Validating a Laser for Measuring Supine and Standing Heights Against Current Measures in Adults

by

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ABSTRACT

The stadiometer is the gold standard human height measure, but recent studies have begun to question whether laser technology is a better tool to measure height. The purpose of this study was to investigate if the laser device has inter-rater reliability, how the laser-device measures supine height in comparison to standard methods, and if the laser device will be consistent in measuring human height shorter, as seen in previous studies. Two investigators measured a total of 80 adults independently. Measurements included knee height, arm span, demi span, supine height by laser, standing height by laser and standing height by stadiometer. There was a strong inter-rater reliability for the laser height measurement: excluding one outlier r=0.998. Supine height measures done with a laser were strongly correlated with arm span, but mean values were closest between supine height and knee height (171.3cm and 171.2cm). The laser measured standing height 0.5cm shorter, on average, than the stadiometer. It is concluded that the laser device is a reliable, validated tool to measure human height, standing or supine.

DEDICATION

I am honored to be where I am today and to be the person I am and I attribute that to my incredibly loving parents, Bryan and Maricela Turner, and to God. My parents have encouraged me in my life and education and give me guidance and direction. The influence of God in my life has been my anchor, allowing my dreams to become reality. My family has been an incredible support, and for them I will always be grateful. I also want to express my deepest gratitude for my wonderful committee, Dr. Carol Johnston, Dr. Mayol-Kreiser, and Dr. Meg Bruening, who individually have supported me in my educational endeavor and have given me guidance in times that I needed it. I appreciate the special attention and care Dr. Johnston and Dr. Mayol-Kreiser have shown to me as I have progressed from my undergraduate to my graduate career. I have found true inspirations and mentors here at Arizona State University that I will always remember and cherish.

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CHAPTER 1

INTRODUCTION

Men and women both overestimate their height by approximately 1.22 cm and 0.68 cm, respectively, and this overestimating worsens with age [1]. This pattern is also seen in another study, though they found that men overestimated their height by approximately 2.3 cm [2]. While this may seem harmless, not properly understanding one's own height may lead to erroneous perceptions of health [1]. Measuring height properly is important in the healthcare field, as height is used in many equations. One equation is to measure BMI, a ratio of height and weight that calculates if the current body weight of a person is well proportioned to their height [3,4]. BMI has been determined by the International Obesity Task Force (IOTF) to be the best way to measure obesity prevalence that is increasing around the world [3]. Improper measurement of height can result in an incorrectly calculated BMI, giving the wrong impression of health [3]. Recent research suggests that height measured by a stadiometer may be taller than that measured by laser devices, by at least 2cm [5,6]. If before overestimating height by only 1.22 cm was a source of concern for calculating BMI, showing that measuring height with what is accepted as a gold standard today, the stadiometer, overestimates height by almost one centimeter requires confirmation [1].

Clinicians also use equations incorporating height to measure caloric needs of patients, such as the equations of Mifflin St. Jeor, Harris Benedict, BMR (basal metabolic rate), TDEE (total daily energy expenditure), and the Hamwi equation to find ideal body weight [3,4]. In all these equations improperly measuring height will give an incorrect caloric count, thereby leading to incorrect caloric intake, which in some clinical cases pay be particularly problematic.

In cases where a patient cannot stand, such as in physical disability cases or if a patient is unconscious, measuring height becomes much more difficult although the need for it to be correct does not change. Currently, height estimates are the standard for assessing a supine patient's height. Common estimates include arm span, recumbent length, knee height, forearm length, and demi span [2, 5, 7-9]. A study shows that arm span yields the lowest error, perhaps making this estimate to be among the best to perform [10]. Another method by Frietag et al. has been developed to measure length, called the bookend method. This method has a metal headpiece and a metal foot piece, using a "sewing" tape measure to measure the length of a body [11]. A laser device may be more efficient in this context as well as for standing height measures.

