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IMU-based Gait analysis for Determining proper assistive device with disabled patients : Case serial

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Gait analysis with IMU technology is effective for people who cannot walk independently in two ways. In previous study, we presented that IMU-based gait analysis allow us to evaluate gait patterns with patients, who needs handling assistive devices. Furthermore, we described its helpfulness for determining best-fitting assistive devices for rehabilitation.   Recent days, we focused on utilizing IMU-based gait analysis for making decision of proper assistive device. It can provide quantitative information of gait parameters without consideration of specific environments and surroundings, so, it is useful for determining the most suitable assistive device for disabled patient. Currently, we initially evaluate gait patterns of patients on first day of their transfer, admission(in-patient) or visit(out-patient) to conclude the most affordable device in tailored way.   10 patients with several disease entities were recruited in this study. Table 1 shows baseline characteristic of patients. Testing tool was Humantrack(Figure 1.), which equipped with fusion-sensor system composed with wireless IMU sensor and Stereo camera. First, IMU sensor provided to patients' abdomen, both thigh, shank and foot dorsum(Figure 1.). And next, calibration of axis was done. Then, patients gait 6m with several assistive devices with video monitoring. During the gait, gait parameters(14 items: gait cycle time(sec), stance phase(%), swing phase(%), velocity(m/s), stride length(m), cadence(step/min), pre-swing(%), initial double support time(%), initial single support time(%), terminal double support time(%), terminal single support time(%), hip joint angle(deg), knee joint angle(deg), ankle joint angle(deg) were detected. Figure 2. shows the result of gait evaluation. The priority factors we gave significance more than others were gait cycle time, stance phase, swing phase, velocity and stride length. All patients were tolerable during 6m gait with IMU-gait evaluation. Patients were evaluated with various assistive devices for finding the fittest one, respectively. If the result showed no significant difference or better performance in superior assistive between two gait analyses, superior level handling devices was adapted. In contrast, if there was difference, inferior level handling devices was adapted.   Patient 1-7 shows cases of final choice with superior level handling devices. And Patient 8 presents final choice of inferior level handling device. In addition, Patient 9-10 appears the fittest choice of assistive device among 3 or more options.   Compared to previous case study, we think there are variations due to patient characteristics such as age, sex, disease entity and general condition. Therefore, there must be a consideration of these affecting factors.   We shows that IMU-based gait analysis may shed light on evaluating disabled patients' gait patterns quantitatively with accuracy, ones again.

Table 1. Baseline characteristics

	Disability	Determined Assistive device
Patient 1 M/65	Right hemiplegia d/t left basal ganglia and left frontal ICH, s/p Left frontotemporal craniotomy, hematoma removal (17/3/12)	Mono-cane vs. Quad-cane ->Mono-cane
Patient 2 M/67	Gait disturbance due to a SAH(18/3/7) b. r/o frontal lobe Syndrome	Independent vs. Mono-cane ->Independent
Patient 3 F/79	Tetraplegia d/t SCI, ASIA D Spine : 1) myelopathy, C4-5 level 2) Disc extrusion, right central zone or OPLL 3) Disc protrusion, left central zone	Quad-cane vs. Walker ->Quad-cane
Patient 4 M/56	Gait disturbance d/t traumatic SDH along the falx and and bilateral tentorium(2018/4/10)	Independent vs. Mono-cane ->Independent
Patient 5 M/60	Right side weakness d/t cervical myelopathy, C4-5, s/p AIF(2017/6/20)	Independent vs. Quad-cane ->Independent
Patient 6 M/49	Right hemiplegia d/t left pons ICH (2017/4/25)	Independent vs. Quad-cane ->Independent
Patient 7 F/76	General deconditioning d/t Gallbladder stone with cholecystitis, s/p laparoscopic cholecystectomy(18/2/13)	Mono-cane vs. Walker ->Mono-cane
Patient 8 F/60	Gait disturbance d/t r/o radiculopathy, L3/4	Quad-cane vs. Walker ->Walker
Patient 9 M/11	Gait disturbance d/t cauda equina syndrome(2018/3/5)	Compared Independent, unilateral Mono-cane, bilateral Mono-cane and Forearm crutch ->Independent
Patient 10 M/85	Gait disturbance d/t Chronic SDH at left cerebral convexity(2018/1/28) 2) R/O recent infarction at right side pons	Compared Mono-cane, Quad-cane and walker ->Q-cane

