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Predictive formulas for estimation of height in sub-Saharan African older people: a new formula (EPIDEMCA study)

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Short running head: Estimation of height in sub-Saharan African elderly.

Conflict of interest: none

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Abstract

Background: Chumlea’s formulas are means of predicting height from knee height (KHt), including among people aged over 60 years who cannot get upright. However, they were developed in Caucasian and African-American people and have not yet been validated in older native Africans. The aims of the study were (i) to assess Chumlea's formulas in older people in Central Africa and (ii) to propose a new validated formula in the same population.

Methods: Height (MHt) and KHt were measured in a population of people over 65 years old from the Republic of Congo and the Central African Republic. Predicted height (PHt) was calculated using Chumlea's formulas for the American black population (CBP) and for Caucasian (CC). The percentages of accurate predictions (± 5 cm) were compared between MHt and PHt. A new formula was estimated after randomization in a derivation sample (n=877) and assessed for accuracy in a validation sample (n=877).

Results: A total of 1754 individuals were included. Prediction was accurate (± 5cm) in 66.8% and 63.2% of CBP and CC, respectively. Overestimation was as high as 24.1% and 29.0%, respectively. As such an overestimation is unacceptable in clinical practice and population surveys, a new formula was proposed: height(cm) = 72.75 + (1.86 * KHt[cm]) - (0.13 * age[years]) + 3.41 * sex (0: women; 1: men). This new formula significantly increases accuracy (71.3%) and decreases overestimation (14.7%). The nutritional status based on body mass index was not different with the MHt and the PHt by the new formula.

Conclusion: Chumlea’s formulas provided a poor estimate of height in this population sample. The proposed formula more accurately estimates height in older native Africans. This formula should be tested in other sub-Saharan African countries in order to extend its use in clinical practice and in future studies.

Key words: norms, reference equation, anthropometric data, ageing, body mass index, ethnicity

Abbreviation list

BMI: body mass index

CAR: Central African Republic

CBP: Chumlea's formula for non-hispanic black people

CC: Chumlea's formula for Caucasian people

ICC: intraclass correlation coefficients

IQR: interquartile range

MHt: Measured height

n: number

PHt: predicted height

P-M: predicted height minus measured height

ROC: Republic of Congo

R^2: coefficient of determination

SD: standard deviation

Introduction

Nutritional status is often assessed using body mass index (BMI), which requires height for its calculation [1]. In epidemiological studies and clinical practice, height may be difficult to measure in older adults because of an inability to stand upright (due to physical disability or spinal distortion). In those instances, an alternative way of estimating height in older adults is essential in order to accurately assess nutritional status. Chumlea et al. [2–4] proposed several formulas with which to estimate height using knee height (KHt) in different populations including African Americans. To the best of the authors' knowledge, these formulas have not been validated in older native central Africans. Despite, the lack of validation of these formulas in sub-Saharan populations, some studies conducted in Africa used different formula to predict height of older people [5–7]. Numerous recent studies have looked at nutritional status in older adults from sub-Saharan Africa [5,6,8–18]. Due to a lack of data on height, BMI could not be calculated in 2.5 to 6.5% of the populations in several studies in Africa [5,8,19,20]. Recently, our research team studied these formulas in Benin and found an accurate prediction of height (±5 cm) close to 80% [21]. The aims of this study were: i) to assess the validity of three Chumlea's formulas to provide predicted height (PHt) in older people from central Africa; ii) if validation failed, to propose a new formula for estimation of height for this population; and iii) to compare BMI and nutritional status according to measured height (MHt) and PHt.

Population and Methods

Study Design

The EPIDEMCA study is a multicenter population-based cross-sectional survey in rural and urban areas in the Central African Republic (CAR - Bangui and Nola) and in the Republic of Congo (ROC - Brazzaville and Gamboma). Conducted between November 2011 and December 2012, its main objective was to assess the prevalence of dementia and to investigate its risk factors. The sample size was estimated *a priori* at 500 in each study site. In urban areas, participant selection was carried out stratified by city subdivision, with random sampling proportional to the size of each subdivision. In rural areas, exhaustive sampling using a door-to-door approach was adopted for logistic and financial reasons. The detailed methodology is described in an open-access publication [22].

