Simple method for assessing standing height using recumbent length in bedridden patients using soft and firm mattresses

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ABSTRACT

Introduction: The accurate measurement of the height of bedridden patients is difficult. Height assessment is required for the calculation of body mass index, which is crucial for determining the nutrition status of a patient. This study aimed to validate recumbent length measurement against the standing height measurement using soft and firm mattresses and to derive predictive equations to calculate the actual height of bedridden patients on mattresses with different firmness. **Methods**: Ninety-nine hospitalised participants (mean age 48.9±13.9 years; range 21–80 years) (49 men, 50 women) and 100 healthy participants (mean age 36.8±13.6 years; range 21–77 years) (50 men, 50 women) were recruited. Standing height was measured using a stadiometer. Recumbent length was measured using a 2 metre long measuring tape. Hospitalised participants lay on soft mattress and healthy participants on firm mattress. **Results**: Using Bland–Altman plot, 96% of hospitalised participants using soft mattress were within 2.5±2.7 cm (mean±2SD) whereas 97% of healthy participants using firm mattress were within 2.1±2.1 cm. The regression equation developed using firm mattress was Standing height (cm) = 0.993 x Recumbent length – 0.943; (r^2=0.982). The regression equation developed using soft mattress was Standing height (cm) = 1.012 x Recumbent length – 4.477; (r^2=0.981). **Conclusion**: We concluded that recumbent length is a valid clinical tool to estimate standing height. Standing height can be estimated from the predictive equations developed for patients lying on soft or firm mattresses.

Keywords: Recumbent length, height, measuring tape, Asian, bedridden

INTRODUCTION

Patients may be immobilised and bedridden because of stroke, head trauma, severe acute brain injury (Creutzfeldt & Hough, 2015) or hip or leg fracture (Selikson, Damus & Hamerman, 1988). The accurate assessment of height in this group is necessary to evaluate body mass index (BMI), which is crucial for determining the nutritional status of these patients. In addition, certain calculations of energy requirements are dependent on height, such as the Harris–Benedict formula (Harris & Benedict, 1918) and Mifflin–St Jeor formula (Mifflin *et al.*, 1990).

A large, multicenter study in Latin America indicated that height at

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admission was only measured in 32.9% patients (Correia & Campos, 2003). Visual estimation of height was reported to be an inaccurate method with large potential errors (Frid *et al.*, 2013; Bojmehrani *et al.*, 2014). Furthermore, the self-reported height of elderly persons with poor cognitive performance has been shown to have significant errors (Sahyoun *et al.*, 2008).

Alternative methods for length measurements of body segments to estimate height in patients with difficulty standing upright have been developed over the years. These include the knee height equation (Chumlea, Roche & Steinbaugh, 1985; Shahar & Pooy, 2003), demi-span equation (Hirani *et al.*, 2010; Bassey, 1986) and arm-span equation (Shahar & Pooy, 2003; Kwok & Whitelaw, 1991). Other studies have used ulna length (Bonell *et al.*, 2017) and knee height (Maleki & Shariatpanahi, 2017) as surrogates for a specific Asian country or ethnic group with subjects drawn from healthy populations and outpatients.

The use of body segment measurements is not without limitations. The measurement of knee height, demi-span, arm span and ulna length require patients to be able to follow commands: knee height requires patients to be in the sitting position (Shahar & Pooy, 2003); demi-span and arm span measurements require patients to outstretch one or both of their arms laterally (Shahar & Pooy, 2003; Hirani *et al.*, 2010) and ulna length is measured with patients laying their left forearm across their chest and touching their right shoulder (Bonell *et al.*, 2017). Some bedridden patients may not be able to follow these simple commands due to their medical conditions. Moreover, these methods may not be applicable if fractures involving these body segments are present. In addition, the knee height

method requires special tools such as callipers, which may not be available in many institutions.

There is growing interest in the measurement of recumbent length (RL), which is taken when lying down, to estimate the standing height (SH), which is the gold standard. RL requires less effort from patients and is easily done because it is measured in the supine position (Venkataraman *et al.*, 2015).

Some studies have compared SH with the RL (Gray *et al.*, 1985; Frid *et al.*, 2013; Luft *et al.*, 2008; Melo *et al.*, 2014; Bojmehrani *et al.*, 2014). These studies have reported that the RL overestimated the SH; furthermore, the reported difference between the values is variable. Gray *et al.* (1985) found that in 108 ambulatory patients, RL was significantly longer than SH by 3.68 cm. Another study by Frid *et al.* (2013) of 55 patients reported an overestimation of 1.9 cm on average compared with SH. They stated that the advantage of RL measurement was that it was direct and gave quick results. Luft *et al.* (2008) compared SH in 116 hospitalised adults with RL measurements using the Luft Ruler and reported that this method overestimated height by 1.6 cm, on the average, in patients > 60 years of age.

