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Original Article

Reference equations for predicting standing height of children by using arm span or forearm length as an index

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Abstract

Background: Standing height (SH) is the most reliable parameter used to predict spirometric values in children, but measurement of this parameter may be difficult in children with thoracic or spinal abnormalities. This study was designed to establish reference equations to estimate SHs of children using their arm span length (ASL) or forearm ulnar length (UL) as an index.

Methods: Children aged 1−17 years were enrolled to measure their SH, body weight, ASL, and UL. Sex and age were also recorded. The relationship between SH and children's weight, age, ASL, and UL were analyzed. Regression equations using different indexes for SH of enrolled cases were used, and adults aged 18−64 years were also enrolled for comparison.

Results: A total of 512 children and 144 adults were enrolled. There was a strong linear relationship between SH and both ASL and UL in children and adults. Pearson's correlation coefficients of SH for ASL and UL were 0.989 and 0.968 ($p < 0.001$) in children and 0.933 and 0.845 ($p < 0.001$) in adults. The linear regression equations for estimating SH in children were calculated as $SH = 9.363 + 0.943\ ASL$ ($r^2 = 0.978, p < 0.001$) and $SH = 14.542 + 5.570\ UL$ ($r^2 = 0.936, p < 0.001$). In adults, age and sex were also added as indexes: $SH = 59.849 + 0.642\ ASL - 0.047\ Age + 3.431\ Sex$ (male = 1; female = 0) ($r^2 = 0.887$, $p < 0.001$) and $SH = 102.824 + 2.317\ UL - 0.049\ age + 6.739\ sex$ ($r^2 = 0.773$, $p < 0.001$).

Conclusion: Both ASL and UL have a significant linear relationship with SHs of children and adults. True SH can be estimated using regression equations with ASL or UL as a single index for situations where direct measurement of SH is difficult.

Keywords: Arm span length; Children; Regression equation; Standing height; Ulnar length

1. Introduction

The pulmonary function test is a crucial test used to evaluate lung function in patients with potential pulmonary dysfunction. The measured lung function may help clinical physicians to assess pulmonary dysfunction, operative risk, and management protocols. To evaluate pulmonary function, normative reference data are required.[1−3] However, normative reference of pulmonary function test may be influenced by multiple factors, including ethnicity, body height, body weight, age, and sex.[3−8] Standing height (SH) is the most common parameter to estimate predictive spirometric values and is used in evaluating the pulmonary function of children. Among these factors, SH measurements may not be reliable in

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Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

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patients with thoracic skeletal deformities. These individuals typically have lower SHs than expected, which may result in an over-estimation of their pulmonary function, which can underestimate their risk of surgery and difficulty of extubation.

As reported in several previous studies, arm span length (ASL) was the most common measure used to estimate patients' true SH.[7–12] However, some patients may not be able to extend their arms. Forearm ulnar length (UL) has been reported to be another choice to estimate patients' true SH for predictive spirometric values.[13] ASL and UL are typically not affected by spinal or thoracic deformities, which suggest that they might serve as an alternative index for estimating SHs.[12] There have been previous investigations worldwide describing the relationship between ASL and height. However, a lack of studies on ASL and UL with SH in children living in Taiwan during last decades may prevent its use in a clinical setting.[4,6,10,13–16] Linear regression equations for estimating true SH from ASL or UL in Chinese children, especially for those <6 years old, are also needed to successfully employ this technique. Therefore, it seems worthy to investigate the relationship between SH and children's ASL and UL and determine the regression equations for the children living in Taiwan.

In this regard, the purpose of this study was to analyze the relationship between SH and ASL or UL in children living in Taiwan and to establish reference regression equations for estimating true SHs of children based on their ASL or UL and to compare these values with those obtained from adults.

2. Methods

2.1. Subject enrollment

This study was approved by the local Institutional Review Board of Taipei Veterans General Hospital (IRB approval number: 2012-06-017A). The study period was from November 2012 to February 2014. Informed consent was obtained from the parents or guardians of all children aged 1–17 years. Exclusion criteria were as follows: presence of spinal or thoracic deformities, non-Taiwanese nationality, refusal to provide age and other data, and difficulty in extending arms. Adults aged 18–64 years also signed informed consent and were included in the analysis for comparison.