table 3-12. Gait parameters, Patient 1-10

	Mono-cane		Quad-cane	
	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	2.3	2.3	2.3	2.6
stance phase(%)	59.8	55.6	57.2	49.9
swing phase(%)	40.2	44.4	42.8	50.1
velocity(m/s)	0.9	0.6	1	0.5
stride Length(m)	0.5	0.5	0.7	0.3
cadence (step/min)				
pre-swing(%)	59.8	55.6	57.2	49.9
initial double support time(%)	19.4	2.9	29.2	12.3
initial single support time(%)	38.3	35	14.5	24.2
terminal double support time(%)	2.9	19.4	12.3	29.2
terminal single support time(%)	41.5	46.3	44	54.9
hip joint angle(deg)	32.4	21.7	32.6	23.7
knee joint angle(deg)	47.7	17.3	40	14.6
ankle joint angle(deg)	30.4	42.7	32.8	36.9

Table 3. Gait parameters, Patient 1 -> similar, choice : mono-cane

	Independent		Mono-cane	
	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	1.4	1.5	1.6	1.6
stance phase(%)	54.6	55.3	57.3	60.6
swing phase(%)	45.4	44.7	42.7	39.4
velocity(m/s)	1	0.8	0.8	0.7
stride Length(m)	0.6	0.6	0.6	0.4
cadence (step/min)				
pre-swing(%)	54.6	55.3	57.3	60.6
initial double support time(%)	8.7	6.8	8.4	10.1
initial single support time(%)	38.3	40.4	38.4	40.4
terminal double support time(%)	6.8	8.7	10.1	8.4
terminal single support time(%)	46.2	43.1	43.1	41
hip joint angle(deg)	25	30	22	27.9
knee joint angle(deg)	32.6	35.1	30.6	32.7
ankle joint angle(deg)	45.6	52.1	42.2	41

Table 4 Gait parameters, Patient 2 -> better in independent gait, choice : no assist

	Quad-cane		Walker	
	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	1.3	1.2	1.3	1.3
stance phase(%)	52.3	56.7	53.6	55.7
swing phase(%)	47.7	43.3	46.4	44.3
velocity(m/s)	0.7	0.7	0.7	0.7
stride Length(m)	0.5	0.5	0.5	0.6
cadence (step/min)				
pre-swing(%)	52.3	56.7	53.6	55.7
initial double support time(%)	5.2	1.3	5.7	5.2
initial single support time(%)	43.7	49.4	40.9	43.7
terminal double support time(%)	1.3	5.2	5.2	5.7
terminal single support time(%)	49.8	44.1	48.1	45.3
hip joint angle(deg)	22.2	22.9	22.5	19.3
knee joint angle(deg)	36.9	34	28.5	31.8
ankle joint angle(deg)	15.8	19.1	11.2	23.4

Table 5 Gait parameters, Patient 3 -> similar, choice : Quad-cane

	Independent		Mono-cane	
	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	1.2	1.2	1.2	1.2
stance phase(%)	66.1	61.1	64.6	60.8
swing phase(%)	33.9	38.9	35.4	39.2
velocity(m/s)	0.8	0.8	0.9	1
stride Length(m)				
cadence (step/min)	96.7	98.5	96.3	96.5
pre-swing(%)				
initial double support time(%)	12.2	15.3	14.1	11.6
initial single support time(%)	38.6	33.7	38.8	35.2
terminal double support time(%)	15.3	12.1	11.7	14
terminal single support time(%)				
hip joint angle(deg)	30.5	20	32	25
knee joint angle(deg)	54.4	50.8	58	59.5
ankle joint angle(deg)	52.5	43.8	57.4	38.4

