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BRIEF COMMUNICATION

Body height prediction model from foot measurements in a Chilean population of university student athletes

Modelo de predicción de la estatura a partir de las medidas del pie en una población chilena de estudiantes universitarios deportistas

Celso Sánchez-Ramírez[1, 2]*

1) Escuela de Ciencias de la Actividad Física, el Deporte y la Salud, Universidad de Santiago de Chile, Chile. 2) Departamento de Morfología y Función, Universidad de Las Américas, Chile.

Abstract

In forensic research, it is important to identify human remains. Body height is an essential aspect in anthropometric characterization. This is the first study in a Chilean population and aimed to develop a height estimation model for a young adult population of athletes from foot measurements. Central Chilean subjects were included (n=139). Height (H), Foot Length (FL), Foot Breadth (FB), and Heel Foot Breadth (HFB) were measured. For both sex and feet, FL was the most correlated with H (Females $r > .8$, $p < .001$; Males $r > .7$, $p < .001$). When only FL is used in the equation, similar values are obtained as when using FL + FB + HFB in females ($R^2 > 65\%$) and males ($R^2 > 51\%$). It was possible to appreciate that the mean of the data obtained from the equations is equal to the mean of the actual data. However, the minimum values tend to be overestimated, and the maximum values tend to be underestimated. It was possible to develop a mathematical model that allows predicting height from the anthropometric measurements of the feet of young adult athletes from the Metropolitan Region of Chile. Furthermore, it was shown that foot length was the measurement most correlated with height and can be used independently in the equations. This study provides valuable information in the forensic medical field, specifically in the identification of bodies in which it is impossible to determine the height directly because they are dismembered or incomplete. Rev Arg Antrop Biol 26 (2), 078, 2024. https://doi.org/10.24215/18536387e078

Keywords: body height; forensic anthropology; foot measurement; Chilean population; foot length

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*Correspondencia a: Celso Sánchez-Ramírez. Universidad de Santiago de Chile, Av. Libertador Bernardo O'Higgins nº 3363, Estación Central, Región Metropolitana, 9170022. E-mail: celso.sanchez@usach.cl

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Resumen
En investigación forense es importante identificar restos humanos. La estatura es un tema esencial en la caracterización antropométrica. Este es el primer estudio hecho en población chilena y su objetivo fue desarrollar un modelo de estimación de la estatura desde las medidas del pie de jóvenes estudiantes universitarios deportistas. Se estudió a 139 adultos jóvenes de la zona central de Chile. Se midió Estatura (H), Largo del pie (FL), Ancho del antepié (FB) y Ancho del talón (HFB). En ambos sexos FL mostró la mayor correlación con H (mujeres r > 0,8; p < 0,001; hombres r > 0,7; p < 0,001). Cuando sólo se emplea FL en la ecuación, se obtienen valores similares que cuando se emplean todas las variables en mujeres (R^2 > 65%) y hombres (R^2 > 51%). Fue posible apreciar que la media obtenida de las ecuaciones es igual a la media de los datos reales. Sin embargo, los valores mínimos tienden a sobreestimarse y los valores máximos a desestimarse. Fue posible determinar un modelo matemático que permite predecir la estatura desde las medidas antropométricas del pie de una población joven deportista. Además, se determinó que la longitud del pie es la medida que más se correlaciona con la estatura y puede ser usada de manera independiente en la ecuación. Este estudio provee información de valor para el campo de la medicina forense, específicamente en la identificación de cuerpos en donde es imposible determinar la estatura de manera directa. Rev Arg Antrop Biol 26 (2), 078, 2024. https://doi.org/10.24215/18536387e078

Palabras clave: estatura; antropología forense; medidas del pie; población chilena; longitud del pie

Knowing the body height of an individual is an essential topic of the subject's anthropometric characterization, which can be a valuable tool to assess the cumulative net nutrition, physical deprivation, and standard of living (Perkins *et al.*, 2016). However, in many cases, obtaining an accurate height measurement in a straight standing position is not possible. For example, when the patient is bedridden, suffers from scoliosis, or has undergone amputation, it becomes necessary to estimate height using measurements of other body parts.

In the anthropologic forensic investigation process, one of the main tasks is identifying unknown human remains, commonly found in massive disasters such as earthquakes, tsunamis, floods, wars, explosions, and transportation accidents (Cattaneo, 2007). To achieve this goal, stature is as essential as other data, including age, sex, and ancestry (Krishan *et al.*, 2011). Moreover, in such situations, it is necessary to have tools that allow us to estimate the height from other body segments.

According to the above, body height has been estimated based on the relationship with various body parts, including the head (Pelin *et al.*, 2010), hand (Igbigbi *et al.*, 2018; Sanli *et al.*, 2005), forearm bones (Duyar & Pelin, 2010), lower leg (Duyar & Pelin, 2003), arm span (Bjelica *et al.*, 2012; Popovic *et al.*, 2013), vertebrae (Pelin *et al.*, 2005), and foot (Hemy *et al.*, 2013; Krishan *et al.*, 2011), among others. In addition, these authors have found that arm span, lower leg, ulna length, and foot length correlate more closely with body height.

Obtaining body height from foot measurements can be a helpful tool. First, the foot is a body segment that is easy to measure since its limits are visible. This characteristic is absent in segments such as the vertebrae, forearm bones, hand, and lower leg, which require precise placement of the proximal and distal limits of the segment. Likewise, recovering feet after a mass disaster is common since they are often found protected in shoes (Budimlija *et al.*, 2003).