2.2. Assessment

SH, ASL, UL, and body weight of enrolled participants were measured with participants bare feet and standing against a wall. ASL was measured from the tip-to-tip of the two middle fingers while the participant was standing or sitting against a wall and stretching both arms as much as possible (Fig. 1A). UL was measured as the length of the right ulnar bone from the ulnar styloid process to the olecranon process (Fig. 1B). Numeric data were measured to the nearest 0.1 cm per length and 0.1 kg per weight. The basic characteristics of the data obtained from the children were categorized into 1–5, 6–10, and 11–17-year-old (y) subgroups for comparison with adults.

2.3. Statistical analysis

Descriptive analysis was performed, and numeric data were presented as mean ± standard deviation. One way analysis of variance tests were used to compare data among groups and were followed by *post-hoc* LSD test for pairwise comparison. Pearson's correlation coefficients were calculated for SH with ASL, UL, body weight, and age. Linear regression models were performed for SH with variables ASL, UL, body weight, age, and sex. SPSS (Version 22.0, SPSS Inc., Chicago, IL, USA) was used for data analysis, and SigmaPlot (Version 12.0, Systat Software Inc. San Jose, CA, USA) was used for drawing graphs. A P-value of <0.05 was considered statistically significant for all results.

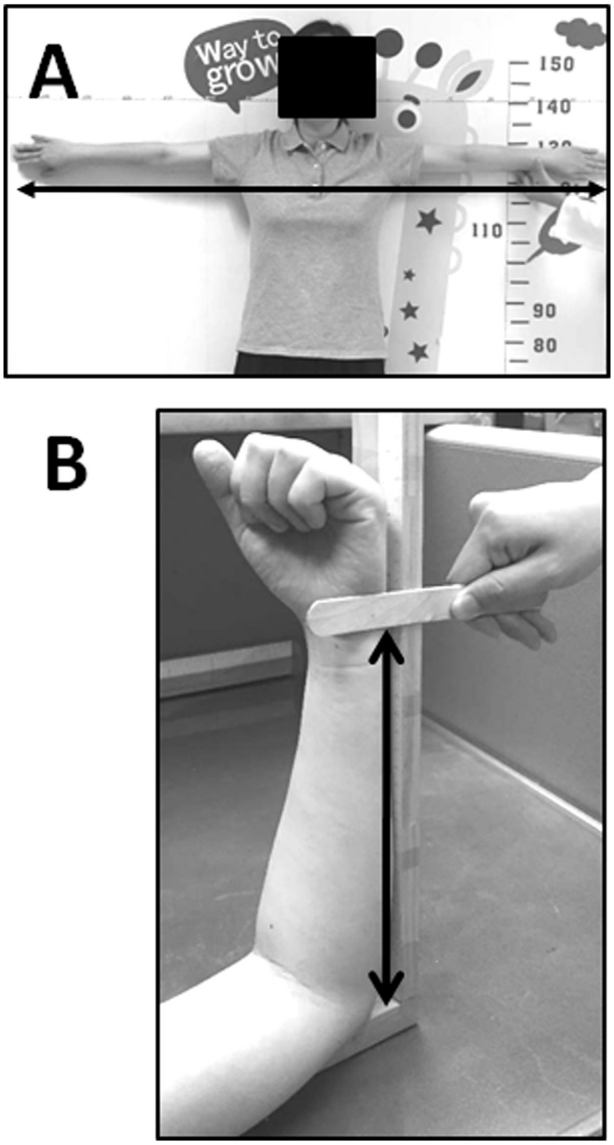
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Fig. 1. Illustrations of measurements of the arm span length (A) and ulnar length of the forearm (B).

Table 1
Age, weight and anthropometric measurements of enrolled children and adults.