A comparative analysis of methods of estimating height in 142 hospitalised patients in Brazil by Melo *et al.* (2014) reported that RL overestimated the actual height by 3 cm in men and 4 cm in women. A quality improvement project by Freitag *et al.* (2010) in 13 staff members reported that a newly designed book-end method that measured height in the supine position resulted in an overestimation of 0.5–3.0 cm compared with SH. Venkataraman *et al.* (2015) reported that measuring height in the supine position was easy, accurate, and reproducible, and asserted that future

studies should focus on validating the supine method with SH as the gold standard.

Bojmehrani *et al.* (2014) evaluated 100 participants undergoing cardiac surgery to determine the accuracy of various methods in measuring the height of mechanically ventilated patients. They reported that the tape measurement method of patients lying supine was inaccurate, with a maximum error as high as 19.0 cm. The authors did not discuss the reasons for the large error; thus far, it is the only study that reported unfavourable results using RL to estimate height.

We noted that the firmness of the mattresses that patients lay on were different. Hospitalised patients lay on soft mattress in the ward and bedridden outpatients either from home or nursing home were transferred to a firm mattress on a trolley bed in the clinic once they arrived in ambulance. Most of the aforementioned studies had not stated the firmness of the mattresses that the participants had lain on. The book-end method by Freitag *et al.* (2010) required participants to lie on a hard aluminium plate, but their study had a small sample size of only 13 participants. In the clinical setting, it would be impractical to transfer bedridden patients to a hard aluminium plate to measure their RL.

The measurement of RL has not been validated in the Asian population and no equations have been proposed for the local population in Singapore. The aim of this study was to validate the method of measuring RL using mattresses of different firmness against SH in Singaporeans and to develop simplified equations to estimate SH from RL for practical use in a clinical setting.

We hypothesise that RL is always more than SH and that the RL measured on soft mattress and firm mattress would differ. We have designed the study to understand these differences.

MATERIALS AND METHODS

Participants

One hundred hospitalised participants (50 men and 50 women) were recruited from the general medicine, cardiac, nephrology, oncology, neurostroke and gastro wards. Another 100 healthy participants (50 men and 50 women) were recruited from hospital staff and visitors. Hospitalised participants used soft mattress in the wards and healthy participants used firm mattress on the trolley bed in the clinic. Postulating that the accuracy of estimation of SH from RL was 100%, 100 subjects were needed for the lower 95% CI to be 96.4%. An increment in the power would have required a larger sample size which may have increased the duration of recruitment. Hence, 100 participants were recruited over a period of 2 years for soft and firm mattress, respectively.

The inclusion criteria were adults aged ≥21 years and able to stand upright. The exclusion criteria were any degree of kyphosis, scoliosis, or leg and back deformities. Pregnant women were excluded for ethical reasons. The study received ethical approval from the National Health Group Domain Specific Review Board (DSRB reference: 2014/01004), and all participants provided informed written consent before participation.

The hospitalised participants were sampled from wards of different disciplines and all the participants fulfilled the inclusion criteria. We did not limit the participants to any particular ward or discipline because, eventually, we aimed to apply the equations developed for use in adult patients across all disciplines and medical conditions. On the other hand, it was challenging

to get the same hospitalised patients to come down to clinic for RL measurement on the firm mattresses due to infection control concerns and similarly it was not practical to push the trolley bed up to ward for each RL measurement; hence healthy participants were recruited to be the subjects for the firm mattresses. Hospitalised patients were recruited to be the subjects for the soft mattresses.

The measurer, who was a dietitian who attended to patients in the ward, screened prospective hospitalised participants based on the inclusion and exclusion criteria. The potential participants were asked if they were able to stand upright and walk to the stadiometer. Consent was taken prior to measurements. The healthy participants were sourced by recruitment posters placed strategically in the lifts and in clinics that were accessible to both staff and hospital visitors. Interested potential participants telephoned the measurer to arrange the time for measurement, which was conducted during office hours. Prospective participants were screened when they arrived at clinic based on the inclusion and exclusion criteria before recruitment.

Procedures
Standing height
Standing height was measured using the SECA stadiometer, model 703 (SECA, Germany) in the wards for hospitalised participants and in the dietetics clinic for healthy participants. The participants stood facing forwards, arms hanging loosely by the side and heels against the rod, with shoes removed. The participant's back was positioned as straight as possible but not leaning on the rod (National Institute for Health Research, Southampton Biomedical Research Centre, 2014). The head was adjusted so that the Frankfort plane was horizontal (i.e., parallel to the floor). Standing height was recorded in

centimetres (cm) to one decimal point. Two measurements were taken, and the average was calculated to one decimal point.

