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Determination of Hand Surface Area by Sex and Body Shape using Alginate

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Abstract Hand surface area (HSA) has been utilized for burned skin area estimation in burn therapy, heat exchange in thermal physiology, exposure assessment in occupational toxicology, and the development of manual equipment/protective gloves in ergonomics. The purpose of this study was to determine the hand surface area to the total body surface area (BSA) and derive a formula for estimating HSA. Thirty-four Korean males (20–60 years old; 158.5–187.5 cm in height; 48.5–103.1 kg in body weight) and thirty-one Korean females (20–63 years old; 140.6–173.1 cm; 36.8–106.1 kg) participated as subjects. The HSA and BSA of 65 subjects were directly measured using alginate. The measurements showed 1) the surface area of the hand had a mean of 448 (371–540) cm^2 for males, and 392 (297–482) cm^2 for females. 2) The hand as a percentage of the total body surface area for males and females was 2.5% and 2.4% respectively, showing no significant difference. 3) The hand as a percentage of BSA by body shape was 2.5% for the lean group and 2.3% for overweight people (p=0.001). 4) When estimating the surface area of a hand, formulae based on hand length or hand circumference were more valid than formulae based on height and body weight. We obtained the following formula for estimating HSA: *Estimated HSA(cm^2)=1.219 Hand length(cm)×Hand circumference(cm). J Physiol Anthropol 26(4): 475–483, 2007* http://www.jstage.jst.go.jp/browse/jpa2
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Keywords: hand surface area (HSA), body surface area (BSA), hand length, hand circumference, estimation

Introduction

Hand surface area (HSA) has been utilized for burned skin area estimation in burn therapy, heat exchange in thermal physiology, exposure assessment of harmful chemicals in occupational toxicology, and the development of manual equipment and protective gloves in ergonomics.

In burn therapy, the accurate estimation of the percentage of body surface area burned is an important factor in providing optimal care for the burn patient, not only in determining the severity and prognosis of the burn, but also in calculating fluid resuscitation and nutritional requirements (Nichter et al., 1985). Traditionally, when assessing the size of a burn, the patient's hand has been used as an estimate of 1% of the total body surface area (BSA) (Rossiter et al., 1996). Advanced Trauma Life Support (ATLS) in the US suggests that the area of the palm is equal to 1% BSA (ACSCT, 1993; Berry et al., 2001). By a common understanding, the palm of the hand does not include the fingers (Jose et al., 2004). According to standard UK teaching, however, the area of the palm including the fingers is equivalent to 1% BSA (Kirby and Blackburn, 1981). Where is the boundary of the palm? Of course, it is not easy to define the exact boundary of the palm on the hand. However, this confusion may often cause the area of a skin burn to be miscalculated.

In thermal physiology, the periphery has meaningful significance in terms of heat exchange. Body heat is exchanged to a considerable degree through the periphery, because the trunk is usually covered with clothing. The hands are almost always exposed to the air. In addition, since hands and fingers are structurally thinner and have greater surface area per unit weight than any other body part, these regions have an important role in thermoregulation. In particular, in terms of flow rate per unit volume of tissue, finger blood flow is approximately 4-5 times as sensitive as forearm blood flow to changes in Tes and $\bar{T}sk$ (Wenger et al., 1975). The change of finger temperature may be an indicator reflecting the heat flow of the internal body (Koscheyev et al., 2005). If we know the hand, palm, and fingers surface area and the percentage to body surface area more precisely, we can estimate heat dissipated from the hands and predict heat flow more accurately. This may contribute to the thermal protection of workers exposed to extreme cold or heat environments in the form of protective work gloves.

In occupational toxicology, the hand is the main body part exposed to harmful chemicals. Some chemicals penetrate the skin through hair follicles, sweat glands, and sebaceous glands. In hot weather in particular, the quantity of chemicals that penetrate the body through the skin may increase because sweating causes tiny pores in the skin to open up. The amount of chemicals penetrating human skin is often expressed per surface area (cm^2).

In addition, HSA is important when BSA is estimated using a whole-body three-dimensional (3D) scanner. Hands are generally very poorly scanned during 3D whole-body scanning. Moreover, most could not be restored without an inordinate amount of effort, and in some cases not at all (Tikuisis et al., 2001). If an accurate equation for estimating the HSA is derived, the applicability of 3D scanning in estimating BSA will increase.

Despite the important roles described above, reports concerning hand and palm surface area measured by direct methods are few. Most previous studies used indirect methods such as tracing on paper, 2D scanning, or triangulation. Moreover, when calculating the percentage of HSA to BSA, the BSA was often estimated based on previous formulas, not directly measured. The best way to get the most accurate HSA is to measure HSA directly. The purpose of this study was 1) to determine the HSA by sex and body shape, 2) to determine the percentage of the HSA to BSA based on the direct measurements, and 3) to derive equations for estimating HSA.