The relationship between body height and foot measurements has been studied in different populations such as Kosovan (Masanovic *et al.*, 2019), Sudanese Arab (Ahmed, 2013), Western Australian (Hemy *et al.*, 2013), Nigerian (Igbigbi *et al.*, 2018), Indian (Karmalkar & Nikam, 2021; Krishan *et al.*, 2011), Turkish (Özaslan *et al.*, 2003; Sanli *et al.*, 2005), Slovak (Švábová (nee Uhrová) *et al.*, 2022), Montenegrin (Vukotic, 2020), and Chinese (Zhang *et al.*, 2017) populations. The most studied anthropometric variable of the foot was its length, which has shown a high correlation with height, with r-values ranging from .58 (Švábová (nee Uhrová) *et al.*, 2022) to .77 (Ahmed, 2013), with sexual dimorphism. Almost all studies propose an equation to predict the height using foot measurements, and these equations differ across studies. This variation is logical, as diverse populations exhibit differences in body size and proportions. This result has been demonstrated even among people from the same geographical area or similar ethnic groups (Masanovic, 2018).

No studies have been published that allow for estimating height from foot measurements in Latin American populations. This fact means that there are twenty countries with more than 656 million inhabitants (information retrieved on the 12th of October 2023 from https://www.statista.com/) without data to aid in identifying human remains based on foot measurements. Therefore, this is the first study of its kind in a Chilean population, aiming to develop a height estimation model for Chilean university student athletes using foot measurements.

MATERIAL AND METHODS

Subjects

The study population consisted of students from the Universidad de Santiago de Chile (In English: University of Santiago of Chile) who actively participated in their representative sports teams. According to data from the institution's Department of Sports Management, 220 students were enrolled in their sports teams at the date of the study. These students agreed to participate in the study, which was formalized by signing informed consent. The methodological design of the study was approved by the Institutional Ethical Committee of the University of Santiago of Chile (Inform nº 577/2015).

Men and women between 18 and 30 years old, residing in Santiago, Chile, were included in the study. Participants were required to have been selected for their sports discipline for at least six months and to have trained for six hours per week. Subjects with amputations, severe misalignments, or acute ankle and/or foot injuries were excluded. In addition, participants were asked about their ethnic group membership, which was collected through a questionnaire.

The sample size analysis indicated that a sample of 141 subjects was required to achieve a confidence level of 95% with a margin of error of 5%.

Measurements

Participants were received in the laboratory and were asked to read and sign the informed consent form. Subsequently, their body mass and height were measured. Height and weight were obtained following the ISAK (International Society for the Advancement of the Kinanthropometry) protocol (Marfell-Jones *et al.*, 2006). A scale equipped with a telescopic measuring rod (Seca, model 220, Hamburg, Germany) was utilized for taking the measurements.

To obtain body mass, subjects were asked to step on the scale wearing only underwear.

Once they stabilized their posture, the recorded value was noted on the instrument. Height was measured with subjects standing in upright position, ensuring their head aligned in the Frankfort plane. After confirming the head position was aligned, the vertex was compressed with the square, and the placement of the feet was verified. Each measurement was taken once. Then, anthropometric measurements of the foot were conducted.

In this study, the foot measurements were Foot Length (FL), Foot Breadth (FB), and Heel Foot Breadth (HFB). Subjects were positioned on a table with a flat surface and instructed to stand with their feet .1 meters apart. The separation was controlled using a piece of wood between both feet, which was removed before taking measurements (Fig. 1a). FL was measured as the linear distance between the most posterior point of the heel and the most anterior point of the toes (Fig. 1b). The latter point could be identified at the apex of either the first or second toe. FB was determined as the linear distance between the most prominent part of the inner side and the most prominent part of the outer side of the ball of the foot (Fig. 1c). HFB was measured as the longer linear distance between both sides of the heel, with the instrument positioned from a posterior angle (Fig. 1d). A manual anthropometer with an accuracy of .1 mm (Spurtar, model Kingcompany, Guangzhou, China) was utilized for these measurements, which were recorded in millimeters.

Statistical analysis

All analyses were performed using the IBM Statistical Package for the Social Sciences (SPSS) version 27. To assess the intraexaminer and interexaminer reliability of the anthropometric measurement technique, a pilot study was conducted involving two evaluators who studied 11 subjects. The measurements were repeated by both evaluators one week later. The intraclass correlation coefficient (ICC) was calculated to evaluate the consistency of both intraexaminer and interexaminer measurements.