	Age	Weight	SH	ASL	UL	SH/ASL	SH/UL
Children							
All (1–17 y)							
Male (n = 248)	6.2 ± 4.0	26 ± 16	117 ± 26	114 ± 26$^{\#}$	18 ± 4$^{\#}$	1.03 ± 0.04$^{\#}$	6.39 ± 0.43
Female (n = 264)	5.8 ± 3.8	24 ± 13	113 ± 24	110 ± 25	18 ± 4	1.04 ± 0.04	6.44 ± 0.52
1–5 y							
Male (n = 134)	3.3 ± 1.4$^{\#}$	16 ± 4$^{\#}$	99 ± 12$^{\#}$	96 ± 13$^{\#}$	15 ± 2$^{\#}$	1.03 ± 0.04$^{\#}$	6.46 ± 0.44
Female (n = 136)	2.8 ± 1.3	15 ± 4	94 ± 11	90 ± 12	14 ± 2	1.05 ± 0.05	6.54 ± 0.42
6–10 y							
Male (n = 75)	7.9 ± 1.6^{a}	28 ± 8^{a}	127 ± 9^{a}	124 ± 9^{a}	20 ± 2^{a}	1.02 ± 0.03^{a}	6.34 ± 0.30$^{\#}$
Female (n = 98)	8.0 ± 1.6^{a}	28 ± 8^{a}	128 ± 11^{a}	125 ± 12^{a}	20 ± 2^{a}	1.02 ± 0.02^{a}	6.45 ± 0.33
11–17 y							
Male (n = 39)	14.2 ± 1.5^{a,b}	55 ± 16 ^{a,b}	158 ± 15 $^{a,b,\#}$	158 ± 16 $^{a,b,\#}$	26 ± 3 ^{a,b}	1.01 ± 0.03 ^{a,b}	6.17 ± 0.32 ^{a,b}
Female (n = 30)	13.9 ± 1.6 ^{a,b}	49 ± 14 ^{a,b}	152 ± 8 ^{a,b}	150 ± 9 ^{a,b}	25 ± 2 ^{a,b}	1.01 ± 0.03 ^{a,b}	6.14 ± 0.33 ^{a,b}
Adult (18–64 y)							
Male (n = 60)	32.6 ± 9.9 $^{a,b,c,*,\#}$	74 ± 12 $^{a,b,c,*,\#}$	174 ± 6 $^{a,b,c,*,\#}$	175 ± 7 $^{a,b,c,*,\#}$	29 ± 2 $^{a,b,c,*,\#}$	1.00 ± 0.02 $^{a,b,*,\#}$	6.11 ± 0.23 $^{a,b,*,\#}$
Female (n = 84)	35.8 ± 9.2 ^{a,b,c,*}	56 ± 11 ^{a,b,c,*}	159 ± 6 ^{a,b,c,*}	157 ± 7 ^{a,b,c,*}	25 ± 2 ^{a,b,*}	1.01 ± 0.03 ^{a,b,*}	6.37 ± 0.32 ^{a,c}

Data are presented as mean ± SD. ASL = Arm span length; SH = Standing height; UL = Ulnar length; y = years old.
$^{a}p < 0.05$ vs. 1–5 y children of the same gender; $^{b}p < 0.05$ vs. 6–10 y children of the same gender; $^{c}p < 0.05$ vs. 11–17 y children of the same gender; $*p < 0.05$ vs. all (1–17 y) children of the same gender. $^{\#}p < 0.05$ vs. female of the same age group.

3. Results

3.1. Participant characteristics

A total of 656 patients were enrolled, including 512 children (248 boys and 264 girls) and 144 adults (60 men and 84 women). General characteristics of all participants, including age, body weight, SH, ASL, UL, and ratios SH/ASL and SH/UL, are presented in Table 1. As shown, SHs were larger than ASLs in children, especially in young children aged 1–5 years. Regarding participant age, SH and ASL were significantly higher in the older group. UL was significantly greater in adult males than in boys aged 11–17 years, but there were no significant differences in females (Table 1).

SH/ASL and SH/UL ratios both tended to be higher in younger children (Table 1). SH/ASL was approximately 1.03–1.05 in young children aged 1–5 years, but it was only approximately 1.00–1.01 in teenagers and adults of both sexes. The SH/UL ratio was as high as ~6.46–6.54 in young children aged 1–5 years, 6.14–6.17 in teenagers, and only around 6.11 in adult males (Table 1). However, the SH/UL ratio in adult females were 6.37 ± 0.32, which was significantly higher than that in adult males and had no significant differences when compared with that in girls aged 6–10 years (Table 1).

3.2. Correlations and linear regression equations for standing height and related parameters

Pearson's correlation coefficients for SH with ASL, UL, age, and body weight are shown in Table 2. ASL, UL, body weight, and age of children all have positive and significant correlations with SH, with no difference between the sexes. Pearson's correlation coefficients for SH was the highest in ASL ($r = 0.989$, $p < 0.001$), followed by UL ($r = 0.968$, $p < 0.001$) and age ($r = 0.950$, $p < 0.001$). The correlations between SH and body weight in children was higher in those with a weight of <30 kg ($r = 0.929$, $p < 0.001$) than in those with a weight of ≥30 kg ($r = 0.747$, $p < 0.001$).