Methods

Sampling subjects

The present study did a stratified random sampling in the range of Korean adults' height and body weight, on the basis of a national anthropometric survey of Korea (Size Korea, 2004). Size Korea (2004) reported that the mean height and body weight of Korean adults (20–59 yrs) was 170.5 cm and 70.5 kg for males, and 157.6 cm and 56.4 kg for females. Based on this report, we divided adult populations by height (4 cm intervals) and body weight (5 kg intervals) into cells. For each cell, we set the number of subjects on the basis of the percentage of the real population by the height and body weight of Koreans. Through this process, a total of 65 Korean adults (34 males, 31 females) participated as subjects. The age, height, and body weight of the 34 males were 30 (20–60) years, 172.9 (158.5–187.5) cm and 68.6 (48.5–103.1) kg, and 35 (20–63) years, 159.0 (140.6–173.1) cm, 59.3 (36.8–106.1) kg for 31 females (Fig. 1). Prior to participation, informed written consent was obtained from all subjects. The present study was approved by the ethics committee of the College of Human Ecology in Seoul National University.

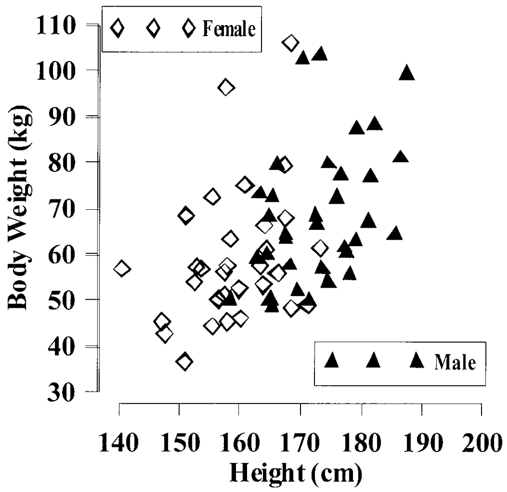

Fig. 1 Scatter plot between height and body weight of the 65 subjects participated in the present study.

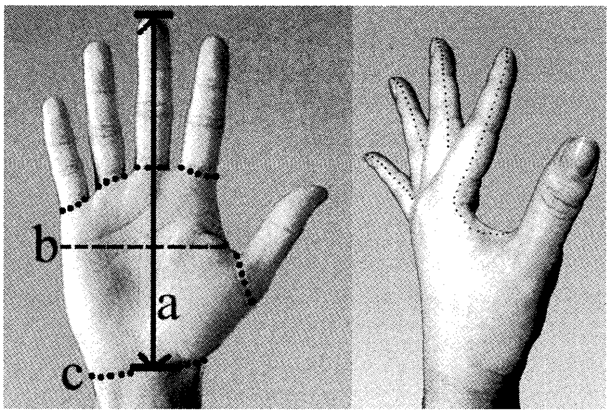

Fig. 2 Anthropometric lines on the hand. On the left picture, dotted lines mean the circumference, a=Hand length (from the wrist circumference to the tip of the middle finger), b=Hand circumference (Metacarpal-Phalangeal Joint Circumference), c=Wrist circumference; In the right-hand picture, dotted lines show the middle lines to divide the skin surface into the top and bottom of the hand and fingers.

Anthropometric items

For independent variables in constructing formulae for estimating HSA, hand length, hand circumference, wrist circumference, height, and body weight were measured (Fig. 2). The thickness of subcutaneous fat was measured for calculating body fat (%), using both a caliper and a supersonic instrument (SEIKOSHA SM-206, Japan). The regions of the body measured were as follows: the chest, the abdomen, and the front thigh for males, and the back of the upper arm (triceps), the left iliocristale point and the front of the thigh for females. Subjects were divided into five groups (lean, slightly lean, normal, slightly overweight, and overweight), based on the following five standards:

① **Body mass index (BMI)** = Weight(kg)/Height(m)^2
Lean BMI<19; Slightly lean 19≤BMI<21; Normal 21≤BMI<26; Slightly overweight 26≤BMI<30; Over-

weight 30≤BMI

② **Body fat (%BF)**=(4.95/Body density−4.50)×100
For males, Lean BF<10%; Normal 10≤BF<20.9; Slightly overweight 21≤BF<26; Overweight BF≥26
For females, Lean BF<15%; Normal 15≤BF<26; Slightly overweight 26≤BF<31; Overweight BF≥31

③ **Broca Index (BI)**=(Present weight(kg)/Normal weight)×100
For males, Normal weight=(Height(cm)−100)×0.9
For females, Normal weight=(Height(cm)−100)×0.85
Too lean BI<80; Lean 80≤BI<90; Normal 90≤BI<110; Slightly overweight 110≤BI<120; Overweight 120≤BI

④ **Modified Broca Index (MBI)**=[{(Present weight(kg)−Normal weight)/Normal weight}×100]+100
For males, Normal weight=0.57×Height(cm)−37
For females, Normal weight=0.56×Height(cm)−38
Lean MBI<90; Normal 90≤MBI<110; Slightly overweight 110≤MBI<120; Overweight 120≤MBI

⑤ **A subjective evaluation** using whole-body photographs

When evaluating the body shape according to these five standards, there were several confusing cases. For example, standard A evaluated one subject as normal, while standard B evaluated that person as slightly overweight. These confusing cases arose in the slightly lean or slightly overweight group, and their body shapes were synthetically evaluated based on five standards.

