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Original article

Sex determination through anthropometry of hand and foot in Thais

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Background: Sex determination is one of the most important aspects in forensic anthropology for the identification of unknown remains, especially dismemberment or mass disaster cases in which mutilated or fragmented remains are usually discovered; it is difficult to establish the identity of a long deceased body. The acquired sex data are used by investigators for narrowing down ante-mortem data which can be derived from the relatives of the deceased before comparing to the postmortem data.
Objective: This study aimed to estimate sex using hand and foot measurements by measuring the external parts of the bodies in a Thai population.
Methods: Subjects were 100 Thai cadavers (50 males and 50 females), 20 - 60 years old, randomly selected. The 8 parameters from the hand and 3 parameters from the foot were measured using Mitutoyo digital calipers in SI units up to the accuracy of 3 decimals after breaking rigor mortis. Collected data were statistically analyzed using SPSS version 22. Cut-off values and accuracies were calculated for sex determinations.
Results: Highly significant sex differences were found in hand parameters and foot parameters with males larger than females (P <0.001), except for the heel breadth; the hand and foot indexes were not significantly different between sexes. The cut-off values for sex determinations were derived from all of the measurements; values that are more than the cut-off point suggest male and less than the cut-off value suggest female sex. Hand length and 3rd finger in both sides showed the highest accuracies for sex determination and accuracies to differentiate between sexs were above 90%. In the foot, the highest accuracy to differentiate sex was the foot length, followed by the foot breadth with accuracy above 80%.
Conclusion: Hand and foot parameters can be successfully applied for sex determination in Thais. Therefore, sex can be determined from the parameters of hands and feet with reasonable accuracy using the cut-off values.

Keywords: Sex determination, anthropometry, dismemberment, hand, foot, Thai.

Identification of an unknown remain is one of the main objectives in a medico-legal death investigation. [1] Criminal investigation of unnatural death always starts from identifying the deceased as stated in the Criminal Procedure Code's approach. For investigators, they have to start with an interview and search for information related to the death from the witness or relatives of the deceased.

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Currently, there are many scientific methods for the identification of unknown remains such as fingerprint identification, DNA analysis and dental records. [2, 3] However, in a case of severely damaged remains, especially dismemberment or mass disaster cases, mutilated or fragmented the remains often cause difficulties in establishing an identity of the deceased. [4]

Forensic anthropology can assist criminal investigators to establish biological profiles which consists of stature, sex, age and ancestry from examining skeletal remains and parts of the body, the acquired biological profiles are then applied by investigators for narrowing down ante-mortem data which can be derived from a relative of the deceased before comparing to the postmortem data.

Determination of sex is considered one of the main parameter of personal identification as it rules out the possible number of matching identities by 50 %.[5, 6] Therefore sex determination should generally be generally the first step in establishing the identity of an individual.[7, 8]

In general, sex determination in forensic anthropology relies on two most commonly methods which are morphological assessment [6] that refers to the visual assessment of the shape of specific skeletal elements and; anthropometry [6] which refers to the measuring and quantifying of anatomical parts of the skeleton.Bones that are used in morphological assessments are the skull and pelvis. [9, 10] As for the anthropometry method, many bones can be used, i.e., the skull, mastoid, mandible, sternum, vertebral column, sacrum, scapula, humerus, ulna, femur, tibia, pelvic and calcaneus. [2, 9, 11]

Sex determination methods, as mentioned above, require removing bones from the bodies which is invasive [12] and may cause evidence destruction. Therefore, this study aims to measure the external parts for sex determination of the dismembered deceased.

Previous studies discovered that hand and foot parameters can be applied for sex determination in Indian cadavers [13] and also in living populations: Turkish populations [14, 15], Nigerian populations[16], American population [17], Mauritian populations [18, 19], Egyptian population [20], Western Australians [12], North Saudi population [21] and Indian population. [7, 22, 23] However, it has never been studied in Thai cadavers. This study collected the data by measuring hand and foot parameters and interpreted this data for sex determination in the Thai population. The purpose of this study was the determination of sex from hand and foot measurements in Thai cadavers in dismemberment cases.