Lasers are used throughout many professions and are trusted tools to measure distance, more exactly than past standard methods [6,12, & 13]. Lasers were first introduced for height measure with animals; measuring racing horse heights [6]. Lasers are used as well within healthcare, notably in radiology and orthodontics [12,13]. With other professions relying exclusively on laser devices to give exact distance measures, it may be argued that the healthcare field should move to this highly reliable technology as well. A recent trial demonstrated the validity and intra-rater reliability of a laser device to measure height [5]. This study will further validate laser technology for measuring height and examine the inter-rater reliability of the technique. Also, realizing the need to improve measurements for those unable to stand, the laser device will be tested for accurately measuring height in the supine position.

Purpose of Study

The purpose of this correlational study is to examine a modified laser device for measuring height in comparison to conventional measures.

Research Aims and Hypotheses

Inter-rater reliability was tested for the device. The device was also used to measure supine height and compared to currently used procedures for measuring supine height. We also investigated the reported difference in laser measure vs. stadiometer measure.

H_1: The device will be highly reliable when used by two investigators.

H_2: The laser measurements of supine height will highly correlate with currently used procedures for measuring supine height.

H_3: The device will measure standing height shorter than conventional measures of height.

Definition of Terms

Gold standard- this refers to a method or tool that is currently acknowledged as the best way of assessing a measurement.

Stadiometer- tool for measuring height that includes a footboard and a vertical adjustable headpiece.

L.A.S.E.R.- Light Amplification by Stimulated Emission of Radiation

Delimitations and Limitations

- Inconsistencies between investigators
- Possibly the laser device

- Participants for this study need to be at least 18 years old and have no physical limitations to stand to be measured. Participants need to be able to come to the Arizona Biomedical Collaborative building for the study to be performed-convenient population.

CHAPTER 2

REVIEW OF LITERATURE

Height in Clinical Aspects

Hospital Setting. Nurses often need to assess the height of patients, but patients who are bedridden, such as in an intensive care unit, measuring their height can be extremely difficult [11].

Measuring Standing Height

The currently used measure of height is stadiometers [14,15]. A wall-mounted stadiometer is considered the "gold standard" to measure standing height [11]. Earthman suggests, when not using a wall-mounted stadiometer, testing the stadiometer against a pole with a known height for accuracy before being used. Then, a portable spirit level will ensure that the stadiometer is properly vertical. Earthman continues that proper technique for measuring height using a stadiometer is removing shoes, and any disruptive hairstyle on top of the head. The person being measured stands facing away from the stadiometer with heels touching the back of the stadiometer, the spine should be in alignment and the shoulders just touching the stadiometer [15]. The head should be in alignment with the Frankfurt plane in adult measures and before the measurement the person being measured should take a deep breath and hold it until the measurement is complete [15]. The headpiece should be lowered to gently touch the top of the head and the measurement is read; this process should be repeated twice and if the measurements are not within 2mm of each other then more measurements should be taken until 2 consistent measures are achieved [15].

Frankfurt Plane. The Frankfurt Plane is the anatomical positioning of the skull used for many important medical procedures for dentistry, orthodontics, and facial reconstruction [16,17]. The path to developing the Frankfurt Plane is a long and complicated history. The debate about cranial positioning reached it's height in the 19th century among all professions dealing with the skull (i.e. anthropologists, craniologists, orthodontists, etc.) as they were concerned with creating the best way to measure and compare skulls. Experts in their field, such as Pierre Broca, Thomas Huxley, and Paul Topinard came up with techniques and identified the various planes of the skull to position and measure the skull, such as using a craniostat to trace the skull or similar measurements [18]. Though, a need for standardization was still present, and that is when "the most important meeting" in dental history took place in Frankfurt-am-Main in August 1882 by the German Anthropological Society, to which gives name to the Frankfurt (sometimes spelled as Frankfort) Plane [18]. Time has slightly altered the original definition of the Frankfurt Plane, but today the Frankfurt plane is accepted as the horizontal line created from the right and left porion to the bottom of the orbitale [18]. In simpler terms, the horizontal line is made from the opening of the ear to the bone below the eye (cheekbone).

Height estimates were first used for forensic and archeological purposes when assessing the height of a deceased person or of a population of an ancient time [10]. In the year 1963, Zorab, Prime, and Harrison were the first to develop equations to estimate height [10]. Zorab, Prime, and Harrison did so to measure the pulmonary function of children with spinal column injuries and were short in stature. They began by measuring tibia length [10].