Measurement of hand surface area

The HSA of 65 subjects was directly measured using alginate according to the following steps: First, lines were marked on both hands according to the demarcated lines shown in Fig. 2. After marking, the HSA was directly measured by an alginate method. Alginate (Jeltrate ® Regular set. DENTSPLY LTD, England) is a fine powder mainly used in forming artificial teeth. The material is hardened by contact with water, but the surface of alginate remains soft, like a rubber glove. After preparing alginate powder, a rubber ball, and a knife (only for the alginate), the alginate powder was put into the rubber ball and water was poured into the ball. After stirring them well, the doughy alginate material was evenly coated on the skin of the hand, about 3 mm thick. One or two minutes later, the material hardened somewhat. Then the alginate was separated from the surface of the skin. Since the demarcated lines were copied inside the alginate pieces, the piece was cut into sub-pieces along the copied lines and the line's contours were copied onto paper. The area of a contour copied on the paper was then scanned by a 2D scanner. The scanned image was transformed into an electronic file (*.bmp), and then an image program (*Image Pro*) calculated the area of the bmp file. The validity and reliability of the alginate method above was reported (Lee and Choi, 2006). The advantage of the alginate method is that it is easier and faster than traditional direct methods. In addition, the small thin parts, like the fingers, were easy to measure.

We measured the surface area of both right and left hands. The surface area of a hand means the average of both hands. The BSA of the 65 subjects was also measured using the alginate method (Lee, 2005). When calculating the percentage of HSA to BSA, the BSA obtained from Lee's study (2005) was used.

Collecting datasets relating to HSA from previous studies

After searching previous studies relating to HSA, a total of 224 datasets (HSA measured-Height-Body weight; 67 adult males, 157 adult females) were collected from Fujimoto et al. (1957), Im (1988), Kurazumi et al. (1994), Kurazumi et al. (2003), Murata (1959), Nakamura (1959), Ogawa (1956), Niya (1931), and Yamada (1958). We tried to get datasets including individual hand length or hand circumference, but few data were available for analysis. Therefore only 224 datasets were applied to test the validity of the formulas obtained from the present study and previous studies.

Data analysis

To analyze the difference of HSA by sex and by body shape, T-test and ANOVA were conducted. Duncan's post hoc test was conducted for items showing significant differences in ANOVA. To analyze the correlation between HSA and other anthropometric items, Pearson's correlation coefficients were calculated using SPSS *v*.12.0. Formulae for estimating HSA were constructed through simple and multiple regression models. The significance difference was set at $p<0.05$.

Results

The hand surface area (HSA)

The whole surface area of the hand was 448 (371–540) cm^2 for males, and 392 (297–482) cm^2 for females (Table 1). The surface area of the palm, including the bottoms of fingers, was 217 (183–259) cm^2 for males, and 189 (141–235) cm^2 for females.

The BSA of the 65 subjects that participated in the present study was also measured using the alginate method (Table 1). The correlation coefficient of HSA and BSA was 0.790 ($p<0.01$, Fig. 3). The percentage of the HSA to the BSA was 2.46 (1.97–2.91)% and 2.39 (1.96–2.69)% of the BSA for males and females, respectively (Table 2). The palm surface area, including the bottoms of fingers, was 1.19 (0.97–1.42)% BSA for males, and 1.15 (0.94–1.35)% BSA for females (Table 2). The percentage of HSA to BSA was larger in males than in females, but the difference was not significant. HSA among the overweight (n=14), the normal (n=18), and the lean (n=10) were compared. The slightly lean and slightly overweight groups were excluded in this analysis. The percentage of HSA to BSA was significantly smaller in the overweight (2.3%) than in the normal (2.5%) or the lean (2.5%) ($p=0.001$, Table 2).

Table 1 Hand and palm surface areas measured in the present study (cm^2)

Male No.	Body shape[a)]	The hand	The palm in-F[b)]	The palm ex-F[c)]	BSA[d)]	Female No.	Body shape[a)]	The hand	The palm in-F[b)]	The palm ex-F[c)]	BSA[d)]
1	SL	415	200	97	15,416	1	O	355	170	78	15,411
2	N	428	211	108	16,875	2	N	333	159	77	14,034
3	O	447	216	97	17,844	3	N	363	172	84	13,642
4	N	494	236	116	16,986	4	L	297	141	75	12,825
5	SO	432	211	106	17,630	5	O	379	190	92	17,337
6	SL	409	208	97	15,800	6	SO	356	168	81	15,540
7	L	443	222	116	15,628	7	SO	435	218	96	16,173
8	O	448	219	109	18,261	8	SO	350	164	77	15,978
9	O	371	189	97	18,770	9	O	451	221	102	18,455
10	N	389	183	98	17,153	10	L	364	168	85	14,598
11	N	434	221	110	17,733	11	N	379	180	82	15,334
12	N	430	200	104	16,784	12	N	382	182	94	15,294
13	L	390	184	99	16,016	13	N	379	186	95	15,867
14	O	436	214	114	22,106	14	O	406	195	95	20,683
15	L	437	211	104	15,885	15	SO	373	182	95	16,233
16	N	430	200	109	17,918	16	SL	360	178	84	14,980
17	N	448	212	113	18,307	17	SO	433	225	101	16,951
18	O	515	241	121	22,753	18	N	398	196	95	15,922
19	SL	458	227	114	17,969	19	L	359	175	87	14,603
20	SL	386	192	97	16,538	20	O	457	222	103	18,468
21	SO	497	239	124	20,324	21	N	381	182	89	16,416
22	N	429	199	103	18,733	22	SL	377	180	89	15,916
23	SO	476	226	115	19,820	23	SO	429	205	106	17,414
24	SL	410	197	104	17,386	24	SO	389	191	96	16,194
25	SL	442	219	111	17,879	25	SL	461	216	107	17,179
26	L	443	212	108	17,617	26	O	401	189	96	19,639
27	SL	443	216	107	18,018	27	N	426	202	99	17,798
28	O	526	251	126	20,661	28	O	482	235	121	22,025
29	SL	495	234	113	19,082	29	L	403	195	97	15,811
30	N	444	223	111	19,127	30	L	374	185	92	15,777
31	SO	477	238	121	20,394	31	SL	410	198	100	17,504
32	L	469	230	119	18,610						
33	N	516	241	124	20,813						
34	O	540	259	123	22,675						
Mean		448	217	110	18,339	Mean		392	189	93	16,452
SD		41	19	9.0	1,938	SD		41	21	10	1,960

