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Accuracy of Wearable Devices for Estimating Total Energy Expenditure: Comparison With Metabolic Chamber and Doubly Labeled Water Method

Accurate estimation of energy expenditure is a key element in determining the relationships between aspects of human behavior, physical activity, and overall health.[1,2] Although wearable devices for estimating energy expenditure are becoming increasingly popular, there is little evidence regarding their validity.[3,4] This study was performed to examine the validity of total energy expenditure estimates made by several wearable devices compared with gold standard measurements for a standardized day (metabolic chamber method) and free-living days (doubly labeled water [DLW] method).

Methods | All protocols were reviewed and approved by the ethics review board of the National Institute of Health and Nutrition, Tokyo, Japan. Written informed consent was obtained from all participants, who were compensated for their participation. Participants were 19 healthy adults (9 men and 10 women) aged 21 to 50 years who were not obese and had no problems performing regular daily activities. Total energy expenditure was measured using 12 wearable devices. Eight were consumer devices selected because the manufacturers claim that they measure total energy expenditure and they are popular according to Japanese sales rankings (JAWBONE UP24, Fitbit Flex, Misfit Shine, EPSON PULSENCE PS-100, Garmin Vivofit, TANITA AM-160, OMRON CaloriScan HJA-403C, and Withings Pulse O_2). The remaining 4 devices are validated for use in research (OMRON Active style Pro HJA-350IT, Panasonic Actimarker EW4800, SUZUKEN Lifecorder EX, and ActiGraph GT3X). All 12 devices were worn simultaneously at randomly assigned positions on the wrist, chest, or waist as appropriate to minimize possible bias owing to placement (**Figure 1**).

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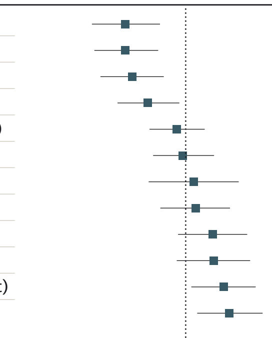
Detailed procedures for total energy expenditure measurement using the metabolic chamber and DLW methods have been described.[5,6] For the metabolic chamber experiment, participants visited the laboratory at 7:30 AM after an overnight

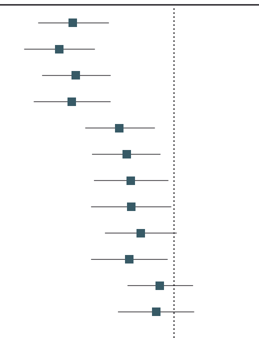
Figure 1. Differences in Total Energy Expenditure in 19 Patients

Device Name (Wearing Position)	Standardized Day (Measured by Metabolic Chamber: 2093.0 ([304.0] kcal/day)): Estimated TEE by Each Device, Mean (SD)	Spearman Rank Correlation Coefficient[a]	Free-living Days (Measured by DLW Method: 2314.4 ([312.6] kcal/day)): Estimated TEE by Each Device, Mean (SD)	Spearman Rank Correlation Coefficient[a]
Withings Pulse O_2 (wrist)	1814.8 (230.3)[b]	0.88	1796.6 (246.5)[b]	0.82
Jawbone (UP24) (wrist)	1815.8 (206.8)[b]	0.89	1724.2 (229.7)[b]	0.81
Garmin Vivofit (wrist)	1844.1 (268.3)	0.90	1811.6 (274.8)[b]	0.85
ActiGraph GT3X (waist)[c]	1919.8 (343.0)	0.88	1789.5 (334.2)[b]	0.80
Suzuken Lifecorder EX (waist)	2051.8 (277.7)	0.93	2034.4 (298.3)	0.83
Panasonic Actimarker (waist)	2081.5 (329.9)	0.92	2069.8 (320.3)	0.85
Epson Pulsense (wrist)	2128.9 (206.2)	0.71	2097.4 (292.9)	0.82
Tanita AM-160 (pocket)	2138.0 (363.3)	0.92	2094.4 (402.3)	0.85
Fitbit Flex (wrist)	2219.3 (327.5)	0.90	2142.5 (354.4)	0.84
Misfit Shine (wrist)	2221.5 (312.4)	0.84	2084.1 (330.8)	0.85
Omron Active Style Pro (waist)	2268.3 (367.2)	0.92	2245.2 (359.5)	0.88
Omron CaloriScan (pocket)	2297.5 (345.5)	0.93	2221.3 (384.5)	0.88

Difference in TEE Between Each Device and Metabolic Chamber (kcal/day), Mean (SD)



Difference in TEE Between Each Device and DLW (kcal/day), Mean (SD)



Spearman rank correlation coefficients were obtained by interparticipant analysis. DLW indicates doubly labelled water; TEE, total energy expenditure.

[a] Significant correlation for Spearman test between standard TEE and TEE estimated by each device.

[b] Significant difference from TEE obtained by the metabolic chamber or DLW method.

[c] TEE was calculated by adding resting metabolic ratio to physical activity energy expenditure provided by ActiGraph.

Figure 2. All 12 Wearable Devices on the Body

Photo of all 12 wearable devices: Fitbit Flex, JAWBONE UP24, Misfit Shine, EPSON PULSENCE PS-100, Garmin Vivofit (wrist), TANITA AM-160, OMRON CaloriScan HJA-403C (hand-held), and Withings Pulse O2, OMRON Active style Pro HJA-350IT, Panasonic Actimarker EW4800, SUZUKEN Lifecorder EX, and ActiGraph GT3X (waist).

fast. After setting and applying all devices, participants entered the metabolic chamber from 9:00 AM to 9:00 AM the following day. They completed 24-hour indirect calorimetry under a standardized protocol simulating normal daily life, which included 3 meals, desk work, watching TV, housework, treadmill walking, and sleeping.

For the DLW experiment, DLW dosing was performed in the laboratory after collection of baseline urine samples. Each participant collected urine in airtight containers on 8 days spread over a 15-day free-living period. Concurrently, the participants wore all 12 devices while awake except when bathing, special activities in which wearing the devices would be difficult, or when charging the battery. The 5 wearable devices worn on the wrist were worn while sleeping. After 15 days, urine samples and all wearable devices were recovered to analyze mean daily total energy expenditure during 15 free-living days.

Results | Total mean (SD) energy expenditure measured by the metabolic chamber (2093 [304] kcal/d) was significantly lower than that measured by the DLW method (2314 [313] kcal/d; $P < .05$). For both gold standard measures, Spearman rank correlation coefficients for most devices were greater than 0.8. Measurements from the 12 devices for a standardized day ranged from 278 kcal/d lower to 204 kcal/d higher than the metabolic chamber. Compared with the DLW measure for free-living days, estimates from the 12 devices ranged from 590 kcal/d lower to 69 kcal/d lower (**Figure 2**).

Discussion | The wearable devices that we tested were able to rank daily total energy expenditure between individuals, but absolute values differed widely among devices and varied significantly from the gold standard measures. Furthermore, all wearable devices underestimated total energy expenditure under free-living conditions. The large variance may be associated with epoch lengths and posture detection (sitting or standing), and underestimation might be due to periods of not wearing the devices during bathing and battery charge.[1,5] Our study was limited by the small sample size and including only nonobese, healthy participants. Although further studies are required, the findings presented herein suggest that most wearable devices do not produce a valid measure of total energy expenditure.

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