Materials and methods

Subjects

In this research, subjects were measure in 100 Thai cadavers (50 males and 50 females) randomly selected from cases brought to the Department of Forensic Medicine, Faculty of Medicine, Chulalongkorn University for medico-legal autopsy, declare the interval for sample collecting. The age of subjects ranged from 20 - 60 years old. Subjects with any injury, disease, fracture or anomaly that affected the hand and foot parameters were excluded. Charred and decomposed cadavers and other conditions that were excluded from the research such as short stature, gigantic stature, or other that out of norm.

Before measurement, rigor mortis was broken and the hand joints were extended. All measurements were taken in the autopsy room using Mitutoyo digital caliper in SI unit with up to the accuracy of 3 decimals.

Measurements

The authors used the same measure landmarks as described by Vallios HV. [24] as shown in Table 1. The measurements that were taken on hand and foot are depicted (Figure 1, 2).

Table 1. Landmarks on hand and foot as described by Vallios HV. [24]

Landmark	Description
Inter-stylion	The middle point of the line connecting the point stylion radiale (the most distal point on the styloid process of the radius) and stylion ulnare (the most distal point on the styloid process of ulna)
Dactylion	The most distal point on the tip of the third finger of the hand
Metacarpal radiale	The point projecting most laterally on the head of the 2nd metacarpal when the hand is stretched
Metacarpal ulnare	The point projecting most medially from the head of the 5th metacarpal
Acropodian	The most forwarding projected point on the head of the 1st or 2nd toe whichever is larger when the subject stands erect
Pternion	The most backwardly projecting point on the heel when the subject is standing upright with equal pressure on both the feet
Metatarsal tibiale	The most medially projecting point on the head of the 1st metatarsal bone when the subject stands erect
Metataesal fibulare	The point most laterally projecting on the head of the 5th metatarsal bone when the subject stands erect

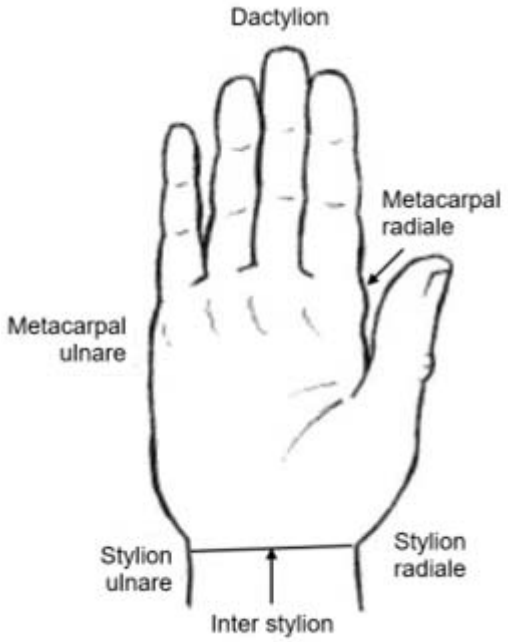

Figure 1. Landmarks for measurement of the hand [24, 26]

Figure 2. Landmarks for measurement of the foot [12, 24]

Hand measurement

Hand breadth (HB) is the distance between the most prominent point, outside of the lower epiphyses of the 2nd metacarpal (Metacarpal radiale), to the most prominent point inside, the point of the lower epiphyses of the 5th metacarpal (Metacarpal ulnare). Hand length (HL) is the distance between the interstylion and dactylion. Palm length (PL) is the distance between the mid-point of the distal transverse wrist (Inter-stylion) crease to the proximal flexion crease of the middle finger. [25] Finger length; Thumb (1D), Index (2D), Middle (3D), Ring (4D), Pinky (5D): Distance between the proximal flexion crease of the finger to the tip of the respective finger (Figure 3). [26]

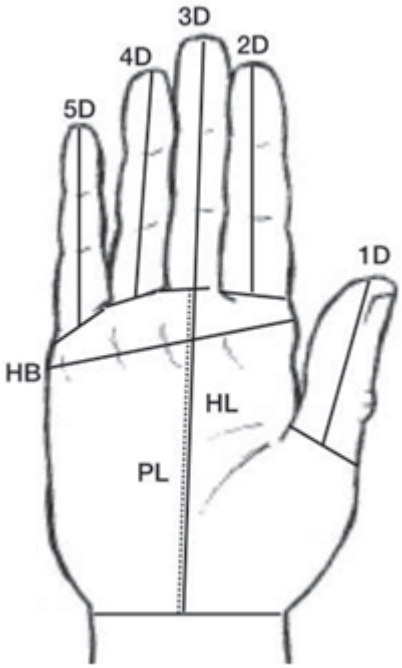

Figure 3. Measurement of the hand [24, 26]