The surface area of the hand and the palm were the mean surface area of both the right and the left; a) L (lean); SL(slightly lean); N(normal); SO(slightly overweight); O(overweight): b) including the bottoms of fingers. We divided the finger surface area into the bottom and the top of the finger based on a middle line between the top and bottom of the finger on a side view. That is, the palm includes the under-half of the sides and the back includes the upper-half of the sides of the hand (Fig. 2); c) Excluding the bottoms of fingers; d) Measured by the alginate method (Lee, 2005).

Formulae for estimating the HSA

Equations for estimating HSA using anthropometric data were derived. The HSA showed a much stronger relationship with items related to hands (e.g., hand length, hand circumference, or wrist circumference) than height or body weight (Fig. 4). Among all variables, an item showing the strongest correlation with HSA was hand length. We derived [Eq. 1] based on hand length (Table 3). Hand length can account for over 99% of the total variance of the HSA (Table 3, Fig. 5). However, the coefficients of correlation were greater in the transformed explanatory variables (e.g., Hand circumference×Hand length) than in a single variance (Fig. 4). Among the transformed variables, a model using the multiple of hand circumference and hand length was appropriate for estimating HSA (Eq. 2). The error of [Eq. 2] was 0.8%. In some cases, the height and body weight may be the only measurements known to researchers. For these cases, we derived [Eq. 3] based on height and body weight. The error of [Eq. 3] was −0.2% (Table 3, Fig. 5).

Application of the [Eq. 3]–[Eq. 5] to the 224 datasets collected from previous studies

As mentioned above, we could not find enough datasets including HSA, hand circumference, and hand length. Therefore, [Eq. 1] and [Eq. 2] could not be tested on the 224 datasets. In applying the [Eq. 3] to the datasets, the correlation coefficient between the HSA measured and the HSA estimated was 0.723, with an error of 2.3% (Fig. 6). When 67 male

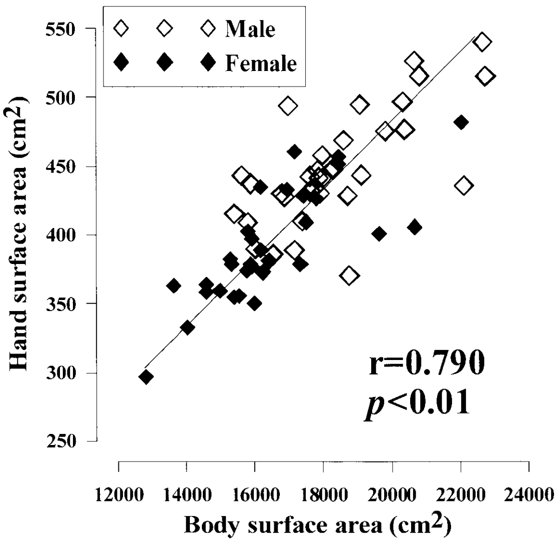

Fig. 3 Relationship of hand surface area (HSA) and body surface area (BSA) (N=65).

datasets were applied to [Eq. 4] and 157 female datasets were applied to [Eq. 5] from US EPA (1985), among the 224 datasets, the correlation coefficient between the HSA measured and the HSA estimated was 0.484 and 0.585 for males and females, respectively (Table 5, Fig. 6).

Discussion

The surface area of the hand had a mean of 448 cm^2 for males, and 392 cm^2 for females. The percentage of HSA was 2.5% and 2.4% for males and females. Since the present study included almost an entire range of Korean physiques, it can be considered that the results represent Korean adults. The whole body and hands of Asians are generally smaller than those of Western people. The HSA of this study, itself, should not be applied to Caucasians or Africans. However, it is reasonable to postulate that the ratio of the hand to the BSA would not be different between Asians and Western people, because HSA was proportional to BSA (Fig. 3).