Self-reported Heights

Self-report in Adults. In studies looking at a large sample size or that are aiming to measure an entire population, measuring individual height and weight is not practical [19]. Therefore many large-scale studies depend on self-reported anthropometric measurements, such as self-reported height [19]. However, it is found that self-reported heights are not accurate, and in men can be overestimated from 1.22 centimeters to as much as 2.3 centimeters [1,2]. Women overestimate their height a little less, with an overestimation of 0.68 cm [1]. When compared to standing heights calculated from knee heights, arm span lengths, or recumbent lengths, self-reported heights were significantly greater [2].

The authors in Rasmussen et al. introduce an interesting idea and variable- the recall ability of the participants. Those who reported they had low recall ability gave the most inaccurate responses to their anthropometric measurements [19]. Rasmussen et al. argues that it is perhaps this variable that makes self-reporting less accurate.

Self-report Among Adolescents. Rasmussen et al. found a different pattern for self-reported height among younger ages when compared to older adult. Among adolescent boys and girls, it was found that only boys overestimated their height by 0.25cm, whereas the girls did not overestimate their height [19]. However, other studies reported that both gendered adolescents overestimate their height [20]. In another study this overestimation by both genders can quantitatively be seen [21]. Girls overestimate their height by 0.68cm and boys overestimate their height by 2.02cm, giving very comparable results to the Merrill & Richardson study as well as to the Froehlich-Grobe study [21].

Alternate Height Measures

There are many ways in which height may be estimated, though the accuracy of these estimates can change depending on ethnicity, gender, socioeconomic status, and age [10].

Standing Heights. Stadiometers are the most used and accepted way of measuring height [14,15]. When stadiometers are not available, alternate forms of measuring height are used such as wall height charts [22]. Although, not much detail was provided, it is assumed that wall height utilized a measurement chart attached to a wall. Standing height has also been measured is by a steel tape measure [23].

Those with cerebral palsy cannot be measured in a conventional manner, thereby necessitating alternate means on how to measure their height [24]. Using current estimate means are not the best measure to use when an accurate health status is being calculated because of a weak relationship between actual height and estimated height [24]. Also, those with spinal cord injuries or those who are bedridden cannot be measured in a conventional manner [2,25]. Without this large population of mobility impaired any large survey does not correctly reflect the health status of a population [2].

Non-standing Heights. Alternative methods are used to measure heights for those who cannot stand (either in wheelchairs or in beds) and more methods continue to be proposed. Though, so far, the majority of these methods are just estimates of height.

In an intensive care unit study, height estimates taken by physicians and nurses were compared to actual heights and weight measures [23]. Significant error in actual and estimated height was found in 86% of the cases, though these errors were found to be less than 10% [23]. Differences between the estimations calculated by the physicians and nurses were present, though, these findings were not significant [23]. Interestingly, the investigators in this study used the ARDSnet formulae to estimate height and weight. This formula is used when a patient is on a ventilator. As discussed later, having an accurate measure for those on a ventilator is important in maintaining good quality of health of the patients [26].

Knee Height. In the Froehlich-Grobe study, knee height was taken with a knee height caliper and the participant sat upright and made a 90° angle with their knee, as measured by a goniometer. The caliper's fixed blade is placed on the far end of the calcaneus and the sliding blade on the anterior side of the distal condyles of the femur [2]. For those who cannot lie completely flat, this estimate is considered the best measure, though more accurate for men than for women [2]. An interesting finding from another study showed that knee height estimates became less reliable as the height increased [24].

Arm Span. According to Froehlich-Grobe study, a participant is to raise their arms to a 90° angle with their body to properly measure arm span. Their arms are to remain straight, and a measure from fingertip to fingertip following the line their shoulder makes. Assistance may be given when needed to hold arms up [2]. In assessment, arm span measures appear to give the largest height estimate in comparison to self-reported height, knee height, and recumbent length [2]. In addition, arm span measurements appear to have the greatest variability, decreasing accuracy [2,25]. However, it is important to note that this variance is only seen with mobility issues and for those with no walking impairments across all ages arm span is a fairly accurate measure [2]. This difference, explains Froehlich et al., is because arm span estimates highest possible height and if a person has been physically impaired from a young age they may have never achieved their highest possible height. Though another study found that arm span yields the lowest error, but can only be applied for ages 18-40 [10]. BMI means using heights calculated by arm span estimates were comparable to the BMI means by the CDC/NCHS in patients who were the least paralyzed by myelomeningocele [8]. This finding supports what Froehlich et al. suggest, that the longer mobility impairment a patient has the less accurate arm span is.