Foot measurement

Foot breadth (FB) is the distance between the points of the anterior epiphyses (distal) of the 1st metatarsal, the most prominent of the inner side of the foot (metatarsal-tibiale), and the joint of the anterior epiphyses of the 5th metatarsal, the most prominent of the outer side (metatarsal-fibulare). Foot length (FL) is the distance from the acropodian to the pternion. Heel breadth (FHB) is the maximum distance from the most protruding point on the medial surface of the heel to the corresponding protrusion on the lateral surface of the heel (Figure 4).

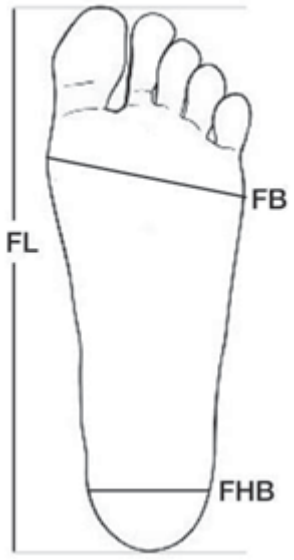

Figure 4. Measurement of the foot [12, 24]

Hand and foot indexes [27]

The hand index is calculated individually for both sexs by using the formula: hand index = (hand breadth/hand length) × 100, while the foot index is calculated individually for both sexs by using the formula: foot index = (foot breadth/foot length) × 100.

Statistical analysis

Statistical analysis was performed using SPSS version 22.0. Normal descriptive data (mean, SD, range) of all measurements were examined. *t*-tests were used to compare the difference between left and right measurements and to compare between male and female.

The sex determination point (cut-off value) was derived for all measurements including hand and foot index calculated from the mean of male and female measurement divided by 2. [20]

Cut-off value = (Mean male value + Mean female value)/2 (1)

A value more than the cut-off value suggests male and value less than the cut-off point suggests female. The accuracy of cut-off values [13] were performed as follows:

Accuracy (%) = (Correctly assigned male + Correctly assigned female)/(Total cases) × 100 (2)

Results

From 100 subjects, mean ages of the male and the female age were 38.31 ± 11.348 and 41.88 ± 11.991 years old, respectively. The descriptive statistics of hand measurements, hand indexes, foot measurement and foot indexes in males and females are shown in Table 2. It was observed that the mean values of all the measurements were higher in males than in females.

Table 2. Descriptive statistics for hand parameters (cm), hand indexes, foot parameters (cm) and foot indexes.