In adults, significantly positive correlations with SH were also noted for ASL, UL, and body weight (Table 2), and this relationship was also similar in men and women. There was a negative correlation between SH and age ($r = -0.241$, $p < 0.05$). Pearson's correlation coefficients for SH was the highest in ASL of adults ($r = 0.933$, $p < 0.001$) (Table 2).

The scatter diagrams and linear regression lines are shown in Figs. 2 and 3, and regression equations are listed in Table 3. In children, there was a strong and positive linear relationship between children's SH and ASL, UL, body weight, and age ($r^2 > 0.8$, $p < 0.001$) (Fig. 2A–D). As shown, ASL had the strongest linear correlation with SH, and the R-squared value was the highest among all parameters ($r^2 = 0.978$, $p < 0.001$) (Fig. 2A). Regarding body weights of children, the scatter diagram revealed a stronger linear relationship in those with weights of <30 kg ($r^2 = 0.862$, $p < 0.001$) (Fig. 2E).

In adults, the positive linear relationships between SH and ASL and UL were strong ($r^2 > 0.7$; $p < 0.001$) (Fig. 3A and

Table 2
Pearson's correlation coefficients of each anthropometric parameter to participants' standing height.

	Arm Span Length	Ulnar Length	Body Weight	Age
Children (1–17 years old)				
All	0.989*	0.968*	0.899*	0.950*
(<30 kg)			0.929*	
(≥30 kg)			0.747*	
Male	0.989*	0.969*	0.912*	0.959*
Female	0.989*	0.966*	0.879*	0.941*
Adult (18–64 years old)				
All	1.933*	0.845*	0.650*	−0.241$^{\#}$
Male	0.833*	0.646*	0.412$^{\#}$	−0.214
Female	0.834*	0.615*	0.275$^{\#}$	−0.160

$*p < 0.001$; $^{\#}p < 0.05$.

