Comparative Analysis of Muscle Fatigue Levels Based on Colonoscopy Controller Configuration Using Electromyography

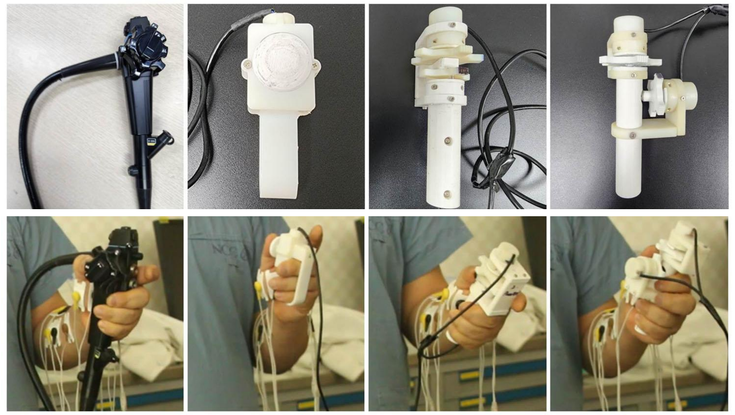
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BACKGROUND

- Endoscopists experience a high incidence of carpal tunnel syndrome, de Quervain's tenosynovitis, and lateral epicondylitis due to awkward positioning, pushing, pulling, and beating of the scope, and repetitive motions during endoscopic procedures. It has been shown that these injuries can begin as early as during fellowship training (20−49% of trainees). Despite the high incidence of injuries, more than 70% of trainees reported receiving no formal training in endoscopic ergonomics. Musculoskeletal symptoms and related injuries can shorten endoscopists' careers and reduce healthcare staff, negatively affecting patient care.
- This study aimed to investigate the differential impacts of various controller types on muscle fatigue, with the aim of identifying a controller design that can alleviate operator fatigue while maintaining or enhancing procedural efficiency and safety.

MATERIALS AND METHODS

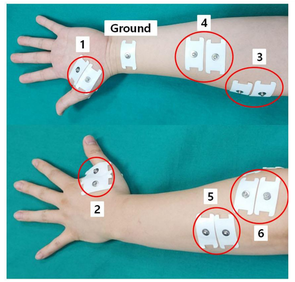
- Three types of controllers were created to control the colonoscopy robot with a 3D printer (Figure 1). The first controller was a thumb controller that minimizes movement and can control left/right and up/down movements identical to the existing endoscope movements. The second was a parallel controller that simulates an existing endoscope and can be operated as a horizontal dial. The third controller was made in the form of a dial that can be operated by simulating an existing endoscope like the second one, but it is made in a vertical form so that it is easy to distinguish left/right and up/down movements.



(a) Conventional (b) Thumb Controller (c) Parallel Controller (d) Vertical Controller

Figure 1. Conventional controller and colonoscopy robot controllers

- EMG signals were measured using a WEMG-8 (LXM5308, Laxtha Inc., Korea) with a sampling frequency of 1,024 Hz.
- Measurements were performed after each controller was gripped in a natural standing position, with electrodes attached to the left hand and arm.



Channel No.	Muscle
1	Abductor pollicis brevis
2	First dorsal interosseous
3	Brachioradialis
4	Flexor carpi radialis
5	Extensor digitorum communis
6	Extensor carpi radialis

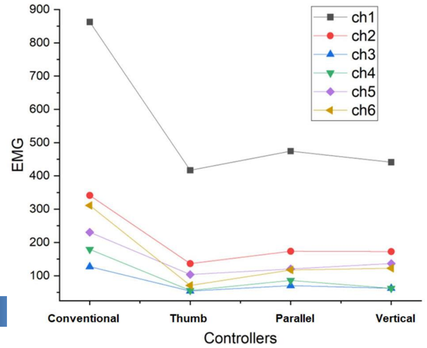
Figure 2. Electrode placement for electromyography measurement

RESULT

Motion	Sex	ch	Conventional Controller			Thumb Controller			Parallel Controller			Vertical Controller		
Parameter			Mean	SD	p-value	Mean	SD	p-value	Mean	SD	p-value	Mean	SD	p-value
Left-Right control	Female	ch1	1155.20	134213.27	control	594.30	103543.73	<0.05	662.87	89593.09	<0.05	618.77	148024.05	<0.05
		ch2	471.47	362.19	control	157.67	45.45	<0.05	215.83	119.54	<0.05	179.70	135.26	<0.05
		ch3	151.53	101.46	control	51.80	17.19	<0.05	78.87	42.49	<0.05	63.30	31.01	<0.05
		ch4	208.93	142.03	control	56.77	21.63	<0.05	98.97	55.52	<0.05	66.33	30.48	<0.05
		ch5	237.33	104.79	control	89.87	56.93	<0.05	109.73	57.15	<0.05	91.80	53.95	<0.05
		ch6	319.53	206.30	control	78.47	36.84	<0.05	130.20	78.19	<0.05	107.00	62.32	<0.05
	Male	ch1	423.45	4927.63	control	151.00	817.26	<0.05	191.50	2828.47	<0.05	174.95	6967.63	<0.05
		ch2	146.3	31.01	control	104.60	28.76	<0.05	110.20	21.14	<0.05	162.05	73.90	0.19
		ch3	91.00	15.38	control	56.95	12.05	<0.05	57.45	10.95	<0.05	60.85	10.13.	<0.05
		ch4	134.95	27.761	control	54.00	13.27	<0.05	66.60	19.81	<0.05	55.80	7.13	<0.05
		ch5	220.75	34.95	control	124.35	65.99	<0.05	136.40	20.59	<0.05	203.90	100.30	0.24
		ch6	298.55	114.23	control	59.25	17.20	<0.05	97.95	9.08	<0.05	145.75	57.30	<0.05
Up-Down control	Female	ch1	887.23	65061.70	control	371.53	26270.46	<0.05	679.00	121641.59	<0.05	517.53	112233.29	<0.05
		ch2	266	77.80	control	243.70	103.25	0.17	157.23	66.30	<0.05	242.33	136.14	0.21
		ch3	104.77	54.75	control	56.73	22.65	<0.05	61.13	23.73	<0.05	76.733	40.92	<0.05
		ch4	132.87	47.12	control	64.10	22.99	<0.05	77.53	38.05	<0.05	78.47	29.75	<0.05
		ch5	161.77	76.57	control	127.33	51.81	<0.05	106.67	32.38	<0.05	113.60	38.46	<0.05
		ch6	190.1	90.85	control	110.70	58.90	<0.05	126.43	72.05	<0.05	122.27	46.92	<0.05
	Male	ch1	594.10	5387.46	control	203.40	5348.78	<0.05	200.90	3883.99	<0.05	156.50	1659.74	<0.05
		ch2	340.65	209.72	control	108.70	44.14	<0.05	105.75	29.23	<0.05	177.65	85.28	<0.05
		ch3	120.3	39.08	control	51.00	5.47	<0.05	52.25	7.87	<0.05	50.60	4.49	<0.05
		ch4	149.1	29.54	control	48.30	8.44	<0.05	59.25	9.98	<0.05	62.00	13.97	<0.05
		ch5	258.65	109.26	control	135.65	41.09	<0.05	163.05	44.73	<0.05	142.80	43.46	<0.05
		ch6	421.1	101.10	control	61.70	18.25	<0.05	128.90	59.66	<0.05	143.00	37.53	<0.05