Recumbent length
The participant lay supine on a soft mattress placed on a hospital bed for hospitalised participants or on a firm mattress on a trolley bed for healthy participants without any pillow and with feet together in a relaxed position. A hard board was placed perpendicular to the top of the head, and a point was marked using scotch tape. Subsequently, a 30-cm ruler was placed perpendicular to the heels to obtain another point, which again was marked with scotch tape. A flexible, non-stretchable 2 metre measuring tape was used to measure the length between the two points in cm to one decimal point. Two measurements were taken and the average was calculated to one decimal point.

Interrater reliability analysis
Separately, another 30 healthy participants were recruited for interrater reliability analysis. Two measurers were involved in the interrater reliability measurements. Each participant had their SH measured twice by measurer 1 and the average was calculated to one decimal point. Then measurer 1 and measurer 2 took turns to take two readings of RL and the average was calculated to one decimal point. The RL readings by measurer 1 were unknown to measurer 2 during the measurement.

Statistical analysis
The data were analysed using the IBM Statistical Package for Social Sciences (SPSS) Statistics Version 24 (IBM Corp.). The Bland–Altman analysis was used to investigate the agreement between the two methods (Bland & Altman, 1986). Two regression equations were derived to estimate SH, one for soft mattress

Table 1. Demographic characteristics of participants

Variables	Hospitalised (soft mattress) n=99	Healthy (firm mattress) n=100
Gender		
Male [n, (%)]	50 (50.5)	50 (50.0)
Female [n, (%)]	49 (49.5)	50 (50.0)
Age range (years)	21.0-80.0	21.0-77.0
Mean age (years±SD)	48.9±13.9	36.8±13.6

SD: standard deviation

and the other one for firm mattress. The validation process is based on study done by Luft *et al.* (2008) and Gray *et al.* (1985).

RESULTS

Of the 100 hospitalised participants, one was excluded from the data analysis because she was unable to position her ankle in a relaxed manner when lying down. This was an isolated case in which the participant fulfilled the inclusion criteria: she could stand upright but when she lay down, both her ankles were plantar-flexed, causing her forefeet to be protruded. We did not encounter similar issues with the other participants. The demographic characteristics of the 100 healthy and 99 hospitalised participants are summarised in Table 1.

In hospitalised participants, the mean±SD of SH was 161.2±9.7 cm and the mean±SD of RL using soft mattress was 163.7±9.5 cm. The SH and RL were significantly different (p <0.001). On the other hand, for the healthy participants, the mean±SD of SH was 164.6±7.7 cm and the mean±SD of RL using firm mattress was 166.7±7.7 cm. The SH and RL were also significantly different (p <0.001).

Bland & Altman (1986) suggested that 95% of the differences between the two measurements must lie within the mean difference±2SD ranges. Using Bland-Altman plot, 96% of hospitalised
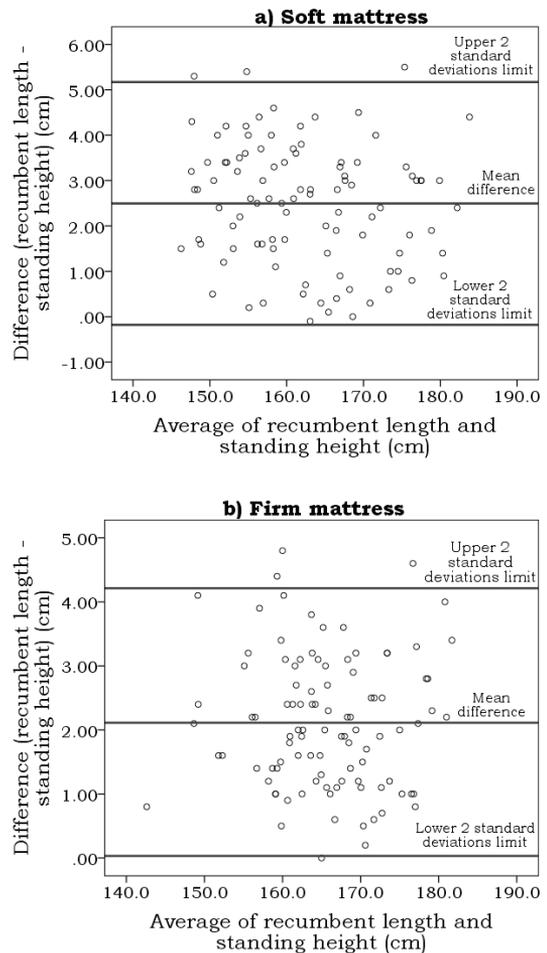