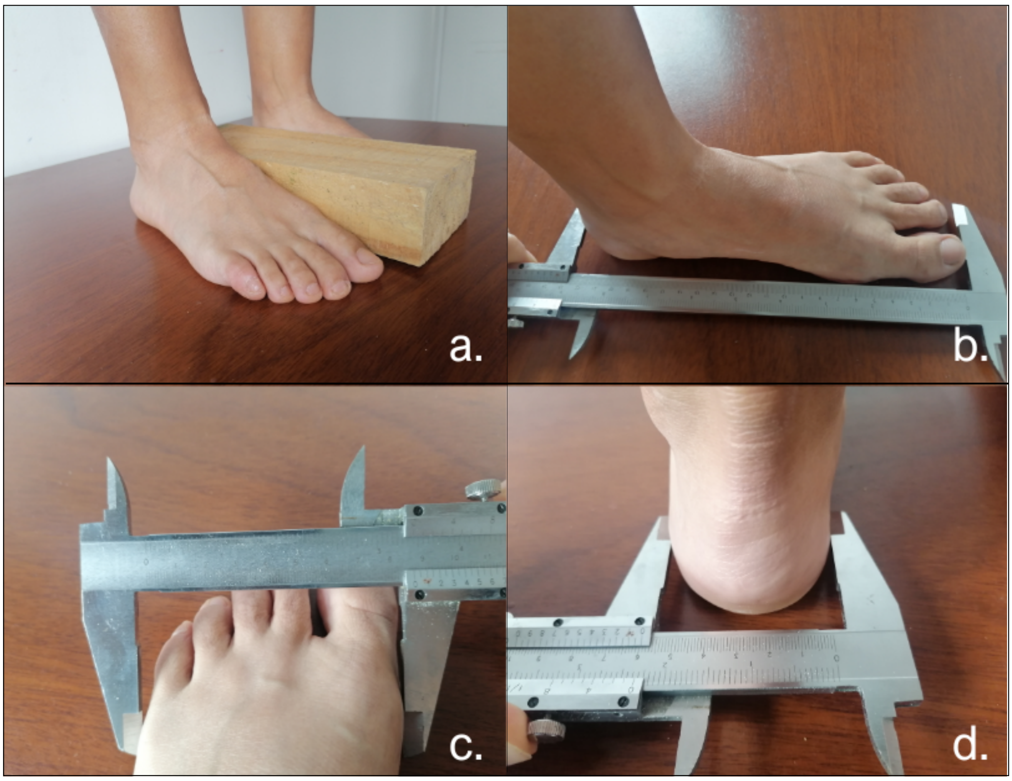

FIGURE 1. Procedure for anthropometric measurements of the foot: **a)** Feet separation by a 10 cm wide piece of wood. **b)** Measurement of Foot Length. **c)** Measurement of Foot Breadth. **d)** Measurement of Heel Foot Breadth.

The Kolmogorov-Smirnov test was used to analyse the distribution of the data. Mean values and standard deviations were computed to summarize each anthropometric variable. The analysis of bilateral differences between right and left feet was performed using a paired t-test. Pearson's correlation coefficient (r) was calculated to determine the correlation between each foot variable and height. Fisher's Z transformation was used to compare correlation coefficients. Simple and multiple linear regression equations were developed to estimate height from foot measurements. A p-value of less than .05 was considered statistically significant.

RESULTS

After applying the exclusion criteria filter, the final sample consisted of 134 subjects of both sexes, including 89 men. Reliability tests, assessed by the intraclass correlation coefficient (ICC), demonstrated high values for both intra examiner (> .88) and interexaminer (> .82) reliability. The standard error of the mean for anthropometric measurements ranged between 1.2 and 5.2 mm.

Women had a mean age, height, weight, and body mass index (BMI) of 22.2 years (± 3.1), 1.64 m (± .08), 62.3 kg (± 7.8), and 23.3 (± 2.7), respectively. On the other hand, men showed mean values of 22.8 years (± 4.4), 1.74 m (± .07), 75.2 kg (± 13.6), and 24.9 (± 3.6) of age, height, weight, and BMI, respectively. BMI values in both sees fell into the normal weight category.

Eight subjects, constituting 6% of the sample, identified themselves as belonging to the Mapuche ethnic group. The remaining subjects indicated that they did not belong to any specific ethnic group.

The descriptive statistics of the measurements of the right and left feet of females is shown in Table 1. The data indicate no significant difference in FL and FB between the two feet. However, HFB showed bila teral asymmetry among females (p = .024). Similar results were observed in Table 2 for the male group, where statistically significant differences between the right and left foot were found (p = .013). Both tables illustrate that all anthropometric foot measurements showed higher values in the male group, which was an expected result.

TABLE 1. Description of anthropometric foot measurements in the female group.

	FEMALES (n = 45)								
	Left Foot				Right Foot				p
	Mean	SD	Min	Max	Mean	SD	Min	Max	
Foot Length (mm)	237.6	11.1	218	268	238.4	10.9	213	266	.074
Foot Breadth (mm)	92.6	5.7	82	105	93	5.9	82	104	.393
Heel Foot Breadth (mm)	59.1	3.6	51	67	58.6	4.1	50	66	.024*

SD: Standard Deviation. *p < .05

TABLE 2. Description of anthropometric foot measurements in the male group.

	MALES (n = 89)								
	Left Foot				Right Foot				p
	Mean	SD	Min	Max	Mean	SD	Min	Max	
Foot Length (mm)	261	13.5	207	291	261.4	12.4	231	288	.528
Foot Breadth (mm)	103.3	6	85	124	103.4	5.7	87	122	.666
Heel Foot Breadth (mm)	65.5	5.2	54	83	64.9	4.9	51	81	.013*

SD: Standard Deviation. *p < .05

Table 3 displays the correlations between the anthropometric variables of the foot and the height of subjects in the female group. It reveals that FL exhibited the strongest correlation with height in both feet ($r > .8$), demonstrating statistical significance ($p < .001$). Following in decreasing order were FB ($r = .5$, $p < .001$) and HFB ($r = .3$, $p < .05$), each showing a consistent trend.