Inclusion criteria

Individuals 65 years of age and older who lived in the study areas at the time were included. Those who declined to participate or presented severe comorbidities (cancers, bedridden condition,) carrying a high risk of death, which did not allow longitudinal follow-up for future studies were excluded.

Ethics

Approval was obtained from the ethical committees supervised by the Ministry of Public Health in CAR, the *Comité d'Éthique de la Recherche en Sciences de Santé* in ROC, and the *Comité de Protection des Personnes du Sud-Ouest et d'Outre-Mer 4* in France. All participants and/or their families gave informed consent prior to inclusion in the study. Written consent was obtained where feasible. For illiterate people, the study's objectives were verbally explained and consent was obtained by thumbprint.

Anthropometric measurements

Anthropometric measurements were performed by 10 medical students (at least in their 6th year), from Bangui and Brazzaville Universities. All students were specifically trained in order to limit the inter-measurer bias. Weight (kg) was measured in an upright position to the nearest 100g using a portable mechanical balance with a weighing capacity of 10 to 150 kg (Seca™ Hamburg, Germany). MHt (cm) was determined at the nearest centimeter using a carpenter's measure along as flat a surface as possible, such as a door or a wall. KHt (cm) was measured in all participants with a paediatric height scale to the nearest centimeter on the right leg with an angle of 90° between the thigh and the leg in a supine position according to Chumlea et al. [2]. The paediatric height scale was placed in line with the lateral malleolus and the head of the fibula; with the soft tissue compressed, the distance from the sole of the foot to the top of the thigh immediately above the condyles of the femur was measured. BMI was calculated by dividing the weight in kilograms by the height in meters squared and rounded to 1 decimal place [1]. Undernutrition was defined as BMI < 18.5 kg/m², normal status as BMI between 18.5 and 24.9 kg/m², overweight as BMI between 25 and 29.9 kg/m² and obesity as BMI ≥ 30 kg/m² [1].

Estimation of height using Chumlea's formulas

Chumlea et al. developed several formulas for estimation of height according to the population. In this study, two Chumlea's formulas were used, one for non-Hispanic American black people (CBP) and one for Caucasian (CC) as used in the study of Marais et al. in a mixed population in South Africa (black African and Caucasian people) [4,7].

CBP [2]:

height (cm) = 79.69 + (1.85 * KHt[cm]) - (0.14 * age[years]) for men (coefficient of determination [R^2]): 70.0%)

height (cm) = 89.58 + (1.61 * KHt[cm]) - (0.17 * age[years]) for women (R^2: 63.0%)

CC [4,7]:

height(cm) = 59.01 + (2.08 * KHt[cm]) for men (R^2: 68.0%)

height(cm) = 75.00 + (1.91 * KHt[cm]) - (0.17 * age[years]) for women (R^2: 59.0%).

Other data

Age was ascertained from official documents, by using historical events [23], or from an informant. Sex and country of residence were also recorded.

Data analysis

Population description

Percentages and median with interquartile range (IQR) were used to describe the study sample.

Validation of Chumlea's formulas

The degree of agreement between PHt and MHt was assessed using Bland and Altman plots and intraclass correlation coefficients (ICC) [24]. The percentage of difference and the 95% limit of agreement were also computed. The mean percentage of difference between PHt and MHt was calculated [21]. Based on clinical and epidemiological experience, a threshold of ± 5 cm (3% of the MHt) was considered as an acceptable threshold for the difference between the predicted and measured heights [21]. This threshold of ± 5 cm was used in a previous study in Benin [21]. The percentage of accurate prediction (between - 5 cm and + 5 cm) was accordingly calculated. A prediction over 5 cm was considered as an overestimation and under 5 cm as an underestimation.

Creation of a new formula

After randomization, two subsamples were created: a derivation subsample (n = 877) to construct the new formula, and a validation subscale (n = 877) to test it. Mann-Whitney and Chi square tests were used to compare the two subsamples. The new formula was created based on a linear multiple regression according to sex, age and KHt in the derivation subsample. The coefficient of determination (R^2) of the linear regression was calculated. Accuracy of this new formula was tested on the validation subsample with Bland and Altman plots and ICC [24]. The percentage of accurate predictions was also calculated with the above-mentioned strategy and compared it to CBP.

BMI and nutritional status assessment

Mann-Whitney test was used to compare BMI calculated with MHt and with all PHt formulas. Chi square test was used to compare nutritional status (undernutrition, normal, overweight and obesity) with MHt and with all PHt formulas.