	Male (n = 50)			Female (n = 50)		
	Minimum	Maximum	Mean ± SD	Minimum	Maximum	Mean ± SD
Hand						
L-HB	7.250	10.878	8.599 ± 0.710	6.192	8.166	7.374 ± 0 .431
R-HB	7.590	10.875	8.685 ± 0.691	6.038	8.552	7.495 ± 0.485
L-HL	17.167	21.806	18.995 ± 1.009	14.355	18.372	16.539 ± 0.848
R-HL	17.122	21.779	19.004 ± 1.025	14.257	18.647	16.554 ± 0.899
L-PL	9.085	12.116	10.830 ± 0.694	6.892	10.760	9.573 ± 0.699
R-PL	5.721	12.100	10.747 ± 1.003	7.033	10.842	9.560 ± 0.672
L-1D	5.327	7.492	6.408 ± 0.564	4.227	6.623	5.560 ± 0.538
R-1D	5.399	7.595	6.443 ± 0.546	4.444	6.474	5.558 ± 0.568
L-2D	6.474	8.687	7.399 ± 0.502	5.915	7.216	6.524 ± 0.338
R-2D	6.066	8.633	7.344 ± 0.531	5.849	7.348	6.539 ± 0.357
L-3D	7.367	9.751	8.240 ± 0.509	6.293	7.908	7.099 ± 0.362
R-3D	7.494	9.760	8.234 ± 0.523	6.165	7.993	7.104 ± 0.338
L-4D	6.564	8.951	7.542 ± 0.578	5.165	7.280	6.508 ± 0.396
R-4D	6.757	9.285	7.582 ± 0.583	5.058	7.427	6.514 ± 0.431
L-5D	5.171	7.776	6.155 ± 0.584	3.900	6.148	5.224 ± 0.405
R-5D	5.246	7.966	6.221 ± 0.611	3.763	5.877	5.255 ± 0.413
L-HI	38.74	59.07	45.316 ± 3.608	40.98	49.71	44.610 ± 2.084
R-HI	39.96	58.15	45.743 ± 3.365	39.71	54.61	45.329 ± 2.811
Foot						
L-FB	8.415	12.119	10.003 ± 0.853	7.010	10.324	8.652 ± 0.788
R-FB	8.438	11.996	9.939 ± 0.8194	6.850	10.301	8.688 ± 0.755
L-FL	22.221	28.298	24.875 ± 1.651	18.710	23.796	21.631 ± 1.032
R-FL	22.429	28.198	24.820 ± 1.641	18.598	23.601	21.588 ± 1.084
L-FHB	5.079	25.801	6.629 ± 2.824	4.354	7.484	5.451 ± 0.612
R-FHB	5.019	25.901	6.625 ± 2.844	4.201	7.234	5.486 ± 0.656
L-FI	35.63	44.76	40.210 ± 2.065	34.41	46.38	40.004 ± 0.455
R-FI	36.45	45.17	40.268 ± 2.068	34.32	47.57	40.050 ± 0.458

The difference between left and right measurements are shown in Table 3; there is no significant bilateral difference in all measurements ($P > 0.05$) except hand breadth in males ($P < 0.05$). However, the bilateral difference in hand breadth were relatively small, on an average, only 0.086 cm.

All measured parameters in males were found to be statistically larger than in females. Table 4 shows the difference in parameters among males and females. The sex difference in all measurements was statistically confirmed by applying independent *t* - tests. Highly significant sex differences were found in hand parameters and foot parameters ($P < 0.001$), except in heel breadth, hand and foot indexes show no significant difference.

All measurements in both sexes were used to derive the cut-off values and calculate the accuracy of sexual differentiation as shown in Table 5. In hand, hand length and 3rd finger in both sides showed highest accuracy for determination of the sexes. Their accuracies to differentiate sex were above 90% (92 - 94%); followed by hand breadth, 2nd finger, 4th finger and 5th finger, which have accuracies above 80% for sexual determination. As for the feet, the highest accuracy to differentiate sex was foot length with an accuracy of 88%, followed by foot breadth (80 - 81%), heel breadth (72 - 73%) and foot index (46 - 49%).

Discussion

In this study, the 8 measurements from hands and 3 parameters from feet in 100 Thai cadavers were used to determine sexs by cut-off values with the highest accuracy of 94% from hand length and 88% from foot length.

Table 3. Statistical comparison of right and left sided.

	Parameters	Mean (cm)		*t* - value	*P* - value
		Left	Right		
Male	HB	8.599	8.685	-2.078	0.043*
	HL	18.995	19.004	-0.300	0.765
	PL	10.830	10.747	0.757	0.453
	1D	6.408	6.443	-0.733	0.467
	2D	7.399	7.344	1.424	0.161
	3D	8.240	8.234	0.246	0.806
	4D	7.542	7.583	-1.048	0.300
	5D	6.156	6.221	-1.036	0.305
	HI	45.316	45.743	-1.912	0.062
	FB	10.004	9.939	1.490	0.143
	FL	24.875	24.820	1.643	0.107
	FHB	6.629	6.625	0.141	0.889
	FI	40.210	40.268	0.0941	0.351
Female	HB	7.374	7.495	-2.879	0.006*
	HL	16.540	16.554	-0.466	0.643
	PL	9.573	9.560	0.303	0.763
	1D	5.560	5.558	0.061	0.952
	2D	6.524	6.539	-0.352	0.726
	3D	7.099	7.104	-0.169	0.867
	4D	6.508	6.514	-0.166	0.869
	5D	5.224	5.255	-0.969	0.337
	HI	44.610	45.329	-2.577	0.013
	FB	8.6512	8.687	-1.006	0.319
	FL	21.631	21.588	0.824	0.414
	FHB	5.451	5.487	-1.229	0.225
	FI	40.004	40.050	-1.329	0.190

Table 4. Statistical comparison of male and female.