TABLE 3. Pearson's r coefficients between anthropometric variables of the foot with the height of the subjects in the group of females.

	FEMALES			
	Left Foot		Right Foot	
	r	p	r	p
Foot Length	.825	< .001	.807	< .001
Foot Breadth	.523	< .001	.485	< .001
Heel Foot Breadth	.348	.01	.333	.013

Table 4 presents the correlations between the anthropometric variables of the foot and the height of the subjects in the male group. Similar to the female group, FL exhibited the strongest correlation with height ($r > .7$, $p < .001$). It was followed in descending order by FB ($r > .4$, $p < .001$) and HFB ($r > .4$, $p < .001$). However, FL and FB showed lower correlation values compared to those observed in the female group. When comparing both groups using z-scores, it became evident that females had significantly higher correlations in FL (z-score 8.61 versus 3.19 in males) and FB (z-score .75 versus .35 in males). On the contrary, HFB showed a slightly higher correlation in males compared to females (z-score .27 versus -.01 in females).

TABLE 4. Pearson's r coefficients between anthropometric variables of the foot with the height of the subjects in the group of males.

	MALE			
	Left Foot		Right Foot	
	r	p	r	p
Foot Length	.71	< .001	.736	< .001
Foot Breadth	.448	< .001	.474	< .001
Heel Foot Breadth	.422	< .001	.425	< .001

Table 5 summarizes the regression equations developed for predicting height based on anthropometric measurements of the foot. Separate equations were derived for each group, considering both the combined variables (FL+ FB + HFB), and individual variables for the right and left foot. It is noteworthy that foot measurements have a more pronounced impact on height prediction in women compared to men, as indicated by the R^2 coefficients. In females, the relationship involving the three anthropometric variables of the foot explains over 67% of the height prediction variability, whereas in males, this value reaches 55%. Using only FL in the equation yields similar R^2 values as when using FL + FB + HFB in females ($R^2 > 65\%$) and males ($R^2 > 51\%$). FB and HFB contribute to the model to a lesser extent, with R^2 values < 28% in both groups. The standard error of estimation (SEE) values indicate the approximate error when using the estimated height values from the equations. Table 5 shows that equations with higher R^2 values also exhibit lower SEE, suggesting errors around .05 meters for both women and men. Likewise, the mean square error (MSE) column in Table 5 shows the average variance unexplained by the regression line. Most equations show very low MSE values approaching zero. However, the male FL variables showed MSE values slightly above .2, though still relatively small compared to the other equations.

TABLE 5. Simple and multiple regression equations for the estimation of height from foot measurements.

	Regression equations	R	R^2	SEE (m)	MSE
FEMALES					
Left Foot: FL + FB + HFB	H = .267 + .006 * FL - .001 * FB + .001 * HFB	826	682	.04	.06
Right Foot: FL + FB + HFB	H = .3 + .006 * FL - .001 * FB - .002 * HFB	816	665	.05	.06
Left Foot: FL	H = .273 + .006 * FL	825	681	.04	.18
Right Foot: FL	H = .274 + .006 * FL	807	651	.05	.17
Left Foot: FB	H = .981 + .007 * FB	523	274	.07	.07
Right Foot: FB	H = 1.049 + .006 * FB	485	235	.07	.06
Left Foot: HFB	H = 1.199 + .007 * HFB	348	121	.07	.03
Right Foot: HFB	H = 1.268 + .006 * HFB	333	111	.07	.03
MALES					
Left Foot: FL + FB + HFB	H = .749 + .003 * FL + .002 * FB + 0 * HFB	720	501	.05	.07
Right Foot: FL + FB + HFB	H = .671 + .004 * FL + .001 * FB + 0 * HFB	739	546	.05	.07
Left Foot: FL	H = .821 + .004 * FL	710	505	.05	.20
Right Foot: FL	H = .702 + .004 * FL	736	541	.05	.21
Left Foot: FB	H = 1.220 + .005 * FB	448	201	.06	.08
Right Foot: FB	H = 1.169 + .005 * FB	474	225	.06	.09
Left Foot: HFB	H = 1.382 + .005 * HFB	422	178	.06	.07
Right Foot: HFB	H = 1.362 + .006 * HFB	425	180	.06	.07

FB: Foot Breadth; **HFB:** Heel Foot Breadth; **H:** Height; **SEE**: Standard Error of Estimation; **MSE:** Mean Square Error

Table 6 displays the results of applying the height prediction equations to the study sample, alongside the actual height data of the subjects. It can be observed that the mean values obtained from the equations are similar to the mean values of the actual data. However, discrepancies are noted in the minimum and maximum values. In both sexes, the minimum values tend to overestimate. while the maximum values tend to underestimate.

TABLE 6. Comparison of the actual height and estimated height from anthropometric measurement equations. Values are expressed in meters (m).