Data were analysed using GraphPad Prism 6.0 (GraphPad Software Inc, La Jolla, CA, USA) and SAS® software v9.3 (SAS Institute, Cary, North Carolina, USA). A p-value <0.05 was the limit of significance. STROBE statement was complied with [25].

Results

Characteristics of the participants

A total of 2,002 individuals 65 years of age and older were included in the EPIDEMCA survey. Height was missing for 167 participants, KHt for 144 and weight for 94. In this study, 1,754 individuals (n=880 in ROC; n=874 in CAR) were analysed.

Table 1 shows the characteristics of the participants. Women accounted for 61.5%, with no significant differences between countries. ROC participants were significantly older than those from CAR (72.0 [68.0 – 78.0] vs. 71.0 [67.0 – 76.0] years, respectively - p= 0.004). The median MHt was 157.0 cm [150.5 – 164.0]; participants were significantly shorter in ROC than in CAR (156.0 [149.9 – 162.0] vs. 158.0 [153.0 – 165.0] cm, respectively - $p < 0.001$). Mean height was 164.0 cm [158.0 – 170.0] among men and 153.0 cm [148.0 – 158.4 among women ($p < 0.001$).

Validity of Chumlea's formulas in older adults from Central Africa

Table 2 presents the accuracy of the PHt calculated using the two Chumlea formulas. Figure 1 shows the Bland and Altman plots for the total sample, ROC and CAR. The ICC was 0.77 (95% confidence interval [95%CI]: 0.71 – 0.82) and 0.78 (95%CI: 0.68 – 0.84) between MHt and CBP and CC, respectively.

The percentages of accurate estimation by the two Chumlea formulas are shown by sex, age and country in Figure 2. The percentage of accurate prediction was higher using CBP (66.8%) compared to CC (63.2%, p =0.028). The agreement was lower among men 75 years of age and older than in younger ones in both countries but not among women.

The CBP and CC overestimated height in 24.2% and 29.0% of cases, respectively.

New formulas for estimation of height for older central Africans

The deviation subsample and validation subsample were not significantly different (Table -1).

Using the derivation subsample, a new sex-adjusted formula was obtained:

- Height(cm) = 72.75 + (1.86 * KHt[cm]) - (0.13 * age[years]) + 3.41 * sex (0: women; 1: men)

(R^2 of this model was 66.9%)

Results of the validation study are presented in Table 3. The ICC was 0.78 (95%CI: 0.76 – 0.81). The percentage of accurate predictions was 71.3% with the new formula and was significantly better than with CBP (65.3%, $p = 0.008$). Figure 3 shows the Bland and Altman plots for the two Chumlea's formulas and the new formula in the validation sample. The distribution of points was homogeneous between the three formulas studied. The majority of points was between the 95% limit of agreement.

Impact on nutritional status assessment

In the whole sample, the mean BMI calculated with the PHt with Chumlea's formulas (19.5 kg/m^2 [17.3 – 22.4], $p<0.001$ and 19.4 kg/m^2 [17.2 – 22.3], $p< 0.001$ with CBP, CC, respectively) was significantly lower than when MHt was used (20.1 kg/m^2 [17.8 – 23.1]). Accordingly, the percentage of older adults with undernutrition was significantly lower when BMI was calculated using MHt (34.3%) rather than PHt (38.7%, $p = 0.008$ and 40.1%, $p = 0.0004$ with CBP and CC, respectively). However, in the whole sample BMI using PHt with the new formula did not differ significantly from BMI using MHt (19.9 [17.7 – 23.0] vs. 20.1 [17.8 – 23.1] kg/m^2, respectively - $p = 0.74$). The percentage of undernutrition defined using height estimated with the new formula did not differ significantly from that defined by MHt (34.3% vs. 34.3%, respectively - $p = 1.00$). Nutritional status using BMI according to the

MHT or PHt in the total sample and in the Republic of Congo and Central African Republic is presented in table 4.