Regarding the percentage of HSA to BSA, the "Rule of Nines" was described by Pulaski and Tennison in the 1940s (Kanysi et al., 1968). It has long been noted that the surface of

Table 2 The percentage of hand surface area to body surface area in the present study (%)

Part	Total (N=65)	Male (N=34)	Female (N=31)	Lean group (N=10)	Normal group (N=18)	Overweight group (N=14)
The hand	2.42	2.46 (1.97–2.91)	2.39 (1.96–2.69)	2.52[a] (2.31–2.84)	2.46[a] (2.27–2.91)	2.26[b] (1.96–2.55)
		p=0.704[a)]			p=0.001[b)]	
The palm including fingers	1.17	1.19 (0.97–1.42)	1.15 (0.94–1.35)	1.22[a] (1.10–1.42)	1.18[a] (1.06–0.39)	1.10[b] (0.94–1.21)
		p=0.503			p=0.005	
The palm excepting fingers	0.58	0.60 (0.52–0.74)	0.56 (0.46–0.62)	0.62[a] (0.58–0.74)	0.59[a] (0.53–0.69)	0.54[b] (0.46–0.61)
		p=0.256			p<0.001	
The thumb	0.26	0.26 (0.18–0.31)	0.26 (0.19–0.30)	0.27[a] (0.25–0.30)	0.26[a] (0.23–0.30)	0.23[b] (0.18–0.27)
		p=0.691			p<0.001	
The index finger	0.26	0.26 (0.19–0.33)	0.27 (0.22–0.33)	0.28[a] (0.25–0.33)	0.26[a] (0.23–0.31)	0.25[b] (0.19–0.29)
		p=0.062			p=0.029	
The middle finger	0.29	0.29 (0.21–0.36)	0.29 (0.23–0.35)	0.30[a] (0.28–0.34)	0.30[ab] (0.26–0.36)	0.27[b] (0.21–0.32)
		p=0.917			p=0.009	
The ring finger	0.26	0.26 (0.20–0.32)	0.26 (0.22–0.31)	0.27 (0.24–0.30)	0.27 (0.23–0.32)	0.25 (0.20–0.29)
		p=0.987			p=0.076	
The little finger	0.19	0.19 (0.13–0.24)	0.18 (0.15–0.22)	0.19 (0.17–0.21)	0.19 (0.16–0.24)	0.18 (0.13–0.21)
		p=0.005			p=0.113	

[a)] Significant difference by sex; [b)] Significant difference by body shape; a,b,ab Significant differences among three groups.

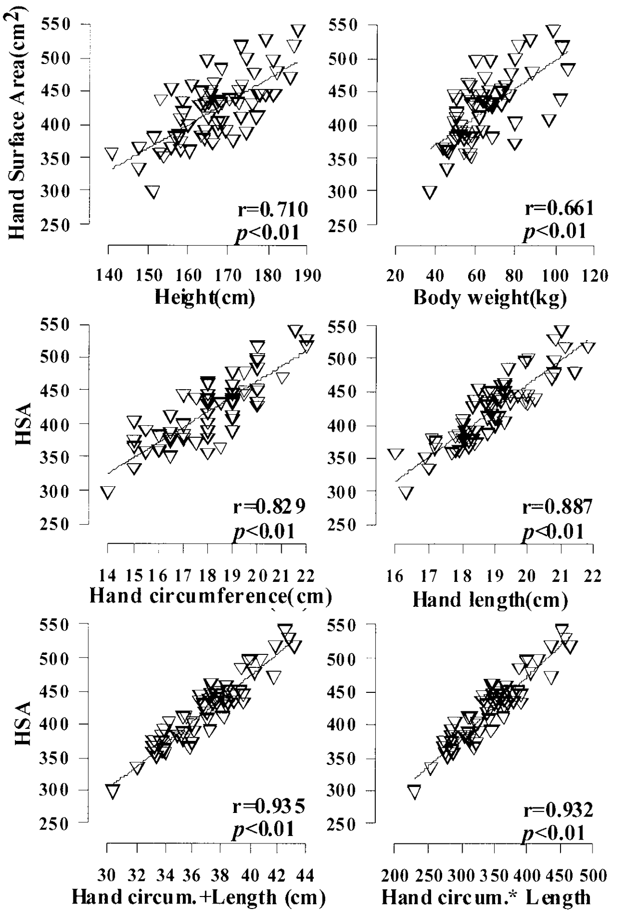

Fig. 4 Scatter plots and correlation coefficients between hand surface area and anthropometric items.

the hand is approximately 1% of the BSA and is commonly used to estimate the size of irregular burns (Sheridan et al., 1995). In burn therapy, students were traditionally taught that the area of a palm excluding fingers is about 1% of the BSA (Jose et al., 2004). However, Nagel and Schunk (1997) reported that the area of the palm, including the fingers, is 1%. According to the present study, the area of the palm, including the fingers, is 1.2%. Therefore, our results are closer to the Nagel and Schunk (1997) report. However, Rossiter et al. (1996) showed that the area of the palm, including fingers, is 0.8% in males and 0.7% in females. These differences may be the result of the fact that 1) the HSA and BSA were not measured using direct methods in some previous studies, and 2) the boundary of the palm is unclear.