	FEMALE			MALE		
Equation	Min	Max	Mean	Min	Max	Mean
Left Foot: FL + FB + HFB	1.55	1.83	1.66	1.64	1.84	1.74
Right Foot: FL + FB + HFB	1.38	1.67	1.52	1.69	1.93	1.82
Left Foot: FL	1.58	1.88	1.7	1.75	1.99	1.87
Right Foot: FL	1.55	1.87	1.7	1.63	1.85	1.75
Left Foot: FB	1.56	1.72	1.63	1.65	1.84	1.74
Right Foot: FB	1.54	1.67	1.61	1.6	1.78	1.68
Left Foot: HFB	1.56	1.67	1.61	1.65	1.8	1.71
Right Foot: HFB	1.57	1.66	1.62	1.67	1.85	1.75
Actual Height	1.43	1.82	1.64	1.58	1.93	1.74

FL: Foot Length; **FB:** Foot Breadth; **HFB:** Heel Foot Breadth

DISCUSSION

This study aimed to develop a height estimation model for a young adult Central Chilean population based on foot measurements. It is noteworthy that this is the first study of its kind conducted in Chilean individuals. In Latin America, a similar study has been conducted in a Brazilian population (Gomes de Moura Júnior *et al.*, 2021).

Since height serves as an indicator of nutritional quality and overall well-being, which are closely linked to socioeconomic conditions, it is worth noting that the measurements were conducted at a state university, a member of the Council of Universities of the State of Chile (information retrieved on the 28th of May 2024 from https://www.uestatales.cl/). In particular, this university's student body distribution across socioeconomic strata closely mirrors that of the country as a whole (Salas & Jara, 2019). Therefore, these findings may offer insights that shed light on aspects of the broader Chilean population.

In recent years, Chile has experienced an influx of illegal immigrants arriving (Thomazy, 2020), often through unauthorized border crossings, particularly in the Atacama Desert. This route poses significant risks, including dehydration, hypothermia, and the danger of landmines, resulting in fatalities (Valenzuela, 2020). This study holds particular significance as it could contribute to the identification of individuals in such circumstances.

The sample consisted of athletes aged between 18 and 30 years residing in the Metropolitan Region of Santiago. Six percent identified themselves as belonging to an ethnic group, a figure lower than the national average (12.8%) (Unidad de Estudios y Estadísticas de Género/Instituto Nacional de Estadísticas, 2018) but consistent with the regional standard (information retrieved on the 1st of October 2023 from https://www.desarrollosocialyfamilia.gob.cl/). This indicates that the majority of the sample identified as Chilean without specifying a particular ethnicity, suggesting that the results of this study may be extrapolated to the population of the entire Metropolitan Region.

The initial investigation examined whether there was a bilateral asymmetry in anthropometric measurements, which was only observed in HFB. Despite achieving statistical significance, it is noteworthy that the difference between the means of this variable was .5 mm in women and .6 mm in men, values below the standard error of the mean obtained in the reliability test. Based on these findings, it can be concluded that the sample did not exhibit bilateral asymmetries in any other anthropometric measurements.

Asymmetries in FL and FB have been described in previous studies (Alabi *et al.*, 2016; Hemy *et al.*, 2013) with differences typically less than 1 mm, consistent with findings in the current investigation. One study also reported statistically significant bilateral differences in FB and HFB, similar to the present study, where differences were less than 1 mm (Krishan *et al.*, 2011). Another study observed asymmetries in FL and FB in a sample of Turkish soccer players, possibly attributed to the unilateral technical movements practiced in soccer (Yamaner *et al.*, 2011). However, these differences between the mean values also did not exceed 1 mm. These findings suggest that symmetry in foot measurements appears to be a common phenomenon in both non-athlete and athlete populations. Therefore, the choice of left or right foot does not appear to significantly influence the forensic applications targeted by this research.

In the present study, foot length was the measurement that correlated most strongly with height, with Pearson's $r > .7$ in males and $r > .8$ in females, both statistically significant ($p < .001$). Similar results were found by Gomes de Moura Júnior *et al.* in a sample of Brazilian subjects. For males, these values align with the findings of nearly all reviewed studies, as summarized in Table 7 (Ahmed, 2013; Gomes de Moura Júnior *et al.*, 2021; Hemy *et al.*, 2013;

Jakhar *et al.*, 2010; Karmalkar & Nikam, 2021; Masanovic *et al.*, 2019; Sanli *et al.*, 2005; Uhrová *et al.*, 2015; Vukotic, 2020). Two studies reported correlations below .7, but their values still exceeded .6 and were statistically significant (Švábová (nee Uhrová) *et al.*, 2022; Zhang *et al.*, 2017). One study reported r < .1 with no statistical significance (Igbigbi *et al.*, 2018).

TABLE 7. Summary of the results of studies conducted in different populations. Correlation coefficients between anthropometric measurements of foot and height are indicated, as well as statistical significance values when available.