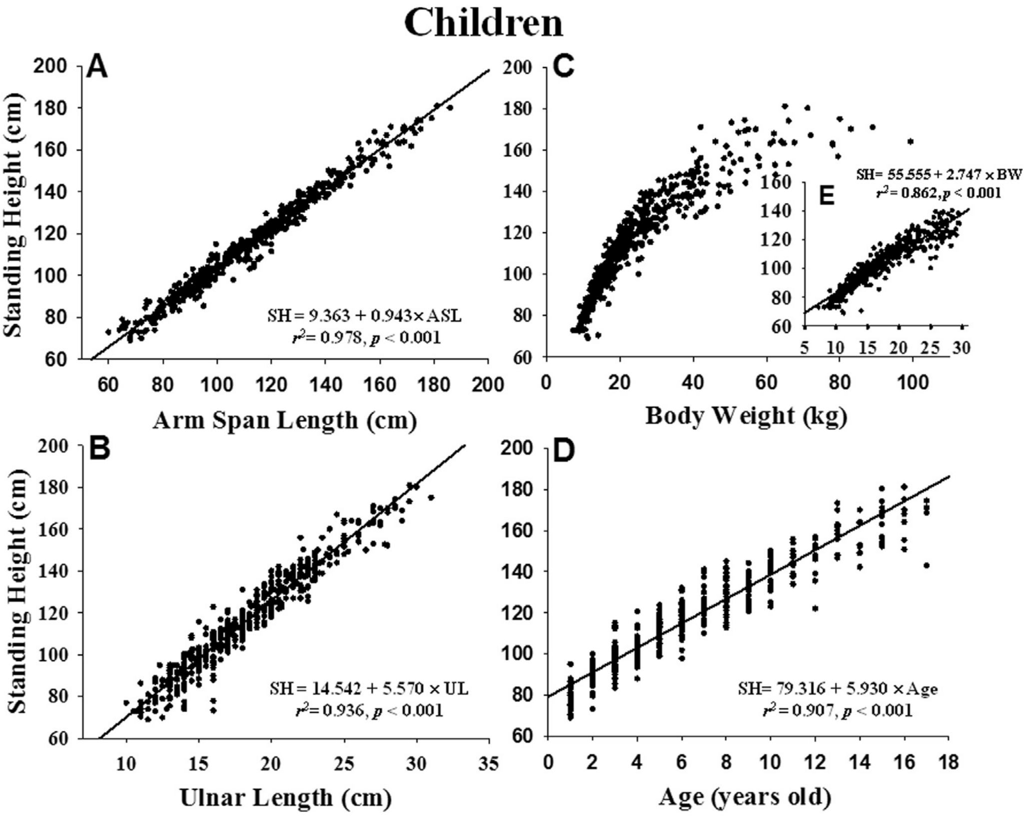

Fig. 2. Scatter diagrams and liner regression lines between standing height and arm span length (A), ulnar length (B), body weight (C), age(D), and those with body weight <30 kg (E) in children aged 1–17 years.

B). The linear relationship between SH and weights was not strong ($r^2 = 0.422$, $p < 0.001$) (Fig. 3C). With regard to age, there was a relatively negative relationship to SH and very low R-squared value ($r^2 = 0.058$, $p = 0.004$) (Fig. 3D).

When combining data from children and adults, linear relationships are still strong for SH with both ASL and UL. However, this strong correlation is not maintained for body weight and age (Fig. 4).

Regression equations used to estimate SH in our study participants are listed in Table 3. As shown in children, the R-squared values are all >0.90 ($p < 0.001$) in using ASL, UL, or age as a single index to estimate SH. We attempted to add gender and/or age in the children's equations, but only age could increase the R-squared values. While in adults, the addition of gender and age into the regression equations slightly increases the R-squared values (Table 3). With regard to children and adults together, the R-squared values of regression equations using ASL or UL as a single index are >0.95 ($p < 0.001$), suggesting a strong correlation.

4. Discussion

The present investigation demonstrates for the first time a significant positive correlation between children's SH and their ASL and UL, as was the case in adults. The linear regression equations used to estimate SHs of children in Taiwan using ASL, UL, weights, and age represent a key finding of this study.

Scoliosis is a common cause of thoracic deformity and may influence patients' pulmonary function. It is defined by the Scoliosis Research Society as a lateral curvature of the spine of >10° and accompanied by vertebral rotation.[17] For patients with scoliosis or a chest wall deformity, pulmonary and cardiac functions have been associated with disease severity. The pathophysiology of scoliosis involves three processes: 1) lung volume reduction, 2) changes in chest wall stiffness, and 3) respiratory muscle weakness. If these processes progress, an increase in the work of breathing, tachypnea, and even respiratory failure could occur.[18–20] Pulmonary function is crucial for effective follow-up checks on respiratory function and for verifying post-operative improvements. Changes in quality of living are evident from improvements in pulmonary function tests.[21–23] Spirometry is the basic and most convenient way to assess pulmonary function in patients with scoliosis. Normative reference values are required to perform spirometry based on pulmonary function tests.[24,25] Generally, the best parameter used to predict spirometry tests in children is SH.[3,4,6] In children with spinal or chest deformities, using SH may underestimate their predicted values and the severity of pulmonary function impairment.

Since SHs are sometimes difficult to measure accurately in patients, estimating SH using different anthropometric parameters has been investigated for many years in a variety of