Ulna Length. Gauld et al. argue that arm span is an inaccurate estimate for height measurement, and they developed a reproducible and precise predictive measure for height by using ulna length. However, it is important to note that this study is delimited only to children [27]. The predictive equation uses ulna length and age to estimate height [27].

Demi-Span. Demi span is measured from the center of the suprasternal notch to the end of the middle finger down an outstretched arm [28]. A new, improved formula for adults has been developed by Hirani & Aresu. The new predictive equation has added age as a variable improving accuracy, compared to the Bassey equation that has no age variable [28].

Recumbent Length. While the participant is lying flat with their head in a Frankfurt plane and with the right leg in line with their hip, a measure is taken from their head down the right side of their body to the bottom of their foot [2]. In the study by Froehlich et al., it was found that recumbent length gave the shortest height estimate when compared to arm span, self-reported height, and knee height. This is considered the best standard of how to measure length if a patient is able to lie completely flat and achieve complete dorsiflexion with their foot [2].

Bookend Method. This is a method designed by Freitag et al. to use in a clinical setting giving more accurate results than estimates, yet easy for the nurses to use. It is very similar to recumbent length, but this is a simplified method that only necessitates using one arm. A metal plate is placed at the head of the patient and at the foot of the patient and a sewing tape measure is used to take the actual measure of the patient [11]. It took minimal training for the nurses in the ICU to adopt this type of measuring and in the end it was found that this method was effective and accurate. An interesting observation, though, shows using this method gives height that is shorter by 1.2cm than actual height [11].

Changes in Height Estimation as We Age. As discussed above there is great variability with when to use arm span measurements. Another factor that could lead to this variability is age. An interesting study by Mitchell & Lipschitz showed that using arm span (identified as total arm span in the study) as a predictive equation had a much higher correlation in young adults than in older adults. It is explained that it is because the bones in the upper body are less affected by age than other bones in the body, thereby reflecting a taller estimation of height than how they measure with conventional methods [9]. Interestingly an association only between leg length, improved childhood conditions and reduced cardiovascular risk has been found among Western cultures, which are factors showing disparity among limb lengths and overall height [29]. In contrast, just as arm span does not give the best account of elderly height, lower limb estimations do not properly estimate the height of children as their lower body grows at a faster rate in comparison to the rest of the body until puberty [30].

Formulas

Knee Height. The formulas found to use to estimate standing height from measured knee height was acquired from a 2012 published nutrition book by Mahan. The table below shows the formulas for knee height to predict height in centimeters. Knee height was acquired by hanging the knees off the table, or taken from a seated position [31].

Gender	Formula (Predicted height in cm)
Adult Males (ages 18-60)	64.19 – (0.04 * age) + (2.02 * KH)
Adult Females (ages 18-60)	84.8 – (0.24 * age) + (1.83 * KH)

Arm Span. The formula to determine how to predict height using arm span came from a study performed by Capderou, Berkani, Becquemin, and Zelter. Their study was performed with Caucasian patients who did not have any spine or chest deformities. Arm span was taken by having participants outstretch both their arms and measurement was taken from the tip of one middle fingertip to the next [32]. It was determined that to best predict standing height from arm span measurements a variable for age and sex were needed and the following formulas in the table were created from an regression analysis.

Gender (ages 20-79 years)	Formulas (Predicted height in cm) (AS= arm span (cm), A= age)
Adult Males	54.1+[0.70 x AS] – [0.08 x A]
Adult Females	43.1+[0.75 x AS] – [0.08 x A]

Demi Span. The formula used to estimate height from demi-span was from a regression analysis that was more accurate than the older Bassey formulas [33]. Demi-spans were obtained by measuring from the center of the sternal notch down an outstretched arm to the middle finger [33]. No differences were seen between white and non-white races. In another study performed by Hirani et al. more accurate formulas were created as it was noticed that as a person ages, the accuracy of these formulas decrease. Since 1994, according to national data, demi-spans and heights of men and women has increased by ~1cm, ages >65 and ages >75, respectively [33]. This change in height then must spur updates in the formulas used to estimate height [33].