Reference	Foot Lenght	Foot Breadth	Heel Foot Breadth	Method	Population
Ahmed, 2013	Female: .622 (p < .001) Male: .773 (p < .001)	Female: .317 (p < .001) Male: .449 (p < .001)	-	Direct Anthropometry	Sudanese Arab
Gomes de Moura Júnior *et al.*, 2021	Female and Males: Left .759 (p < .001) Right .782 (p < .001)	Female and Males: Left .516 (p < .001) Right .503 (p < .001)	Female and Males: Left .347 (p < .001) Right .312 (p < .001)	Direct Anthropometry	Brazilian
Hemy *et al.*, 2013	Female: Left .746 Right .738 Male: Left .703 Right .697	Female: Left .424 Right .48 Male: Left .423 Right .401	Female: Left .355 Right .373 Male: Left .412 Right .395	Footprint	Western Australian
Igbigbi *et al.*, 2018	Female and Males: Left -.058 Right -.046	Female and Males: Left .065 Right .1	-	Direct Anthropometry	Nigerian
Karmalkar & Nikam, 2021	Female and Males: Left .674 (p < .05) Right .675 (p < .05)	Female and Males: Left .216 (p > .05) Right .179 (p > .05)	-	Direct Anthropometry	Southwestern Indian
Krishan *et al.*, 2011	Female: Left .661 (p < .001) Right .581 (p < .001)	Female: Left .375 (p < .001) Right .353 (p < .001)	Female: Left .376 (p < .001) Right .405 (p < .001)	Direct Anthropometry	Northern Indian
Jakhar *et al.*, 2010	Female: .719 (p < .01) Male: .725 (p < .01)	-	-	Direct Anthropometry	Northern Indian
Masanovic *et al.*, 2019	Female: .675 (p < .001) Male: .73 (p < .001)	-	-	Direct Anthropometry	Kosovan

TABLE 7. Summary of the results of studies conducted in different populations. Correlation coefficients between anthropometric measurements of foot and height are indicated, as well as statistical significance values when available. (continuation)

Reference	Foot Lenght	Foot Breadth	Heel Foot Breadth	Method	Population
Sanli *et al.*, 2005	Female: .609 (p < .001) Male: .716 (p < .001)	-	-	Direct Anthropometry	Turkish
Švábová (nee Uhrová) *et al.*, 2022	Female: Left .55 (p < .01) Right .58 (p < .01) Male: Left .58 (p < .01) Right .62 (p < .01)	Female: Left .29 (p > .05) Right .19 (p < .05) Male: Left .36 (p < .01) Right .3 (p < .05)	-	Footprint	Slovak
Uhrová *et al.*, 2015	Female: Left .63 (p < .01) Right .63 (p < .01) Male: Left .71 (p < .01) Right .71 (p < .01)	Female: Left .46 (p < .01) Right .45 (p < .01) Male: Left .41 (p < .01) Right .39 (p < .01)	-	Direct Anthropometry	Slovak
Vukotic, 2020	Female: .666 (p < .001) Male: .648 (p < .001)	-	-	Direct Anthropometry	Montenegrin
Zhang *et al.*, 2017	Female: .582 (p = .01) Male: .578 (p = .01)	Female: .234 (p = .01) Male: .343 (p = .01)	-	Direct Anthropometry	Han Chinese
Present Study	Female: Left .825 (p < .001) Right .807 (p < .001) Male: Left .71 (p < .001) Right .736 (p < .001)	Female: Left .523 (p < .001) Right .485 (p < .001) Male: Left .448 (p < .001) Right .474 (p < .001)	Female: Left .348 (p = .019) Right .333 (p = .025) Male: Left .422 (p < .001) Right .425 (p < .001)	Direct Anthropometry	Central Chilean

Comparing this outcome with the studies summarized in Table 7, the present study showed the highest correlation between height and foot length in women (r > .8). This result is in agreement with that reported by Gomes de Moura Júnior in a Brazilian population (r = .8). Two other studies (Hemy *et al*., 2013; Jakhar *et al*., 2010) reported slightly lower values (r > .7) in Western Australian and North Indian populations. This finding is intriguing as it suggests that Chilean women in the Metropolitan Region exhibit a higher correlation between foot length and height than other populations studied worldwide. This could indicate a trend in Latin American populations; however, further studies of this type are needed in other countries within this geographic area to confirm this observation.

In the present study, BF presented correlations of .5 or more in women. Similar results were obtained in three studies: one with a Slovak sample (Uhrová *et al*., 2015), another with a sample of Western Australians (Hemy *et al*., 2013), and a third in a Brazilian sample (Gomes de Moura Júnior *et al*., 2021). Two studies reviewed show r > .3 (Ahmed, 2013; Krishan *et al*., 2011), while three studies reported r < .3 (Igbigbi *et al*., 2018; Švábová (nee Uhrová) *et al*., 2022; Zhang *et al*., 2017). In men, the correlation in this study was .45 and .47, which aligns with the values found in studies developed with Sudanese, Western Australian, and Slovak populations (Ahmed, 2013; Hemy *et al*., 2013; Uhrová *et al*., 2015).

Heel Foot Breadth was the least considered variable in the studies reviewed. The three studies that included this variable revealed correlation values similar to those found in the present study, with r > .3 and slightly higher values in men than in women (Gomes de Moura Júnior *et al*., 2021; Hemy *et al*., 2013; Krishan *et al*., 2011).

Consistent with other studies, all the equations proposed in this study proved to be statistically significant and allowed for the prediction of the mean height values of the sample (Ahmed, 2013; Anwar *et al*., 2021). Interestingly, using only FL yields results similar to those obtained when using FL, FB, and HFB combined. Given this finding, it is recommended to use either the equations that include all three anthropometric measurements or the one that only includes FL, due to the lower SEE values obtained. On the contrary, the equations using only FB and HFB are less accurate and not recommended. However, in the absence of FL in forensic practice, they can still be used as an initial diagnostic method.