Several previous studies reported that the surface area of the palm, including digits, was always less than 1% (Table 4). Those studies did not measure the HSA directly. Instead, they traced the contour of the palm on paper (or used a 2D scanner) with the digits held together. In this process, the sides of each finger were not included in the palm. If so, which area should be the sides of the fingers be included in: the palm or the back of hand? It is natural that the palm includes the under-half of the sides and the back includes the upper-half of the sides of the hand.

Since the percentage of the both hands surface area had a range of 4.6–5.7% of BSA (Tikuisis et al., 2001; Kurazumi et al., 1994; US EPA, 1985), the surface area of the hand is about 2.3–2.8%. This means that the surface area of the palm, including digits, would be more than 1% of BSA. Therefore, in traditional teaching that considers the hand about 1% of BSA, 'the hand' should be considered as the palm including the

Table 3 Regression models derived from the present study for estimating HSA

Formula	r^2	SEE	Error[a] (%)	Absolute error[b] (%)
Eq.1 HSA=22.348 Hand length	0.996	28.5	0.99	5.54
Eq.2 HSA=1.219Hand length×Hand circumference	0.997	23.3	0.76	4.62
Eq.3 HSA=1.765Height$^{0.725}$×Weight$^{0.425}$	0.994	34.3	−0.20	6.08

All regression models above were excluded a constant in equations. Hence the r^2 of Table 3 is not the square value of 'Pearson's r' of Fig. 4; Formula's Unit: Area expressed in 'cm^2', height, length and circumference expressed in 'cm', Body weight expressed in 'kg'; [a] Error=(HSA estimated-HSA measured)100 / HSA measured; [b] Absolute error=| HSA estimated-HSA measured | 100 / HSA measured.

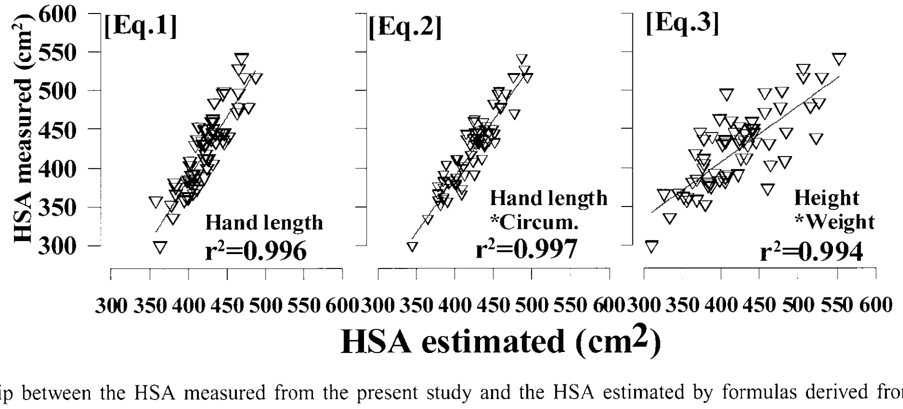

Fig. 5 Relationship between the HSA measured from the present study and the HSA estimated by formulas derived from the present study ([Eq. 1] HSA=22.348 Hand length; [Eq. 2] HSA=1.219 Hand length×Hand circumference; [Eq. 3] HSA=1.765 Height$^{0.725}$×Weight$^{0.425}$).

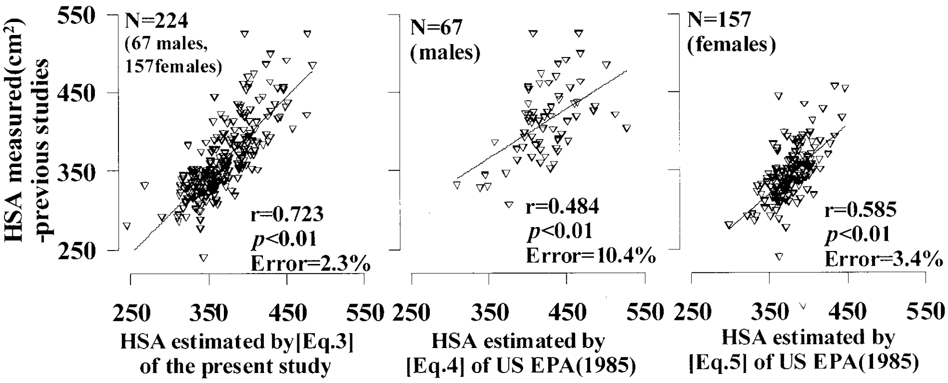

Fig. 6 Relationship between the HSA measured from previous studies and the HSA estimated by formulas derived by the present study and the US EPA (1985) ([Eq.3] HSA=1.765 $Height^{0.725} \times Weight^{0.425}$; [Eq.4] HSA=128.5 $Height^{-0.218} \times Weight^{0.573}$; [Eq.5] HSA=115.5 $Height^{0.0274} \times Weight^{0.412}$).