	Parameters	Mean (cm)		*t* - value	*P* - value
		Male	Female		
Hand	L-HB	8.599	7.374	10.428	0.000**
	R-HB	8.685	7.495	9.969	0.000**
	L-HL	18.995	16.540	13.173	0.000**
	R-HL	19.004	16.554	12.708	0.000**
	L-PL	10.830	9.573	9.025	0.000**
	R-PL	10.747	9.560	6.954	0.000**
	L-1D	6.408	5.560	7.689	0.000**
	R-1D	6.443	5.558	7.954	0.000**
	L-2D	7.399	6.524	10.209	0.000**
	R-2D	7.344	6.539	8.889	0.000**
	L-3D	8.240	7.099	12.912	0.000**
	R-3D	8.234	7.104	12.839	0.000**
	L-4D	7.542	6.508	10.439	0.000**
Foot	R-4D	7.583	6.514	10.422	0.000**
	L-5D	6.156	5.224	9.268	0.000**
	R-5D	6.221	5.255	9.261	0.000**
	L-HI	45.316	44.610	1.198	0.234
	R-HI	45.743	45.329	0.667	0.506
	L-FB	10.004	8.652	8.236	0.000**
	R-FB	9.939	8.687	7.947	0.000**
	L-FL	24.875	21.631	11.778	0.000**
	R-FL	24.820	21.588	11.620	0.000**
	L-FHB	6.629	5.451	2.884	0.005*
	R-FHB	6.625	5.486	2.758	0.007*
	L-FI	40.211	40.004	0.382	0.703
	R-FI	40.268	40.050	0.400	0.690

*$P < 0.05$, ** $P < 0.001$

Table 5. Cut-off values (cm) and calculated accuracies to differentiate between sexes.

	Parameters	Cut-off point	Accuracy (%)
Hand	L-HB	7.986	85
	R-HB	8.090	86
	L-HL	17.767	94
	R-HL	17.779	94
	L-PL	10.201	76
	R-PL	10.154	83
	L-1D	5.984	76
	R-1D	6.001	77
	L-2D	6.961	81
	R-2D	6.941	86
	L-3D	7.669	92
	R-3D	7.669	94
	L-4D	7.025	84
Foot	R-4D	7.048	85
	L-5D	5.690	85
	R-5D	5.738	82
	L-HI	44.963	50
	R-HI	45.536	52
	L-FB	9.328	81
	R-FB	9.313	80
	L-FL	23.253	88
	R-FL	23.204	88
	L-FHB	6.040	72
	R-FHB	6.055	73
	L-FI	40.108	49
	R-FI	40.159	46

Hand and foot parameters were found to be statistically larger in males than in females for both left and right sides, similar to Varu PR, *et al.* [13] in Indian cadavers. Moreover, similar results were also found in other living populations such as the studies of Zeybek G, *et al.* [14], Ozden H, *et al.* [15], and Sanli SG, *et al.* [28] on Turkish populations, Danborno B. and Elukpo A.[16] on Nigerian populations, Fessler DM, *et al* [17] on an American population, Jowaheer V, *et al.*[18] , and Agnihotri A, *et al.* [19] on Mauritian populations, Aboul-Hagag KE, *et al.* [20] on an Egyptian population, Hemy N. and Ishak NI. [12, 26] on Western Australians, Ibrahim MA, *et al.* [21] on North Saudi population, and Dey S, *et al.* [7], Krishan K, *et al.* [22], Kanchan T, *et al.* [23], and Sen J, *et al.*[29] on Indian populations. However, the hand and foot parameters measurements vary between populations and could be caused by factors such as genetics, environment and social conditions. Therefore, investigations on the development of population-specific standards are warranted. [8, 30 - 32]

Regarding the bilateral differences in this study, all parameters were found to be non-statistical on both sides except hand breadth which was found to be statistically larger on the right side in males and females which are similar to the previous studies by Varu PR, *et al.* [13] and Krishan K, *et al.* [22]

The results showed the statistical differences of hand parameters between males and females, except hand index which was found to be non-statistically different in both left and right sides. For foot parameters, foot breadth and foot length were significantly different between males and females. No statistically differences were observed in heel breadth and foot index between males and females in both left and right sides. There was no statistical difference in foot index, similar to that reported by Krishan K, *et al.* [22] On the other hand, Varu PR, *et al.* [13], found that hand and foot indexes were statistically different between males and females.