Gender	Formulas (Predicted height in cm) DS= demi-span (cm)
Adult Males (25-45 years)	[DS x 1.33] + 65.8
Adults Males (>65 years)	73.0 + [1.30 x DS] – [0.1 x age]
Adult Females (25-45 years)	[DS x 1.31] + 64.0
Adult Females (>65 years)	85.7 + [1.12 x DS] – [0.15 x age]

Predictive Equations Using Height

There are many equations used in nutrition to assess the health of patients that use height as a variable. Some are used to assess caloric needs, such as the Mifflin St. Jeor or Harris Benedict equations [3,4]. Both of these equations calculate for resting energy expenditure and in each of these equations height is an important variable along with weight and age [4]. The Mifflin St. Jeor and Harris Benedict equations are used in clinical settings, whether it is for giving nutrition advice to a client or assessing how many calories a patient in the hospital needs, both equations are used commonly [4]. Other predictive equations that use height are to assess fatness of an individual, such as BMI or the Hamwi equation [3]. BMI is commercially very well known, and will be discussed in more depth. The Hamwi equation is a very quick and easy equation that is commonly used on the Nutrition Care Forms filled out by registered dietitians [3].

Height and Stature in Health

Importance of BMI. In an article by Froehlich-Grobe, et al., they discussed that there was no established manner in which to measure the height of those who cannot stand. Therefore federal studies measuring BMI, such as the National Health and Examination Survey (NHANES), do not measure the BMI of those who are mobility impaired, including those who have difficulty standing straight and those that are bedridden. Data for this population are lacking in this respect because there is no established method of measuring the height of those who cannot stand [2]. When using height estimates BMI varies greatly because of the high variability between height estimates. Recumbent lengths give shorter height estimates and therefore higher BMIs, whereas arm span estimates give taller height estimates giving smaller BMIs, and when these estimates are compared to self-reported height measures BMI numbers change greatly [2]. This could lead to significant error in BMI classification and clinically place patients in incorrect weight categories [2].

Among the younger population, it is shown that since adolescents overestimate their height, and underestimate their weight, they are often in the wrong BMI classifications [20].

The International Obesity Task Force (IOTF) discussed which method would be the best to assess obesity around the world, and it was decided that BMI was the most adequate measure to determine obesity in children and teenagers [3]. BMI should also be accurate enough to measure overweight and obesity in adults [3]. This, again, emphasizes the need to have accurate height measures.

Important relationships exist between BMI and cardiovascular disease and diabetes [34]. With most studies relying exclusively on BMI to predict outcomes related to weight, the components to calculating BMI should be accurate [34].

Need for Proper Length Measurements Outside of BMI. In other illnesses proper height, or in some cases length measure, is needed to properly treat the disease. Those with a spinal cord injury have equations to predict their pulmonary function that have a height variable [25]. The Garshick et al. study suggests making supine lengths part of a regular medical assessment so that correct pulmonary function predictions can take place.

Views of Stature in Regards to Health, (Self)-perception and Beauty. Relationships of leg length (length of tibia and femur), sitting height (trunk and head height) and/or their ratios between risks of overweight or obesity, cardiovascular disease, diabetes, malfunctioning liver and some cancer types have been found [30]. A study in Sweden conducted a survey resulting in women and especially men who are shorter than average would report having worse overall health than those of average height [35]. A similar relationship was found in men; moreover in women those of smaller statures reported to be ill for longer periods of time than those of average height [35]. In the same study, as an overall assessment of height and health, those that were taller reported the best health when compared to those who were of average height, who reported average health, and when compared to the reports by those that were shorter, shorter people recorded they have the worst overall health [35]. When height is looked at historically, there is a definite presence of the importance of height [36]. Height was a defining characteristic for populations, because when one thinks about it, height is one of the first traits assessed upon meeting a new person and was a common recorded characteristic as new lands and people were discovered [36]. In the 1930s, height was used to assess the health of miners and was associated to nutritional deficiencies [36].