Figure 1. Bland–Altman plots for a) soft mattress and b) firm mattress. The difference in recumbent length and standing height is plotted against their average
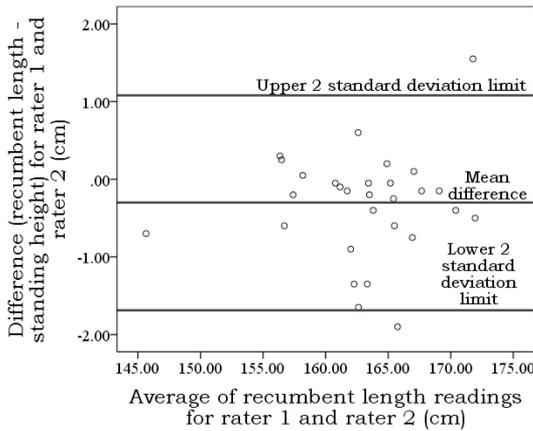
Figure 2. Bland–Altman plots for interrater reliability. The difference in recumbent length and standing height for rater 1 and rater 2 is plotted against their average

participants using soft mattress were within 2.5±2.7 cm whereas 97% of healthy participants using firm mattresses were within 2.1±2.1 cm (Figure 1). Both results were acceptable as there were more than 95% of the participants within the mean±2SD ranges.

For interrater reliability analysis, the Bland-Altman plot was chosen because it shows agreement between two measurers whereas intraclass correlation (ICC) shows agreement for a group of measurers. From the Bland-Altman plot, 93.3% of the participants were within -0.3±1.4 cm (Figure 2). Based on Figure 2, only two readings were out of mean±2SD but the percentage of outliers was high due to small sample size (n=30).

Linear regression equations were calculated for both RLs using soft and firm mattresses and presented in Table 2. Regression equations adjusted for age and gender were developed as well given the wide age range. Using paired t-test, we compared the difference of the SH calculated from adjusted and unadjusted equations for both groups. The mean difference of SH calculated from adjusted and unadjusted equations was 0.07±0.43 cm (p=0.11) for soft mattress and 0.03±0.26 cm (p=0.20) for firm mattress. We found that there was no significant difference between the SH calculated from adjusted and unadjusted equations for both groups. The scatter plots between SH and RL for soft and firm mattresses are shown in Figure 3.

DISCUSSION

Measuring height can be a challenge in bedridden patients. This is also the group who need nutritional support the most (Gray *et al.*, 1985). A reliable assessment of height is crucial for an accurate nutritional assessment, so as to deliver a tailored nutritional intervention that is specific to the patient. Many studies have been carried out in the past comparing RL and SH but none were done in the Asian population. We were interested in validating RL measurement against SH, using simple tools such as measuring tape and clip-board in our local population and to derive equations
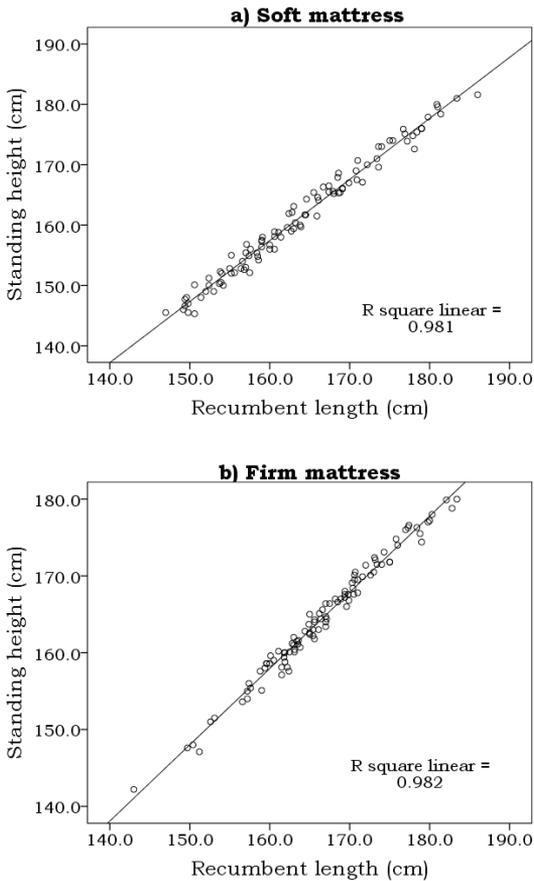
Table 2. Unadjusted and adjusted equations for estimating standing height using soft and firm mattresses

