	4.9	4.4	8	2	37	47	7	5	31	43	8	4	27	39
Control cohort	C-P33	Male	75	65	156	26.71	2	9	5.2	5.5	11	4	43	58	9	7	34	50	9	3	32	44
Control cohort	C-P34	Male	57	60	166	21.77	2	6.8	4.2	4.9	10	4	39	53	8	3	31	42	8	4	28	40
Control cohort	C-P35	Female	71	66	168	23.38	2	7	3.5	3.6	9	4	35	48	10	2	28	40	7	3	31	41
Control cohort	C-P36	Female	67	80	153	34.17	2	6.7	4	3.4	10	3	37	50	7	5	29	41	9	2	28	39
Control cohort	C-P37	Female	73	77	157	31.24	3	6.9	4.3	3	9	2	37	48	6	3	29	38	8	3	32	43