Table 6 Gait parameters, Patient 4 -> similar, choice : no asist

	Independent		Quad-cane	
	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	1.9	2	2.4	2.3
stance phase(%)	61	55.5	66.3	52.1
swing phase(%)	39	44.5	33.7	47.9
velocity(m/s)	0.5	0.3	0.3	0.3
stride Length(m)	0.2	0.2	0.2	0.1
cadence (step/min)				
pre-swing(%)	61	55.5	66.3	52.1
initial double support time(%)	13.8	19.9	24.3	26
initial single support time(%)	29.3	36.31	37.9	33.2
terminal double support time(%)	19.7	14.2	25	24.8
terminal single support time(%)	39.5	43.3	35.2	39.5
hip joint angle(deg)	22.1	9.4	16.4	8.9
knee joint angle(deg)	33	13.6	33.7	12.6
ankle joint angle(deg)	16.5	12.3	11.2	10.1

Table 7 Gait parameters, Patient 5 -> better in independent gait, choice : no assist

	Independent		Quad-cane	
	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	1.3	1.3	2.9	3
stance phase(%)	56.9	61.1	66.4	47.4
swing phase(%)	43.1	38.9	33.6	52.6
velocity(m/s)	1.2	1	0.4	0.3
stride Length(m)	1	0.9	0.2	0.3
cadence (step/min)				
pre-swing(%)	56.9	61.1	66.4	47.4
initial double support time(%)			29.4	6.7
initial single support time(%)	46.5	50.4	29.8	24.6
terminal double support time(%)			6.9	29.6
terminal single support time(%)	47.4	43.8	33.9	63.8
hip joint angle(deg)	55.6	51.1	25.7	14
knee joint angle(deg)	57.5	50.4	42.9	13.7
ankle joint angle(deg)	19	30.1	16.3	10.6

Table 8 Gait parameters, Patient 6 -> better in independent gait, choice : no assist

	Mono-cane		Walker	
	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	1.7	1.8	3	3.2
stance phase(%)	58.1	56.7	68.4	61.1
swing phase(%)	41.9	43.3	31.6	38.9
velocity(m/s)	0.7	0.5	0.4	0.5
stride Length(m)	0.5	0.5	0.4	0.3
cadence (step/min)				
pre-swing(%)	58.1	56.7	68.4	61.1
initial double support time(%)	13.2	9.8	43.9	17
initial single support time(%)	33.7	31	17	7.3
terminal double support time(%)	9.8	13.2	17	43.9
terminal single support time(%)	43.3	46	37.4	31.8
hip joint angle(deg)	24.7	14.2	18.3	11.3
knee joint angle(deg)	32.9	18.1	24.9	14.8
ankle joint angle(deg)	24.3	20.3	33.7	16.5

Table 9 Gait parameters, Patient 7 -> better in mono-cane gait, choice : mono-cane

	Quad-cane		Walker	
	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	2.4	2.5	1.7	1.7
stance phase(%)	61.3	63.3	56.9	57.8
swing phase(%)	38.7	36.7	43.1	42.2
velocity(m/s)	0.4	0.4	0.6	0.6
stride Length(m)	0.2	0.3	0.5	0.5
cadence (step/min)				
pre-swing(%)	61.3	63.3	56.9	57.8
initial double support time(%)	18.1	3.9	6.1	5.2
initial single support time(%)	37.1	39.5	42.8	45.1
terminal double support time(%)	3.9	18.1	5.2	6.1
terminal single support time(%)	40.9	38.6	45.9	43.6
hip joint angle(deg)	25.9	31.1	37.3	31.6
knee joint angle(deg)	50.1	40.7	56.3	42.2
ankle joint angle(deg)	52.4	42.9	60.5	43

Table 10 Gait parameters, Patient 8 -> better in walker, choice : walker

	Mono-cane		Quad-cane		Walker	
	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	1.3	1.3	1.3	1.3	3	1.3
stance phase(%)	55.9	51.9	55.9	56.9	43.3	53.1
swing phase(%)	44.1	48.1	44.1	43.1	56.7	46.9
velocity(m/s)	0.1	0.6	0.1	0.4	0.3	0.4
stride Length(m)	0	0.3	0	0.2	0.1	0.2
cadence (step/min)						
pre-swing(%)	55.9	51.9	55.9	56.9	43.3	53.1
initial double support time(%)	0.8	20.9	4.2	12.3	288.2	281.6
initial single support time(%)	43.3	29.5	39.3	39.7	527.7	511.8
terminal double support time(%)	20.9	0.8	12.3	4.2	281.6	288.2
terminal single support time(%)	35	48.8	44.2	43.9	57.9	41
hip joint angle(deg)	14.6	18.2	14.9	49.1	6.5	14.6
knee joint angle(deg)	27.2	32	35.5	29.5	8.6	21.9
ankle joint angle(deg)	10.5	17.9	7.9	18.5	3.5	25.5