Beauty is based off of perceptions of proportions, making height and segments of height (limb length) important aspects to how people view themselves, and how others view them [30]. Body proportions and leg lengths are an important part of how we view beauty because they are signs of good health and fertility [30]. Another interesting relationship exists between leg length and the environment of a child, showing that in a person grows up in adverse surroundings as a child, they will show stunted leg growth [30].

Importance of Correct Caloric Calculations

There are other strategies or formulas that can be used to calculate the caloric needs of an individual that do not use height, such as 25kcal/kg [26]. Though, all of the following conditions require specific caloric calculations that are very important for the proper care of an individual. Since there are many formulas that may be used clinically to calculate caloric needs, some including height and others not, understanding these conditions still pertain to the importance of measuring exact height because of the formulas that do use height may be used, and because BMI is still often considered in each of these conditions [37].

Enteral Feedings. As mentioned earlier, predictive equations using height are used to estimate the calorie needs of an individual [3,4]. Properly calculating the caloric needs of a patient using a ventilator is extremely important, as feeding a patient too many calories can lead to serious complications, such as ventilator-associated pneumonia [26].

Refeeding. Refeeding syndrome (RS) is a very serious condition that was first recognized at the end of the second world war when concentration camp prisoners started dying after re-introducing food too quickly. Understanding and recognizing refeeding clinically became present in the early 1980s as patients who had an electrolyte, vitamin, and protein-energy imbalance were overfed [37]. Unfortunately, still today this condition is often forgotten and overlooked [38]. The pathophysiology behind refeeding is that during starvation insulin and metabolism decreases, where glucagon increases. The body utilizes the glycogen stores for about 2 days, and then the body starts lipolysis and gluconeogenesis from the fat and amino acid stores, respectively [37]. Over time, mineral and vitamin stores in the body are being used and slowly depleted. When consumption begins again there is an immediate spike in insulin and metabolism, where glucagon levels decrease. However, the vitamin and mineral concentrations in the body are so depleted that the proper enzymatic reactions, such as the Krebs cycle, are unable to take place as needed and this puts a heavy strain on the organs, including renal dysfunction and decreased respiratory and cardiac muscle function [37]. Despite the clinical significance of this syndrome, only about 50% of cases are properly identified in patients, though the true incidence level is not known [37,38]. The National Institute of Clinical Excellence (NICE) in the UK has created guidelines in 2006 to help improve diagnosis and care for patients at risk of refeeding syndrome [37]. One part of identifying patients at risk of RS, among other criterion, is patients who are either at a BMI of <18.5 kg/m^2 (minor risk) or <16 kg/m^2 (major risk). If a patient is determined to be at risk of RS there is a strict regimen of how many calories they should be fed initially and the following days [37]. Refeeding syndrome is a serious condition and the best ways to prevent it are for healthcare professionals to watch for patients who are at risk of malnourishment, such as patients suffering from anorexia nervosa, alcoholism, depression, surgery or inflammatory bowel disease [38].

Pediatric. Children should not be thought of as "mini-adults" as they have different and greater needs per kilogram of body weight [39]. When it comes to evaluating the health of a child, body weight and height are widely used. Height, or growth, is a key measure of nutrition and health of a child [40]. Standardized Z-scores have been created by the World Health Organization (WHO) to categorize the health of a child based on weight comparisons with children of the same height [39]. Pediatric malnutrition can then be classified and diagnosed based on a chart with the different height and weight categories [39]. Seeing weight loss in a child is a sign of acute malnutrition, but stunted growth is a sign of chronic malnutrition [39]. Chronic malnutrition is defined as being malnourished for 3 months or longer, and malnutrition does not just happen outside of professional healthcare; malnutrition may take place during hospitalization [39]. When a child is being assessed for malnutrition weight and height are carefully attained, along with skinfold measurements, arm (and possibly head) circumference, and muscle mass measurements and these values are compared against standard WHO and CDC (Center for Disease Control and Prevention) charts [39]. There are two types of malnutrition, illness-related and non-illness-related, and when a child is determined to be malnourished a test of their muscle strength and cognitive level is assessed [39]. Though, with the rising prevalence of overweight and obese children, appropriate recognition of this condition is important to properly assess malnutrition [40]. Malnutrition is a serious condition that not only affects the aforementioned developmental milestones, but also other important physiological functions such as immunity. Children who enter hospitals, and especially children who have lengthy stays, should be well monitored for malnutrition [39].