Firmness	Unadjusted and adjusted equations	r^2	Error rate (cm)
Soft	SH = 1.012 RL – 4.477	0.981	-3.18 to 2.60
	[†]SH = 0.953 + 0.973 RL + 0.007 A + 1.076 G	0.983	-3.15 to 2.48
Firm	SH = 0.993 RL – 0.943	0.982	-2.71 to 2.11
	[†]SH= 2.746 + 0.973 RL – 0.017 A + 0.484 G	0.982	-2.53 to 2.07

RL, recumbent length; SH, standing height; A, age; G, gender (1= male, 0= female)
[†]Equations adjusted for age and gender

Figure 3. Scatter plots between standing height and recumbent length for a) soft mattress and b) firm mattress

to estimate SH. We hypothesised that RL overestimated SH and that the readings could be different depending on the firmness of the mattress that patients lie on. These were the reasons for our study.

The present study confirmed that RL was always greater than SH, a finding which was consistent with other similar studies (Gray *et al.*, 1985; Frid *et al.*, 2013; Luft *et al.*, 2008; Melo *et al.*, 2014). However, the aforementioned studies reported different values of overestimations of RL compared to SH and were carried out in non-Asians. The present study is valuable because it derived two predictive equations to

estimate SH using RL on mattresses with different firmness i.e. on soft and firm, and was validated against SH in our local population in Singapore. To the best of our knowledge, this is the first study validating the RL equations against SH in an Asian population.

As reported by Gray *et al.* (1985), the difference observed in RL and SH is probably due to true difference of the body length and is not a consistent bias or inaccuracy in RL measurement. Keller & Nathan (1999) reported that axial loading of the intervertebral discs occurs in static and upright postures, which compresses them and leads to height loss, whereas in recumbent postures, discs unload and regain their original height. This explains why RL is longer than SH.

The studies discussed earlier used various tools to measure RL such as a measuring tape (Gray *et al.*, 1985; Melo *et al.*, 2014; Bojmehrani *et al.*, 2014; Venkataraman *et al.*, 2015), sliding callipers (Frid *et al.*, 2013), Luft Ruler (Luft *et al.*, 2008) and the book-end method (Freitag *et al.*, 2010). Some of the tools were expensive and not easily available because they were custom-made in their respective institutions. However, the measuring tape and clip-board that were used in this study are simple, inexpensive, easily available, and easy to be carried and cleaned. Therefore, our proposed measurement method is not only reproducible but also practical in routine clinical settings.

This study is the first to address the firmness of the mattress that subjects lie on during RL measurement. In this study, we observed that the firmness of mattress did affect RL and thus we included it as a variable represented by hospitalised participants for soft mattress and healthy participants for firm mattress. This study showed that the difference between RL and SH was greater when participants lay on

a soft material. The soft mattress was observed to sink with weight causing a longer curvature. Hence two regression equations were developed to correct the RL for estimating SH in patients lying on soft and firm beds respectively. Since there was no significant difference between SH calculated from adjusted and unadjusted equations for both soft and firm mattresses, we decided to adopt the unadjusted equations to reduce the complexity of the equation.

Our study has several limitations. This study did not take into account the reported diurnal variation of height which has been reported to be greater in the morning and gradually reduced towards the evening (Krishnan & Vij, 2007). In this study, SH was measured during office hours between 8.30am to 5.30pm. The age and other characteristics of hospitalised participants were not matched and may not be comparable with that of healthy participants as the recruitment for both groups was done concurrently. Another limitation of our proposed method was that it excluded patients with contractures who were unable to straighten their legs or body. This problem was addressed by Finch & Arumugam (2014) who developed and validated a simple bedside method using measuring tape but their study was done in only 24 participants. An alternative measurement method to estimate height must be developed for this group of patients.

Future studies may consider measuring RL at a specific time of the day to minimise diurnal variation and to match the age of participants of both groups to reduce variability. The exclusion criteria should be revised to disqualify those who could not position their ankle in a relaxed manner when they lie down for measurements before recruitment. A larger sample size is needed in future research to test the interrater reliability.

CONCLUSION

We concluded that RL is a valid clinical tool to estimate SH. Two linear regression equations were developed to estimate SH from RL measured on soft and firm material respectively.

Authors' contributions

WWY, principal investigator, conceptualised and designed the study, collected and compiled the data, interpreted the data, prepared the draft of the manuscript and reviewed the manuscript; LSL, conceptualised and designed the study, interpreted the data, assisted in preparing the manuscript and reviewed the manuscript; CYH, calculated the sample size, performed statistical analysis, interpreted the data and reviewed the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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