The cut-off values and accuracy of all previous reports are shown in Table 6, and 7. With regard to hand parameters, hand length showed the highest accuracy (94%) for sex determination similar to the study in Western Australian (93.3%). [12] Whereas in Indian populations, the highest accuracy is hand breadth. [7, 13, 22] Hand index in this study and previous studies had lower accuracies for sex determination than other parameters.

Table 6. Comparison of cut-off values to differentiate sex from hand parameters and hand index.

Population	Side	Cut-off value (% Accuracy)		
		HB	HL	HI
Western Australia [12]		8.48 (91.3%)	18.57 (93.3%)	-
Indian [7]	Left	7.94 (80.2 - 83.5%)	18.39 (76.9 - 80.2%)	43.27 (51.6 - 59.3%)
	Right	7.82 (81.3 - 82.4%)	18.28 (79.1 - 81.3%)	43 (46.2 - 58.2%)
North Indian[22]	Left	7.71 (84%)	17.49 (79.5%)	44.11 (56%)
	Right	7.83 (86%)	17.54 (79.5%)	44.68 (56.5%)
Indian [13](Deceased subject)		7.7 (82%)	17.2 (73.25%)	44.6 (69.5%)
Present study	Left	7.986 (85%)	17.767 (94%)	44.963 (50%)
(Deceased subject)	Right	8.090 (86%)	17.779 (94%)	45.536 (52%)

Table 7. Comparison of cut-off values to differentiate sex from foot parameters and foot index.

Population	Side	Cut-off value (% Accuracy)			
		FB	FL	FHB	FI
Western Australia[12]		9.81 (82%)	26 (83.5%)	6.4 (90.5%)	-
Indian [29]	Left	9.45 (81.1 - 81.7%)	23.12 (81.7 - 82.9%)	-	40.9 (58.3 -58.9%)
	Right	9.44 (80.6 - 84%)	23.09 (80.6 - 82.9%)	-	40.9 (56.6-58.9)
North Indian[22]	Left	9.05 (86%)	23.65 (83.5%)	-	38.29 (56%)
	Right	9.12 (88.5)	23.68 (82%)	-	38.53 (55.5%)
Present study	Left	9.328 (81%)	23.253 (88%)	6.040 (72%)	40.108 (49%)
(Deceased subject)	Right	9.313 (80%)	23.204 (88%)	6.055 (73%)	40.159 (46%)

Regarding the cut-off values in foot parameters, foot length showed the highest accuracy (88%) for sex determination, followed by foot breath (80 - 81%) and heel breadth (72 - 73%). In Western Australians, the highest accuracy for sex determination is heel breadth, follow by foot length and foot breadth. [12] For Indians, two previous studies found that foot breadth and foot length had similar accuracies (>80%) for sex determination. [22, 29] Foot index in these studies and other previous ones showed lower accuracy for sex determination than other parameters.

This study was carried out on cadavers while most other studies were performed in living populations except the study by Varu PR. [13] which was also carried out on cadavers. A limitation of this study is the postmortem changes with rigor mortis; they might affect the measurement values. So, hand and foot were straighten out prior to measurement in an anatomical position.

Conclusion

In this study, hand and foot parameters can be successfully applied for sex determination. Therefore, sex can be determined from the parameters of hands and feet with reasonable accuracy using the cut-off values. Hand length and 3rd finger of both sides showed accuracies of sex determination above 90% (92 - 94). The highest accuracy to differentiate between sexs is the foot length with an accuracy of 88%. Hand length and foot length showed higher accuracies for sex determination than other parameters. Values that are more than the cut-off point suggest male and less than the cut-off point suggest female. As other populations show differences in hand and foot parameters and indexes, results from the present study can be used in the Thai population. Similar studies should be carried out in other populations to find out specific cut-off values of hand and foot parameters.

For higher accuracy in sex determination, further studies should be performed in living subjects and with larger sample sizes.

Conflict of interest

None of the authors has any potential conflict of interest to disclose.

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