Height can have other health applications as well because height is used to assess how well the child is receiving treatment, known as “growth velocity” [40]. In understanding pediatric height, the growth potential of the child as determined by genetics should be considered [40]. The average height of the biologic parents is used to determine if the child is reaching the appropriate height, because if a child is short it is important to determine whether this is due to genetics or nutritional reasons [40]. Another assessment of pediatric height is whether the weight of the child is fitting for the height of the child [40]. This may be assessed through BMI, but there are also CDC weight-for-height charts that classify children into appropriate percentiles [40]. Height has many clinical applications and importance in pediatrics.

Bedridden. Earthman provides a strong argument and carefully describes the complex issues at assessing the nutritional health of those that are bedridden. In her study she delves into the pros and cons of various bedside methods and non-bedside methods and how to properly analyze the data. This is important to contemplate because there is such a wide net to assess the nutritional status of a bedside patient that many patients are not being properly assessed and consequently not properly taken care of. She calls for a need to come to a consensus on how to assess these patients to improve their quality of care [15].

Lasers

The term ‘laser’ is actually an acronym, or properly stated, L.A.S.E.R., and stands for Light Amplification by Stimulated Emission [41]. Lasers began in 1960, and they originated from M.A.S.E.R. (microwave amplified stimulated emission radiation), which was developed by Dr. Charles Townes, a Nobel Prize winner [41].

Laser Uses. Lasers are used widely in many fields. In construction lasers are used to measure the distance between objects [42]. Lasers are used by law enforcement to measure distances of vehicles and possible threats. SWAT (special weapons and tactics), telecommunications, forensics and speed enforcement all use lasers in other ways to measure distance [42]. Hence, the importance of these applications demonstrates the trust placed on lasers in different fields, be it for measuring distance or for another purpose. Lasers have given these fields tremendous advantages, accelerating and advancing what can be done [43]. For example, rather than common measures being done by two people using both hands, distance can be taken by one person using one hand [43].

Laser Uses in the Health-care Field. Lasers also have a substantial presence in healthcare. In one study by Kusnoto & Evans, laser scanners were found to be reproducible and accurate for not only measuring length, but also depth and width for mouth scans. This opened a new field for laser use in orthodontics [44]. In another study it was discovered that using an ultrasound-laser technique to measure spine issues is a quick, easy, accurate, and reliable when compared to radiographic techniques that are less invasive [45]. Likewise this opens a whole new door to how lower-leg measurements are done when analyzing lower back pain [45]. Lasers are used by dermatologists as a treatment for acne, as shown in a study by Politi et al. Using a cooling-vacuum-assisted tip with a laser has been shown as an effective way of treating acne [46]. Optometry is a field where lasers are very well known with the LASIK eye surgery. Lasik stands for laser-assisted in-situ keratomileusis, or, simply, LASIK is an eye corrective surgery done by a laser to correct for myopic and myopia astigmatism [47].

Lasers to measure height

Lasers First Used to Measure Height in Animals. The use of a laser to measure height was a study by Kleijn et al. in racing ponies. Determining the exact height of racing ponies is very important since a pony measuring too tall is classified as a horse; yet for purposes of speed ponies are desired to be as tall as allowed creating a need to accurately and consistently measure their height [6]. Lasers were examined for accuracy and reliability as compared to the conventional measuring stick [6]. In the Kleijn et al. study they used the laser by attaching it to a board and placing it on the pony's shoulders pointing down and the laser was found to be the more accurate measure. They also determined that the laser measures were highly repeatable and consistent despite the location of measurement [6].