Motion	Channel	Conventional Controller			Thumb Controller			Parallel Controller			Vertical Controller		
Parameter		Mean	Standard Deviation	p-value	Mean	Standard Deviation	p-value	Mean	Standard Deviation	p-value	Mean	Standard Deviation	p-value
Left-Right control	ch1	862.5	212475.64	control	416.98	109723.98	<0.05	474.32	108534.26	<0.05	441.24	138546.15	<0.05
	ch2	341.4	103906.82	control	136.44	2233.07	<0.05	173.58	11362.86	<0.05	172.64	13021.75	<0.05
	ch3	127.32	7082.06	control	53.86	237.63	<0.05	70.3	1227.36	<0.05	62.32	610.22	<0.05
	ch4	179.34	13577.98	control	55.66	346.96	<0.05	86.02	2233.20	<0.05	62.12	596.64	<0.05
	ch5	230.7	7039.44	control	103.66	3898.31	<0.05	120.4	2271.96	<0.05	136.64	8700.81	<0.05
	ch6	311.14	30354.57	control	70.78	1008.26	<0.05	117.3	3905.07	<0.05	122.5	3939.28	<0.05
Up-Down control	ch1	769.98	61638.31	control	304.28	24544.82	<0.05	487.76	129476.68	<0.05	373.12	98988.60	<0.05
	ch2	295.86	22001.92	control	189.7	11527.48	<0.05	136.64	3581.83	<0.05	216.46	14813.68	<0.05
	ch3	110.98	2425.78	control	54.44	323.27	<0.05	57.58	376.58	<0.05	66.28	1165.92	<0.05
	ch4	139.36	1717.05	control	57.78	401.52	<0.05	70.22	977.20	<0.05	71.88	665.82	<0.05
	ch5	200.52	10397.56	control	130.66	2260.27	<0.05	138.74	2387.42	<0.05	125.28	1816.65	<0.05
	ch6	282.5	21916.50	control	91.1	2770.50	<0.05	127.42	4454.33	<0.05	130.56	1954.17	<0.05

Table 1. Electromyography signal data according to muscle location for each controller



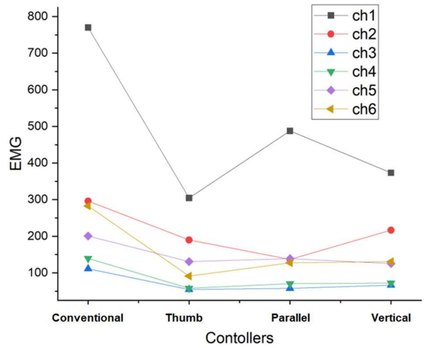


Figure 3. Graphs of electromyographic signals from each of the six muscles when four controllers (conventional, thumb, parallel, and vertical) were used: (a) left/right movement control and (b) up/down movement control

- The results of the EMG signal analysis are shown in Table 1. The difference in the EMG signals by the controller was greater for the left/right movement control than for the up/down movement control. A comparison of the EMG signal results for each controller is shown in Figure 3
- The left/right motion control had the same direction of movement as the parallel, vertical, and thumb controllers. In contrast, for the up/down motion control, the directions of movement of the parallel, vertical, and thumb controllers were different.
- The EMG signals of the abductor pollicis brevis, which plays an important role in the movement of the thumb, including abduction and flexion, showed the highest signal in all measurements for all controllers. The EMG signals of the abductor pollicis brevis in the conventional controller were significantly higher than those in the other controllers for both up/down and left/right motions ($p<0.05$).

CONCLUSION

- Here, we evaluated from an ergonomic perspective whether a new robot controller can reduce musculoskeletal injuries compared with existing controllers during colonoscopy procedures through objective EMG analysis. Our results indicated that the robotic controller was more effective in minimizing muscle fatigue, highlighting the potential of controllers with innovative designs to improve ergonomic safety and reduce the risk of musculoskeletal injury for endoscopists.

Acknowledgements

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