Discussion

To the best of the authors' knowledge, this study is the first to assess the validity of Chumlea's predictive formulas for estimating height in older native central Africans. These formulas require simple criteria for their use, such as age, sex and KHt [2]. KHt is the fundamental measurement necessary for the application of these formulas. KHt should be measured as recommended to avoid biasing the prediction of height [2]. These formulas have been created and validated in different populations over 60 years old. Their main limitation is the lack of validation of these formulas in sub-Saharan populations. Recent years have seen an increase in nutritional studies in older adults in sub-Saharan Africa [5,6,8–18,20]. In the absence of a validated formula, previous work used CBP and CC formulas. CBP was used in Pilleron et al. and Samba et al., studies in Central Africa, [5,6,19], and CC was used in one study in South Africa but in several ethnic groups [7]. According to the results of this study, the validity of these formulas (CBP and CC) is not adequate in these two countries of Central Africa (ROC and CAR). These formulas may lead to misclassification of individuals based on BMI. Validated tools with which to assess height as accurately as possible when its measurement is impossible are required. Therefore, a specific formula was created that performed better and allowed for better categorisation of participants based on their nutritional status as assessed by BMI. Chumlea's formulas tended to overestimate height in this population leading to increased estimation of the prevalence of undernutrition, which is not the case with the new formulas. However, CPB was better than the formula for Caucasian applied in sub-Saharan populations. CC is not recommended for use in this population. Moreover, CPB seems more reliable in other African countries such as Benin [21]. The principal strengths of this study are the large sample size and the multicenter design including rural and urban areas in two neighboring countries in central Africa. In addition, use of a more precise formula validated in this specific population to estimate height would improve the screening of nutritional disorders in elderly Africans in both epidemiological surveys and clinical settings. The main aim is reliable screening of undernutrition in older sub-Saharan African people, which is found in 8.3 to 34.7% and associated with chronic diseases [26]. Information on the use of this simple tool should be developed in Africa. However, in these populations, nutritional status may sometimes not be studied with the measurement of weight and height even estimated, in the absence of appropriate measuring equipment. Other simple anthropometric criteria can be used to screen undernutrition such as brachial circumference or mid-upper arm muscle circumference requiring the measurement of the tricipital skin fold [5]. Moreover, these anthropometric measurements are simple to obtain and require little equipment (measuring tape and Harpenden caliper). This equipment is also more easily transportable than a mechanical or electronic weight scale and a height scale, allowing easier screening mainly in rural areas. Several limitations must also be acknowledged. Anthropometric measurements may be subject to inter-measurer variability. However, all researchers were specifically trained during three weeks and examiners were selected according to their performances during the training [22]. This variability was probably limited. The plastic height scales used during the survey may have been slightly deformed by high temperatures, leading to small variations in measurement between the beginning and the end of the survey. Moreover, some conditions such as knee arthrosis, rheumatoid arthritis could modify the KHt measurement but to the best of the authors' knowledge, studies on this subject have not been found. Patients with these conditions were not excluded. Validation of the present formula in another independent sample of older people of CA is required. Moreover the new formula could be validated in other countries of sub-Saharan Africa, for example in Benin where height predictive formulas have also been studied [21].

Conclusion

In an older native African population, Chumlea's original formulas provide poor estimation of height. This could be overcome by creating population-specific formulas that are essential to the efficient screening of poor nutritional status (undernutrition and overweight/obesity) in older adults in SSA. It seems important to test this formula in other sub-Saharan African countries to develop its use in both epidemiologic surveys and clinical settings in sub-Saharan Africa.

Authors' contributions:

PJ, BM, SP, MG, PM, BNB, PMP and JCD designed the research; SP, MG, PM and BNB provided databases; PJ and BM performed statistical analysis; PJ, BM, SP, MG, PMP, PF and JCD wrote the paper. All authors approved the final manuscript.

Figure legends

Figure 1: Bland and Altman plots between measured height and predicted height with the two Chumlea's formulas in the total sample (n=1754), in the Republic of Congo (n=880) and the Central African Republic (n=874).

Chumlea's formula for non-Hispanic Black people: A: in the total sample, B: in ROC, C: in CAR; Chumlea's formula for Caucasian people: D: in total sample, E: in ROC, F: in CAR.

CAR: Central African Republic; ROC: Republic of Congo; SD: standard deviation.

Figure 2: Percentage of accurate prediction between measured height and height predicted using the two Chumlea formulas according to sex and age in the total sample (n=1754), in the Republic of Congo (n=880) and Central African Republic (n=874).