In this research, the SEE values are similar to those in other studies, which have reported estimated errors of approximately 6 cm (Švábová (nee Uhrová) *et al*., 2022), 5 cm (Hemy *et al*., 2013; Krishan *et al*., 2011; Uhrová *et al*., 2015), and 4 cm (Ahmed, 2013; Jakhar *et al*., 2010; Masanovic *et al*., 2019; Sanli *et al*., 2005). Therefore, it is reasonable to expect these error values when using the estimating equations. It is worth noting that the model fitted the female sample better than the male sample, although the differences were marginal. This trend is further corroborated by the root mean square error analysis.

The manuscript presents an exploratory study of an anthropological variable not previously considered in research in Chile. It has two important limitations that need to be acknowledged. First, the sample size is too small to represent the population of university student athletes from the chosen institution, as it did not reach the 141 subjects required by the sample size calculation. Second, the distribution between men and women was not representative of either the university population or the country's population. Future studies should focus on a representative sample of the entire country or, at least, the country's central zone where the greatest number of inhabitants are concentrated.

This study represents the first attempt to develop an estimation model for a Chilean population. However, it can be improved by using a larger sample and including participants from different geographical areas within central Chile. Likewise, there is a need to replicate this study in other areas of the country where ethnic diversity is more pronounced. For example, in the north of Chile, there are ethnic groups descended from peoples such as Atacamenians and Incas. In the south, there are descendants of the Tehuelche, Ona, or Picunche, among others.

CONCLUSION

This study successfully developed a mathematical model to predict height from the anthropometric measurements of the feet of a Chilean population of university student athletes from the Metropolitan Region of Chile. The model is valid and aligns with standards from studies conducted on other populations worldwide. Furthermore, it was demonstrated that foot length is the measurement most correlated with height and can be used independently in the equations. This study provides valuable information for the forensic medical field, specifically for identifying bodies where it is impossible to determine the height directly due to dismemberment or incompleteness.

CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

AUTHOR CONTRIBUTIONS

Celso Sánchez-Ramírez: Conceptualization, Project adminitration, Metholodogy, Data Analysis, Writing, Review and Editing.

REFERENCES

Ahmed, A. A. (2013). Estimation of stature using lower limb measurements in Sudanese Arabs. Journal of Forensic and Legal Medicine, 20(5), 483–488. https://doi.org/10.1016/j.jflm.2013.03.019

Alabi, A. S., Oladipo, G. S., Didia, B. C., & Aigbogun, E. O. (2016). Foot length and preference: implication in footwear design. *Global Journal of Anthropology Research*, *3*(2), 25–30. https://doi. org/10.15379/2410-2806.2016.03.02.01

Anwar, F., Alimgeer, K. S., Kumar, R., & Somrongthong, R. (2021). Comparing log-based and exponent-based functions to predict human height by foot length. *International Journal of Medical Toxicology and Forensic Medicine*, *11*(2), 30902. https://doi.org/10.32598/ijmtfm.v11i2.30902

Bjelica, D., Popović, S., Kezunović, M., Petković, J., Jurak, G., & Grasgruber, P. (2012). Body height and its estimation utilising arm span measurements in Montenegrin adults. *Anthropological Notebooks*, *18*(2), 69–83.

Budimlija, Z. M., Prinz, M. K., Zelson-mundorff, A., Wiersema, J., Bartelink, E., Mackinnon, G., Nazzaruolo, B. L., Estacio, S. M., Hennessey, M. J., & Shaler, R. C. (2003). World trade center human identification project: experiences with individual body identification cases. *Croatian Medical Journal*, 44(3), 259–263.

Cattaneo, C. (2007). Forensic anthropology : developments of a classical discipline in the new millennium. *Forensic Science International*, *165*(2–3), 185–193. https://doi.org/10.1016/j.forsciint.2006.05.018

Duyar, I., & Pelin, C. (2003). Body height estimation based on tibia length in different stature groups. *American Journal of Physical Anthropology*, *122*(1), 23–27. https://doi.org/10.1002/ajpa.10257

Duyar, I., & Pelin, C. (2010). Estimating body height from ulna length: need of a population-specific formula. *Eurasian Journal of Anthropology*, *1*(1), 11–17.

Gomes de Moura Júnior, J., Granja Porto Petraki, G., Marques Zimmerle, C., Portela Lima de Morais, R., & Azoubel Antunes, A. (2021). Estudo da correlação da estatura com medidas antropométricas plantares para fins de identificação humana. *Brazilian Journal of Forensic Anthropology & Legal Medicine*, *4*, 73–100.

Hemy, N., Flavel, A., Ishak, N. I., & Franklin, D. (2013). Estimation of stature using anthropometry of feet and footprints in a Western Australian population. *Journal of Forensic and Legal Medicine*, 20(5), 435–441. https://doi.org/10.1016/j.jflm.2012.12.008

Igbigbi, P. S., Ominde, B. S., & Adibeli, C. F. (2018). Anthropometric dimensions of hand and foot as predictors of stature: A study of two ethnic groups in Nigeria. *Alexandria Journal of Medicine*, *54*(4), 611–617. https://doi.org/10.1016/j.ajme.2018.11.002

Jakhar, J. K., Pal, V., & Paliwal, P. K. (2010). Estimation of height from measurements of foot length in Haryana Region. *Journal of Indian Academy of Forensic Medicine*, *32*(3), 231–233.