Table 11 Gait parameters, Patient 9 -> fittest in quad-cane, choice : quad-cane

	Independent		Unilateral mono-cane		Bilateral mono-cane		bilateral forearm crutch	
	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.
gait cycle time(sec)	1.3	1.3	1.3	1.3	1.5	1.5	2	2.1
stance phase(%)	52.9	54.7	54.4	55	53.2	54.6	55.5	59.5
swing phase(%)	47.1	45.3	45.6	45	46.8	45.4	44.5	40.5
velocity(m/s)	0.9	1	1	1.1	0.7	1.1	0.6	0.7
stride Length(m)	0.8	0.8	0.8	0.9	0.5	0.8	0.4	0.4
cadence (step/min)								
pre-swing(%)	52.9	54.7	54.4	55	53.2	54.6	55.5	59.5
initial double support time(%)	9.3	7.4	5.7	412.4	3.1	3.5	4.3	13.1
initial single support time(%)	33.4	37.4	34.2	36.1	744.8	47.8	35.6	14.8
terminal double support time(%)	7.4	9.3	12.4	5.7	3.5	3.1	13.1	4.3
terminal single support time(%)	49.8	45.9	47.7	45.8	48.5	45.6	47	403.8
hip joint angle(deg)	35.9	38.3	39.5	39.9	35.7	30.9	28.1	28.8
knee joint angle(deg)	40.4	37.2	70.5	34	38.2	38.2	35.4	34.7
ankle joint angle(deg)	12.2	18.5	15.5	25	26.5	32.6	34.4	27.4

Table 12 Gait parameters, Patient 10 -> best in independent gait, choice : no asist

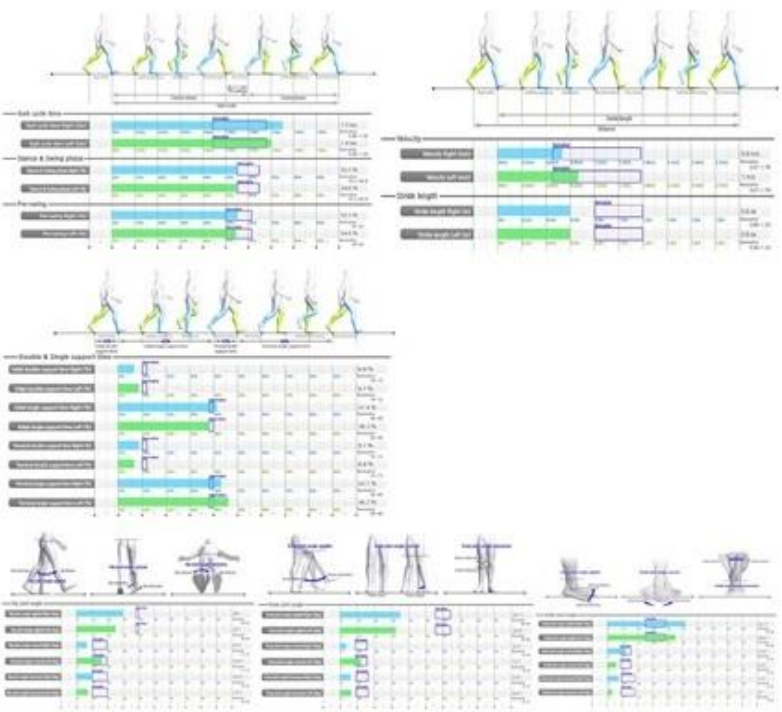

Figure 1. IMU-based gait evaluation(HumanTract)
Figure 2. Gait report(HumanTract)