Total Sample: A: men; B: women; Republic of Congo: C: men; D: women; Central African Republic: E: men; F: women

Dark column: Chumlea's formula for non-Hispanic Black people; clear column: Chumlea's formula for Caucasian people

CAR: Central African Republic; CBP: Chumlea's formula for non-Hispanic Black people; CC: Chumlea's formula for Caucasian people; ROC: Republic of Congo.

Figure 3: Bland and Altman graphics between the measured height and the height predicted using the three Chumlea formulas and the created formula in the validation subsample (n=877).

A: Chumlea's formula for non-Hispanic Black people; B: Chumlea's formula for Caucasian people; C: Created formula.

SD: standard deviation

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Figure 1: Bland and Altman plots between measured height and predicted height with the two Chumlea's formulas in the total sample (n=1754), in Republic of Congo (n=880) and Central African Republic (n=874).

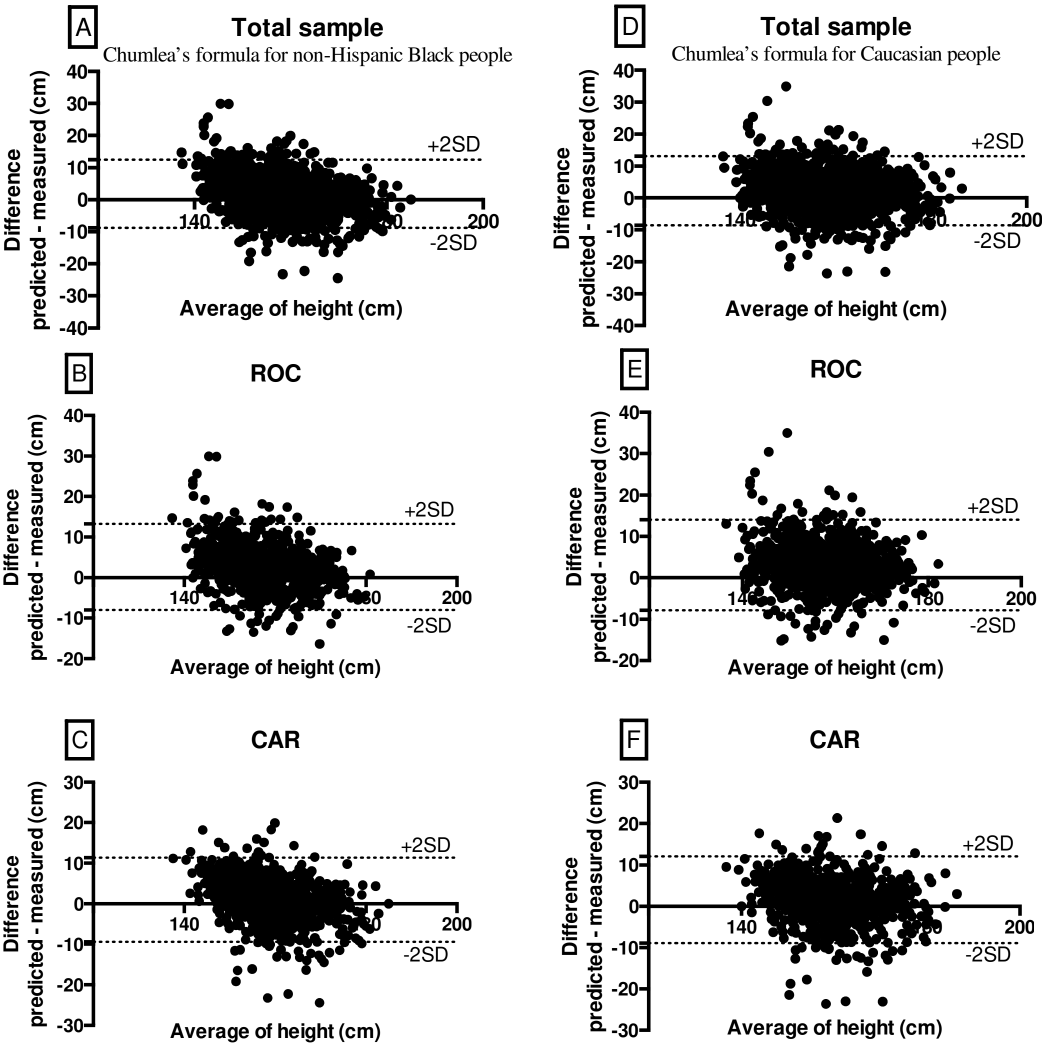

Figure 2: Percentage of accurate prediction between measured height and height predicted using the two Chumlea's formulas according to sex and age in the total sample (n=1754), in the Republic of Congo (n=880) and Central African Republic (n=874).