Karmalkar, A. S., & Nikam, V. R. (2021). Prediction of stature from long bones versus hand and foot measurements: A comparative study of the Kolhapur population. *The National Medical Journal of India*, *34*(3), 154–157. https://doi.org/10.25259/NMJI_79_20

Krishan, K., Kanchan, T., & Passi, N. (2011). Estimation of stature from the foot and its segments in a sub-adult female population of North India. *Journal of Foot and Ankle Research*, *4*(1), 24. https://doi.org/10.1186/1757-1146-4-24

Marfell-Jones, M. J., Olds, T., Stewart, A. D., & Carter, L. (2006). *International standards for anthropometric assessment*. International Society for the A dvancement of Kinanthropometry (ISAK).

Masanovic, B. (2018). Standing height and its estimation utilizing arm spam and foot length measurements in Dinaric Alps population: a systematic review. *SportMont*, *16*(2), 101–106. https://doi.org/10.26773/smj.180619

Masanovic, B., Gardasevic, J., & Arifi, F. (2019). Relationship between foot length measurements and body height: A prospective regional study among adolescents in northern region of Kosovo. *Anthropologie*, *LVII*(2), 227–233.

Özaslan, A., Işcan, M. Y., Özaslan, I., Tuğcu, H., & Koç, S. (2003). Estimation of stature from body parts. *Forensic Science International*, *132*(1), 40–45. https://doi.org/10.1016/S0379-0738(02)00425-5

Pelin, C., Duyar, I., Kayahan, E., Zagyapan, R., Agildere, A. M., & Erar, A. (2005). Body height estimation based on dimensions of sacral and coccygeal vertebrae. *Journal of Forensic Sciences*, *50*(2), JFS2004010–4, https://doi.org/10.1520/JFS2004010

Pelin, C., Zagyapan, R., Yazici, C., & Kürkcüoglu, A. (2010). Body height estimation from head and face dimensions: a different method. *Journal of Forensic Sciences*, *55*(5), 1326–1330. https://doi.org/10.1111/j.1556-4029.2010.01429.x

Perkins, J. M., Subramanian, S. V., Smith, G. D., & Özaltin, E. (2016). Adult height, nutrition, and population health. *Nutrition Reviews*, *74*(3), 149–165. https://doi.org/10.1093/nutrit/nuv105

Popovic, S., Bjelica, D., Molnar, S., Jaksic, D., & Akpinar, S. (2013). Body height and its estimation utilizing arm span measurements in Serbian adults. *International Journal of Morphology*, *31*(1), 271–279.

Salas, V., & Jara, R. (2019). Cambios en el perfil socioeconómico de estudiantes de educación superior en Chile. *Observatorio de Políticas Públicas USACH, Minuta 14*. https://economia.usach.cl/index.php/informes-y-notas/observatorio-de-politicas-en-educacion-superior

Sanli, S. G., Kizilkanat, E. D., Boyan, N., Ozsahin, E. T., Bozkir, M. G., Soames, R., Erol, H., & Oguz, O. (2005). Stature estimation based on hand length and foot length. *Clinical Anatomy*, *18*(8), 589–596. https://doi.org/10.1002/ca.20146

Švábová (nee Uhrová), P., Caplova, Z., Beňuš, R., Chovancová (nee Kondeková), M., & Masnicová, S. (2022). Estimation of stature and body weight from static and dynamic footprints – Forensic implications and validity of non-colouring cream method. *Forensic Science International*, *330*, 111105. https://doi.org/10.1016/j.forsciint.2021.111105

Thomazy, G. (2020). Tendencias actuales y nuevos desafíos de los migrantes en Chile. *Acta Hispanica*(II), 409–421. https://doi.org/10.14232/actahisp.2020.0.409-421

Uhrová, P., Beňuš, R., Masnicová, S., Obertová, Z., Kramárová, D., Kyselicová, K., Dörnhöferová, M., Bodoriková, S., & Neščáková, E. (2015). Estimation of stature using hand and foot dimensions in Slovak adults. *Legal Medicine, 17*(2), 92–97. https://doi.org/10.1016/j.legalmed.2014.10.005

Unidad de Estudios y Estadísticas de Género. (2018). *Radiografía de Género: Pueblos Originarios en Chile 2017*. Instituto Nacional de Estadística de Chile.

Valenzuela, E. (2020). Frontera y luchas migrantes: riesgos y desafíos en el norte de Chile. In B. Frey, A. Forcintio, & A. Pardo (Eds.). *Migraciones, Derechos Humanos y Acciones Locales* (pp. 92–105). Hispanic Issues On Line 26.

Vukotic, M. (2020). Body height and its estimation utilizing foot length measurements in Montenegrin adolescents: a national survey. *Nutrición Hospitalaria*, 37(4), 794–798. http://dx.doi.org/10.20960/nh.03056

Yamaner, F., Karakabey, K., Kavlak, Y., & Sevindi, T. (2011). Foot morphology of Turkish football players according to foot preference. *African Journal of Biotechnology*, *10*(26), 5102–5108. https://doi.org/10.5897/AJB10.2622

Zhang, X., Wei, Y., Zheng, L., Yu, K., Zhao, D., Bao, J., Li, Y., Lu, S., Xi, H., Xu, G., & Wen, Y. (2017). Estimation of stature by using the dimensions of the right hand and right foot in Han Chinese adults. *Science China Life Sciences*, *60*(1), 81–90. https://doi.org/10.1007/s11427-016-0051-8