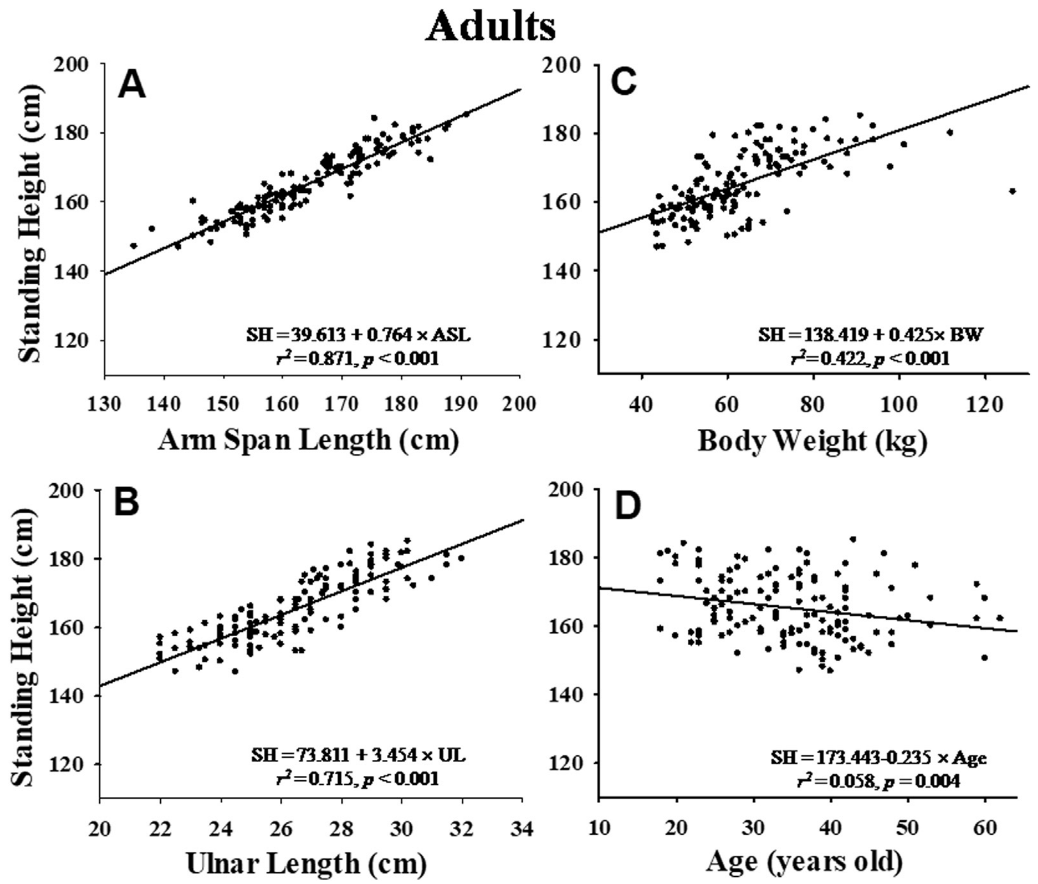

Fig. 3. Scatter diagrams and liner regression lines between standing height and arm span length (A), ulnar length (B), body weight (C), and age (D) in adults aged 18–64 years.

Table 3
Reference equations for estimating true standing height (SH) based on different parameters.

Linear regression equations	SEE	r^2
Children(1–17 years old)		
SH = 9.363 + 0.943 ASL*	3.607	0.978
SH = 14.542 + 5.570 UL*	6.118	0.936
SH = 55.555 + 2.747 BW*(<30 kg)	6.046	0.862
SH = 79.316 + 5.930 A*	7.370	0.907
SH = 19.152 + 0.805 ASL* + 0.959 A*	3.392	0.980
SH = 36.406 + 3.596 UL* + 2.289 A*	5.194	0.954
SH = 19.517 + 0.802 ASL* + 0.980 A*−0.504 G	3.378	0.981
SH = 37.289 + 3.519 UL* + 2.376 A*−0.111 G	5.162	0.955
Adults (18–64 years old)		
SH = 39.613 + 0.764 ASL*	3.366	0.871
SH = 73.811 + 3.454 UL*	5.500	0.715
SH = 56.954 + 0.650 ASL* + 3.444 G*	3.191	0.883
SH = 99.808 + 6.718 UL* + 2.368 G*	4.503	0.767
SH = 59.849 + 0.642 ASL*− 0.047 A + 3.431 G*	3.172	0.887
SH = 102.824 + 2.317 UL*− 0.049 A + 6.739 G*	4.496	0.773
Children & Adults (1–64 years old)		
SH = 9.295 + 0.945 ASL*	3.690	0.985
SH = 13.626 + 5.651 UL*	6.427	0.955

A = age (years old); ASL = arm span length (cm); BW = body weight (kg); UL = ulnar length (cm); G = gender (male = 1, female = 0); SEE = standard error of the estimate; SH = standing height; y = years old. *p < 0.001.

populations (Table 4).[7–10,12–16,25–29] It has been demonstrated previously that a significant difference in the accuracy exists across races.[12] Furthermore, many previous investigations have analyzed only children,[8,13–16,26,27] while some specifically focused on adults.[7,9,12,25,28,29] However, only a few inquiries into both children and adults exist.[10] In the prior analysis of children, many investigations have focused on children >5 years,[14–16,26,27] while Forman et al. evaluated children <6 years in the United States and reported that ASL or different measured ULs were able to reliably estimate heights in healthy children.[13] Our study investigated this relationship in young children aged ≥1 year, and the data reported herein suggest similar findings.