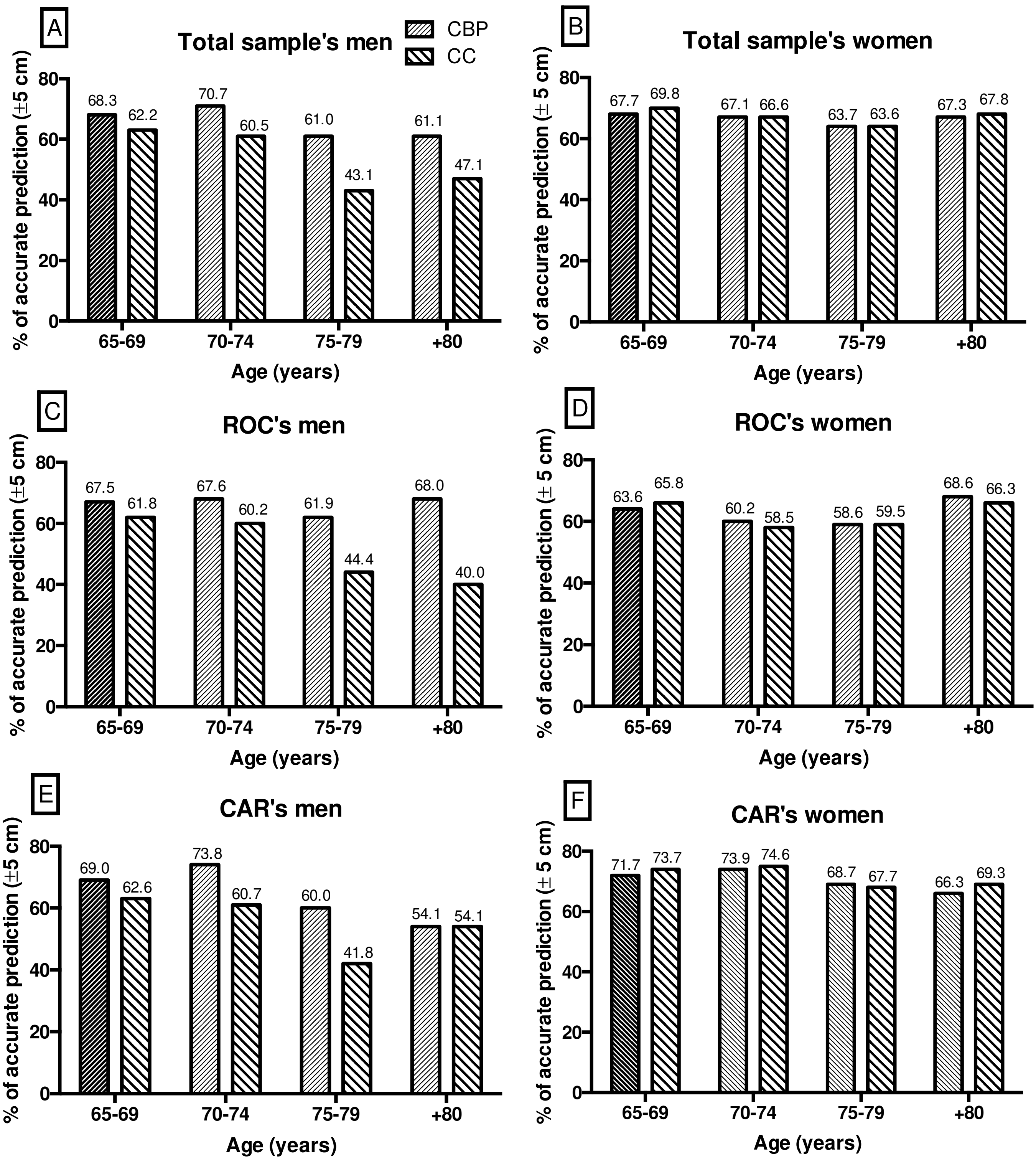

Figure 3: Bland and Altman graphics between the measured height and the height predicted using the two Chumlea's formulas and the created formula in the validation subsample (n=877).