Table 4 The percentage of hand surface area to body surface area in previous studies (Unit: %)

Source	Method	Subjects	The palm (including digits)	The palm (excluding digits)
Amirsheybani et al. (2001)	Tracing method	Male (N=81) Female(N=131)	0.85 (0.1) 0.79 (0.1)	
Berry et al. (2001)	Digital scan	Healthy Overweight Obese	0.83 (0.71–0.88)[a] 0.71 (0.62–0.81)[b] 0.70 (0.58–0.80)[b]	
Perry et al. (1996)	—	20 adults 10 children	0.77 (0.74–0.80) 0.82 (0.78–0.87)	
Rossiter et al. (1996)	Tracing method	Male (N=36) Female (N=34)	0.81 (0.6–0.9) 0.67 (0.5–0.8)	0.52 (0.4–0.6) 0.43 (0.3–0.5)
Sheridan et al. (1995)	Tracing method	Male and female (N=8)	0.81 (0.1)	0.49 (0.1)

Table 5 Previous formulas for estimating the surface area of the hand and the error in applying the formulas to the 65 subjects of the present study

Source	Formula	Pearson's correlation (r)	Error[a)] (%)	Absolute error[b)] (%)
Mignano and Konz (1994)	HSA=26.5Length−88.47 (r^2=0.70)	0.887**	−1.5	5.0
US EPA (1985)	[Eq. 4] Male: HSA=(257/2)×$W^{0.573}$×$H^{(-0.218)}$ (p=0.001, r^2=0.575) [Eq. 5] Female: HSA=(131/2)×$W^{0.412}$×$H^{0.0274}$ (p=0.1, r^2=0.447)	0.731**	3.9	7.5
DuBois and DuBois (1916)	HSA=2.22×Hand Length[c)]×Hand circumference	0.932**	−9.6	9.7
Banerjee and Sen (1955)	HSA=2.432×Hand Length[c)]×Hand circumference	0.932**	−1.0	4.7

The unit: Area expressed in 'cm^2', Height, Length and Girth expressed in 'cm', Body weight expressed in 'kg'; [a)]Error=(HSA estimated-HSA measured)100 / HSA measured; [b)]Absolute error=|HSA estimated-HSA measured|100 / HSA measured; [c)]Hand length in DuBois and DuBois (1916)=Lower posterior border of the radius to the tip of the second finger.

bottoms of the fingers and half of the sides between the fingers.

We have just solved an important problem, but certain other questions may arise. Is there any difference between the right and left hand, or males and females, or the lean and the overweight? First, there is no difference between the right and left hand in the present study. This confirms previous reports. Amirsheybani et al. (2001) and Kurazumi et al. (1994) also reported that there was no significant difference between hands (right & left hands, dominant & non-dominant hands).

Regarding difference by sex, a significant sex difference was noted when measuring the area of the palm, including digits, which was 0.8% in males and 0.7% in females ($p<0.001$) in a previous study (Rossiter et al., 1996). Amirsheybani et al. (2001) also found a difference between males and females when the average percentages of body surface area represented by the palm surface area of hand were compared ($p<0.001$). For the present study, the percentage of HSA to BSA was greater in males (2.5%) than in females (2.4%), but the difference was not significant.

Regarding difference by body shape, it seems clear that the more overweight an individual is, the lower the percentage of HSA to BSA. Berry et al. (2001) and Kurazumi et al. (1994) have reported a similar tendency to the present study (Table 4). It is important to remember that there is a significant difference by body shape, not by sex.

It is useful to use a formula for estimating HSA. The formula may be a help when calculating the amount of harmful chemicals that penetrated the skin or when estimating burn size. Some formulae have been proposed and can be divided into two categories (Table 5). One category includes formulae based on height and body weight. The other includes formulae based on anthropometric items directly related to the hand. According to the present study, the formula of the second category was more valid to estimate HSA. When applying the height and body weight of the 65 subjects that participated in the present study to five different kinds of formulae collected from previous studies, the error of formulae based on height and body weight was larger than the error of a formula based on just 'hand length' (Table 5). Therefore, when estimating the HSA, we recommend formulae based on explanatory variables directly related to 'the hand'. Formulae based on body weight and height can be selected as an alternative, just in case hand size is unknown.

Conclusion

We have clarified the relative percentage of hand surface area (HSA) to total body surface area (BSA). One of the strong points in the present study was that the anthropometric range of subjects was large enough to avoid extrapolation. The other advantage is that the hand surface area was measured directly, and the percentage of HSA to BSA was based on BSA measured directly. The percentage of HSA to BSA for males and females was 2.5% and 2.4% respectively, but showed no significant difference. The percentage of HSA to BSA by body shape was 2.5% for lean individuals and 2.3% for the overweight, and showed a significant difference.

When estimating the surface area of the hand, formulae based on the anthropometric characteristics of the hand were more valid than those based on height and body weight. Therefore, we recommend a formula based on hand length and hand circumference for estimating HSA: $HSA(cm^2)=1.219 Hand\ Length(cm)\times Hand\ circumference(cm)$ ($r^2=0.997$, SEE$=23.5\ cm^2$).