ASL was reported to be a good index to predict pulmonary function parameters. In Iran, Golshan et al. had reported an equation to predict ASL for children and adults as ASL (cm) = −7.3908 + 1.057 × SH.[10] By using data of our study subjects, we could also obtain a similar equation as ASL (cm) = −9.839 + 1.052 × SH.

Although ASL seems to be the best substitute of SH in the majority of patients, some cases may have difficulty extending their arms for measurement. In this regard, UL is an easy method of measuring only one forearm and is a good index to estimate children's SH. Previously, Gauld et al.

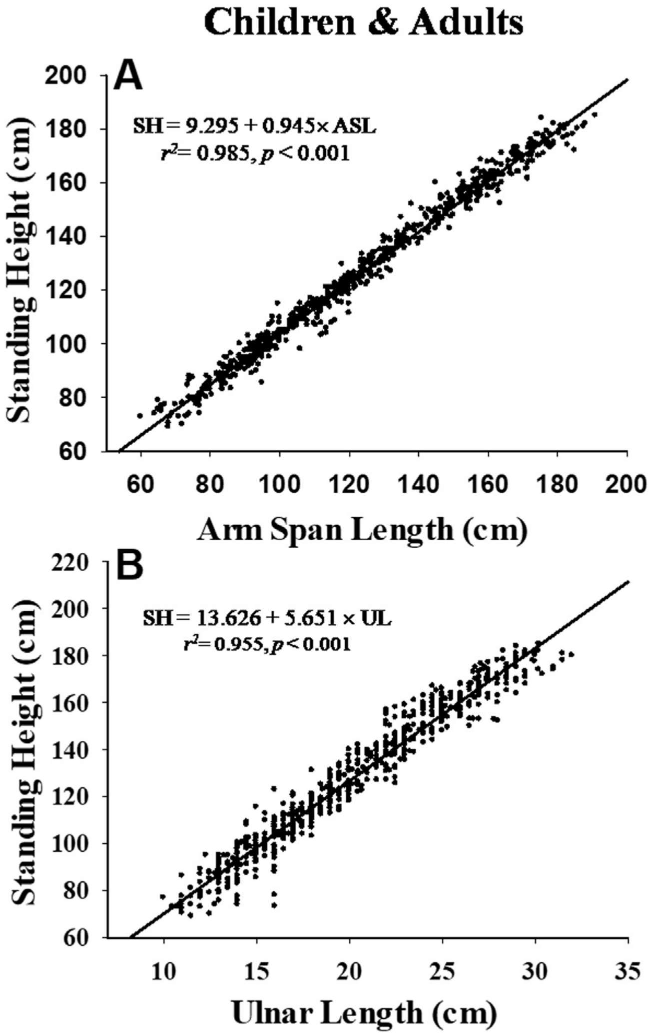

Fig. 4. Scatter diagrams and liner regression lines between standing height and arm span length (A) and ulnar length (B) for all enrolled children and adults aged 1–64 years. Scatter diagrams for body weight (C) and age (D) are presented without regression lines for clarity.

supported the use of ulnar measurements to predict SH in school-age children as they are both reproducible and precise.[14] Thus, this measurement seems superior to ASL when neuromuscular weakness, joint, or spinal deformity exists.[14] Therefore, we also suggest the use of UL to calculate the patient's SH if they have difficulties which prevent directly measuring SH or ASL.

Our study revealed a linear relationship between SH and ASL, UL and age, which was strong for all children aged 1–17 years. The addition of age and sex into the regression equations resulted in similar R-squared values and had little overall improvement on regression equations (Table 3). Therefore, we suggest calculating SH of children using ASL or UL as the only index as the addition of age/sex does not appreciably improve accuracy but could potentially reduce it. Additionally, we noted that the linear relationship between SH and body weight was much stronger when body weight was <30 kg than when it was ≥30 kg (Fig. 2C and E). Therefore, if body weight is the only available variable to estimate SH of little children, it is better to use the specific regression equation for those with body weight of <30 kg (Table 3). This issue has not been mentioned by any previous investigations.