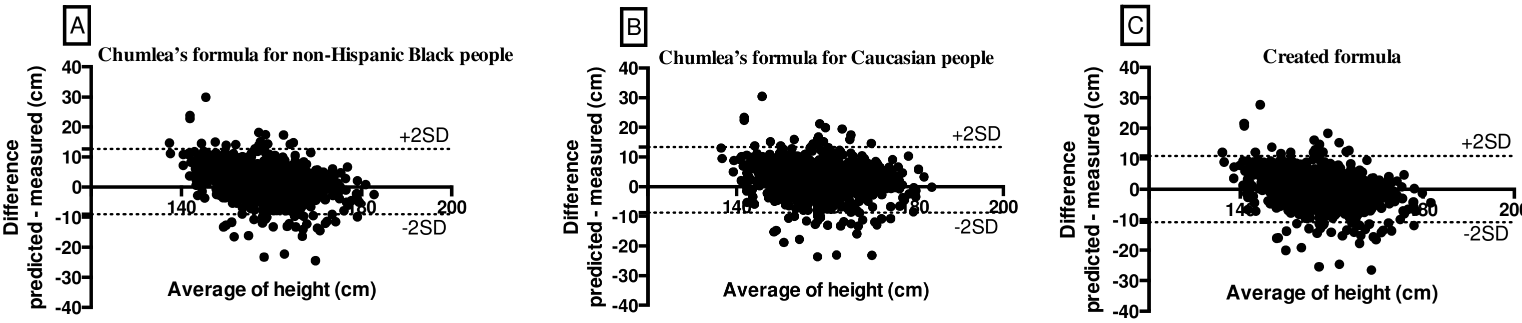

Table 1: Characteristics of the total sample (n=1754), derivation subsample (n=877) and validation subsample (n=877)

	Total sample (n = 1,754) median (IQR) or n (%)	Derivation subsample (n = 877) median (IQR) or n (%)	Validation subsample (n = 877) median (IQR) or n (%)	p Derivation subsample vs. validation subsample
Women	1079 (61.5)	555 (63.3)	524 (59.7)	0.13
Age (years)	72.0 (67.0 - 77.0)	71.0 (78.0 - 77.0)	72.0 (67.0 - 77.0)	0.63
ROC	880 (50.2)	441 (50.3)	439 (50.1)	0.92
Rural area	899 (51.3)	463 (52.8)	436 (49.7)	0.20
Weight (kg)	49.0 (43.0 - 59.0)	49.0 (43.0 - 59.0)	49.0 (43.0 - 58.8)	0.89
Height (cm)	157.0 (150.5 - 164.0)	157.0 (150.2 - 163.8)	157.0 (151.0 - 164.0)	0.91
KHt (cm)	50.0 (48.0 - 52.0)	50.0 (47.5 - 52.0)	50.0 (48.0 - 52.0)	0.78
BMI (kg/m^2)	20.1 (17.8 - 23.1)	20.2 (17.7 - 23.2)	20.90 (17.8 - 23.0)	0.81

BMI: body mass index; IQR: interquartile range; KHt: knee height; ROC: Republic of Congo.

p (chi square test or Mann-Whitney test): derivation vs. validation subsamples.

Table 2: Prediction of height (PHt) using the two Chumlea's formulas compared to measured height (MHt) in the total sample (n = 1754), in the Republic of Congo (ROC, n=880) and in the Central African Republic (CAR, n=874).

	Height		Bias		95% limit of agreement			Prediction		
Total sample (n=1754)	Mean (cm)	SD	P-M (cm)	%	From	to	% between limit	Accurate (%)	Under 5 cm (%)	Over 5 cm (%)
- MHt	157.4	9.4	-	-	-	-	-	-	-	-
- CBP	159.2	7.4	1.8	1.1	-8.8	12.4	94.2	66.8	9.1	24.1
- CC	159.7	8.3	2.3	1.4	-8.5	13.1	94.4	63.2	7.8	29.0
ROC (n=880)										
- MHt	155.9	7.3	-	-	-	-	-	-	-	-
- CBP	158.5	7.8	2.6	1.6	-8.0	13.2	94.5	64.2	6.7	29.1
- CC	158.9	8.3	3.0	1.9	-7.9	14.0	95.2	59.8	6.1	39.1
CAR (n=874)										
- MHt	159.0	9.1	-	-	-	-	-	-	-	-

- CBP	160.0	7.4	1.0	0.6	-9.4	11.4	94.6	69.4	11.4	19.2
- CC	160.5	8.3	1.5	0.9	-9.0	12.1	94.7	66.6	9.5	23.9

CBP: Chumlea's formula for non-hispanic Black people; CC: Chumlea's formula for Caucasian people; P-M: PHt minus MHt; SD: standard deviation.