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References

American College of Surgeons Committee on Trauma (ACSCT) (1993) Advanced trauma life support manual for physicians. American College of Surgeons, Chicago

Amirsheybani HR, Crecelius GM, Timothy NH, Pfeiffer M, Saggers GC, Manders EK (2001) The natural history of the growth of the hand: I. Hand area as a percentage of body surface area. Plast Reconstr Surg 107: 726–733

Banerjee S, Sen R (1955) Determination of the surface area of the body of Indians. J Appl Physiol 7: 585–588

Berry MG, Evison D, Roberts AHN (2001) The influence of body mass index on burn surface area estimated from the area of the hand. Burns 27: 591–594

DuBois D, DuBois EF (1916) A formula to estimate the approximate surface area if height and weight be known. Arch Intern Med 17: 863–871

Fujimoto K, Watanabe M, Ogawa R, Haraoka N, Kitasumi M (1957) Study on the body surface area of Japanese (V. 5): On the surface area and estimating equation between 15 and 17 years old. Nagasaki Sohgo Kohshu Eiseigaku Zasshi 6: 118–132 [*In Japanese*]

Im S (1988) A study on the body surface area of Korean women-Centering around twenties to forties-. Ph. D. Dissertation. Hanyang University, Seoul [*In Korean*]

Jose R, Roy D, Vidyadharan R, Erdmann M (2004) Burns area estimation-an error perpetuated. Burns 30: 481–482

Kanysi GA, Crikelair GF, Cosman B (1968) The rule of nines: its history and accuracy. Plas Reconstr Surg 41: 560–563

Kawabata A (1940) New formula for calculating body surface area. Nippon Seirigaku Zasshi 5: 245–254 *[In Japanese*]

Kirby NG, Blackburn G (1981) Field study pocket book. HMSO, London

Koscheyev VS, Leon GR, Coca A (2005) Finger heat flux/temperature as an indicator of thermal imbalance with application for extravehicular activity. Acta Astronaut 57: 713–721

Kurazumi Y, Horikoshi T, Tsuchikawa T, Matsubara N (1994) The body surface area of Japanese. Jpn J Biometeorol 31: 5–29

Kurazumi Y, Tsuchikawa T, Kakutani K, Matsubara N, Horikoshi T (2003) Evaluation of the conformability of the calculation formula for the body surface area of the human body. Jpn J Biometeorol 39: 101–106

Lee JY (2005) Study on the body surface area of Korean adults. Ph.D Dissertation. Seoul National University, Seoul

Lee JY, Choi JW (2006) Validity and reliability of an alginate method to measure body surface area. J Anthropol Physiol 25: 247–255

Mignano BP, Konz S (1994) The surface area and volume of the hand. Proc Human Factors Erg Soc 38th Annual Meeting: 607–610

Murata Y (1959) Studies on the body surface area of the Japanese female, Report 3. On the measurement values of the surface area of the bodies of Japanese females. Jpn Med J 15: 273–284

Nagel TR, Schunk JE (1997) Using the hand to estimate the surface area of a burn in children. Pediatr Emerg Care 13: 254–255

Nakamura T (1959) Study on the body surface area of Japanese (V. 7): On the surface area and estimating equation for the women between 20 and 40 years old. Nagasaki Sohgo Kohshu Eiseigaku Zasshi 8: 246–259 [*In Japanese*]

Nichter LSN, Williams J, Bryant CA, Edlich RF (1985) Improving the accuracy of burn surface estimation. Plas Reconstr Surg 76: 428–432

Niya G (1931) Study on the body surface area of Japanese (V. 3). Jpn J Nation's Health 8: 440–460

Ogawa R (1956) Study on the body surface area of Japanese (V. 3): On the surface area and estimating equation between 18 and 20 years old. Nagasaki Sohgo Kohshu Eiseigaku Zasshi 5: 5–18 [*In Japanese*]

Perry RJ, Moore CA, Morgan BD, Plummer DL (1996) Determining the approximate area of a burn: an inconsistency investigated and re-evaluated. BMJ 22: 230–231

Rossiter ND, Chapman P, Haywood IA (1996) How big is a hand? Burns 22: 230–231

SIZE KOREA (2004) 2004 National anthropometric survey of Korea. Korean agency for technology and standards in Korea Ministry of Commerce, Industry and Energy [*In Korean*]

Sheridan RL, Petras L, Basha G, Salvo P, Cifrino C, Hinson M, McCabe M, Fallon J, Tompkins RG (1995) Planimetry study of the percent of body surface represented by the hand and palm: sizing irregular burns is more accurately done with the palm. J Burn Care Rehabil 16: 605–606

Tikuisis P, Meunier P, Jubenville CE (2001) Human body surface area: measurement and prediction using three dimensional body scans. Eur J Appl Physiol 85: 264–271

US EPA (1985) Development of statistical distributions or ranges of standard factors used in exposure assessments. Office of Research and development, U.S. EPA No. 600/8-85-010, Washington DC

Wenger CB, Roberts MF, Nadel ER, Stolwijk JA (1975) Thermoregulatory control of finger blood flow. J Appl Physiol 38: 1078–1082

Yamada (1958) Study on the body surface area of Japanese (V. 6): On the surface area and estimating equation for men between 20 and 40 years old. Nagasaki Sohgo Kohshu Eiseigaku Zasshi 7: 41–54 [*In Japanese*]

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