In the present study, the values of measured ASL of children were slightly higher in children aged 1–17 years. These findings are consistent with a recent report by Monyeki's, who demonstrated this in children aged 8–18 years.[8] We further noted that the ratios SH/ASH and SH/UL were higher in younger children, and ASL/SH was close to 1.0 in adults. We enrolled adults aged 18–64 years, and most of them were <40 years; therefore, there were no elders included in the present investigation. Capderou et al. published a report in which they enrolled participants aged 20–90 years and found a larger ASL than SH.[9] Furthermore, Pothirat et al. found in elderly adults (>65 years) that they also have a mean ASL, which exceeded the mean SH at a ratio of 1.05 ± 0.03.[25] In summary, our findings support many previous findings. Specifically, there is a trend of slower growth in ASL than in body height during early childhood, which results in the ASL value being smaller than SH. Therefore, ASL may be nearly equal to SH by early adulthood, and they could become larger than SH as the individual progresses into older adulthood. One possible explanation for this is that SH usually becomes attenuated in people aged >65 years while ASL does not shorten. Therefore, care should be taken to use a reliable regression equation, which is appropriate to the participants' age, particularly when aiming to estimate a patient's SH while using ASL or UL as an index.

In the present study, we determined regression equations not only for children but also for adults (Table 3). As shown in Fig. 4 and Table 3, the linear relationships between SH and both ASL and UL are still strong, even when children and adults are combined. Thus, simple equations with ASL or UL are adequate to accurately estimate SH for anyone aged <65 years. This is supported by a report from Golshan et al. who enrolled participants aged 5–85 years for predictive spirometric values using ASL as a single index.[10] They concluded that ASL-derived equations are as competent as traditional equations for pulmonary function tests.[10] Therefore, ASL or SH may both be used to predict values of pulmonary function test in children and adults.

Potential limitations of this investigation include the small sample size, especially with regards to adults. However, it is important to note that the primary aim of this investigation was to include children's data and we have obtained strong evidence of the linear relationships between SH and ASL or UL. Therefore, these results suggest that the regression equations are reliable, especially for children aged 1–17 years.

In conclusion, both ASL and UL have significantly positive linear relationships with SH's of children and adults in Taiwan. Using the regression equations to calculate SH from ASL or UL may be a convenient means to estimate SH in children whose SH cannot be directly measured.

Table 4
Reports in the relationship of standing heights and different anthropometric variables of children and adults from 2000 to 2017.

Reported Year (ref)	Authors	Participants' Age (years)	Measured variables	Study place	Regression equation to estimate SH
Children					
2003[15]	Torres et al.	6–10	ASL, SitH	Brazil	No
2004[14]	Gauld et al.	5–15	ASL, UL, LLL	Australia	Yes
2009[26]	Mazicioglu et al.	6–17	ASL	Turkey	Yes
2010[27]	Yabanci et al.	7–14	ASL, MUAC, WC	Turkey	No
2014[13]	Forman et al.	<6	ASL, UL	United States	Yes
2015[16]	Zhu et al.	6–17	ASL, SitH, UL, UAL,LLL	China	No
2016[8]	Monyeki et al.	8–18	ASL, WC, MUAC, Skin folds	South Africa	Yes
Children &Adults					
2007[10]	Golshan et al. [c]	5–85	ASL	Iran	Yes
2017	Chen et al. [a]	1–64	ASL, UL	Taiwan	Yes
Adults					
2001[7]	Mohanty et al. [b]	20–29	ASL, SitH, LLL	India	No
2003[28]	Shahar et al. [d,e]	30–86	ASL, Half-ASL, Demi-span, LLL	Malaysia	Yes
2003[29]	Zverev et al.	20–76	ASL	Malawian	Yes
2015[25]	Pothirat et al.	72 ± 8	ASL	Thailand	No
2016[12]	Lahner et al. [d,e]	18–24	ASL, Half-ASL, Demi-span	South Africa	No
2017[9]	Capderou et al.	20–90	ASL	France	Yes

ASL = arm span length; LLL = lower leg length; MUAC = mid-upper arm circumference; FUL = forearm or ulnar length; SitH = sitting height; WC = waist circumference; UAL = upper arm length; y = years old.

[a] The present study.

[b] Women only.

[c] They made a regression equation to calculate ASL by using SH as an index.

[d] Half-ASL: the length between the sternal notch to the tip of middle finger.

[e] Demi span: length between the sternal notch to the web of the middle finger.

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