Table 3: Prediction of height (PHt) using the two Chumlea's formulas and the created formula compared to measured height (MHt) in the validation subsample (n=877).

	Height		Bias		95% limit of agreement				Prediction		
All (n=877)	Mean (cm)	SD	P-M (cm)	%	From	to	% between limit	ICC (95%CI)	Accurate (%)	Under 5cm (%)	Over 5cm (%)
- MHt	157.5	9.3	-	-	-	-	-	-	-	-	-
- CBP	159.3	7.4	1.8	1.2	-9.1	12.7	94.4	0.76 (0.70 – 0.81)	65.3	8.8	25.9
- CC	159.8	8.3	2.3	1.4	-8.7	13.4	94.6	0.77 (0.67 – 0.83)	61.8	7.8	30.4
- Created formula	157.5	7.5	0.0	0.0	-10.8	10.9	94.1	0.78 (0.76 – 0.81)	71.3*	14.0*	14.7*

*Comparison of percentage of prediction with CBP vs. created formula, $p < 0.05$

CBP: Chumlea's formula for non-Hispanic Black people; CC: Chumlea's formula for Caucasian; CI: confidence interval; ICC: intraclass correlation coefficient; P-M: PHt minus MHt; SD: standard deviation.

Table 4: Nutritional status using body mass index (BMI) according to the measured or predicted height in the total sample (n=1748), Republic of Congo (n=878) and in Central African Republic (n=870).

	Total sample			
	measured	CBP	CC	Created formula
BMI (kg/m^2) median (IQR)	20.1 (17.8 - 23.1)	19.5 (17.3 - 22.4)*	19.4 (17.2 - 22.3)*	19.9 (17.7 - 23.0)
Undernutrition n (%)	600 (34.3)	676 (38.7)*	701 (40.1)*	599 (34.3)
Normal status n (%)	868 (49.7)	811 (46.4)	797 (45.6)	857 (49.0)
Overweight n (%)	199 (11.4)	183 (12.4)	174 (10.0)	204 (11.7)
Obesity n (%)	81 (4.6)	78 (4.5)	76 (4.3)	88 (5.0)
	Republic of Congo			
	measured	CBP	CC	Created formula
BMI (kg/m^2) median (IQR)	20.4 (18.0 - 23.6)	19.8 (17.3 - 22.9)*	19.8 (17.3 - 22.9)*	20.2 (17.8 - 23.5)
Undernutrition n (%)	265 (30.2)	320 (36.5)*	328 (37.4)*	281 (32.0)

Normal status n (%)	444 (50.6)	410 (46.7)	408 (46.5)	432 (49.2)
Overweight n (%)	116 (13.2)	102 (11.6)	97 (11.0)	110 (12.5)
Obesity n (%)	53 (6.0)	46 (5.2)	45 (5.1)	55 (6.3)
	Central African Republic			
BMI (kg/m^2) median (IQR)	19.7 (17.5 - 22.2)	19.2 (17.3 - 22.1)	19.1 (17.1 - 22.0)*	19.7 (17.6 - 22.5)
Undernutrition n (%)	335 (38.5)	356 (40.9)	373 (42.9)	318 (36.6)
Normal status n (%)	424 (48.7)	401 (46.1)	389 (44.7)	425 (48.8)
Overweight n (%)	83 (9.6)	81 (9.3)	77 (8.8)	94 (10.8)
Obesity n (%)	28 (3.2)	32 (3.7)	31 (3.6)	33 (3.8)

* Comparison between measured height and predictive formulas, $p < 0.05$

CBP: Chumlea's formulas for non-Hispanic Black people; CC: Chumlea's formulas for Caucasian people; IQR: interquartile range.