Lasers Used to Measure Human Height. The first study found in literature used to measure human height came from a study by Mayol-Kreiser et al. where a laser device (similarly designed as that used by the pony study) was used to measure height and was compared against stadiometer measures, which is the conventional measure [5]. The laser device created had a head plate with levelers to ensure the head plate was parallel to the ground and perpendicular to the wall with the laser attached to point down in front of a person and takes the distance from their head to the ground [5]. In the same study, stadiometer measurements were also taken and compared to the laser measurements and a very high correlation was found between the two measures, as in the pony study [5,6].

Patterns in Laser Vs. Stadiometer Measures and Advancements. Between the Kleijn et al. study and Mayol-Kreiser et al. studies an interesting pattern between lasers and stadiometers was found: laser measures and stadiometer measures differed by approximately 2 cm, with stadiometers consistently giving the shorter measurements [5,6]. Not related to laser height, but a shorter measure (1.2cm) is also observed by the bookend method than what is measured by the stadiometer [11].

Some limitations found in the study by Mayol-Kreiser et al. were that the head plate sometimes was not long enough for those who had larger fronts. To measure the correct distance the laser point much hit the ground and if a participant had a large front the laser dot would not reach the ground [5]. This necessitated moving the laser device forward and consequently losing the correct plane and there was a need to stand above persons that were too tall [5]. Stated modifications that can be made are elongating the head plate and placing levelers under the head plate eliminating the need to stand above the person being measured [5].

Need for Innovation

Disruptive Technology. Disruptive technology is an idea that as new innovations in technology arise old technologies become extinct. Forbes describes it as being a product that allows consumers to do the same thing but "better and cheaper" [48]. Some modern examples on the Forbes list are the Fitbit, Jawbone and iHealth, both replacing the traditional pedometer for measuring physical activity, and driverless vehicles such as cars or drones are predicted to eventually lead out the competition [48]. Stadiometers have been a trusted tool in healthcare for decades, but just as Fitbits have modernized the pedometer, using lasers to measure height is forward thinking.

Gaps in Literature and Relevancy

Stadiometers are the currently accepted form of measuring standing height. Properly understanding the importance of validity, reliability, precision, reproducibility, and repeatability is key to understanding the need of investigating the validity and reliability of the measurement tools used in healthcare. Validity is how well a tool measures the "true" value of a particular measurement [15]. Where reliability is how consistent a measure is, either with the same person using the tool (known as intra-rater reliability) or between more people using the tool (known as inter-rater reliability) [49].

Precision with tools refers to how well the tool gives the same value after repeated measures. Reproducibility and repeatability are similar in that reproducibility is referring to how well other operators can use the same tool and receive the same results in a different environment where repeatability refers to other operators using the same tool in similar environments and receiving the same results [15]. Scrutinizing current measuring tools is important because though the stadiometer has always been an accepted measure it should be discussed if there is nothing better to measure height as technology has improved since the invention of the current stadiometer. Especially when height has such a critical role in understanding the health of children and adults, advancements should be considered and investigated.

CHAPTER 3

METHODS

Methods

Participants. There were very few criteria that the participants need to meet for this study. Participants were 18 years or older and able to stand. Volunteers needed to agree to visit the Arizona Biomedical Collaborative building to participate in the study.

Study Design. This study was a cross-sectional correlational study that required a one-time visit from each volunteer. Participants provided consent prior to participation. The Institutional Review Board at Arizona State University approved this study. For this study we recruited and measured a total of 80 participants. Demographic data was collected from each participant including their age, gender, and weight at time of survey. Weight for each participant was taken at the start of the study along with four height measures; supine laser measurement, height estimate measurements, standing height with a stadiometer, and standing height with the laser device. For each height measurement, three separate measurements were taken and averaged. Two investigators took the same measurements in consecutive fashion. Upon being awarded the research grant, each participant received a $10 cash incentive at the completion of his or her participation funded by the Graduate Program Student Association (GPSA). Participation in the study took 30-40 minutes per participant.

Variables. There was be 5 variables recorded from each subject; supine measure from laser, height estimates calculated from knee height, arm span, and demi span, standing height measured by stadiometer, and standing height measured by the laser device. Another variable that was studied is the inter-rater reliability of the laser device. Two investigators consecutively, but independently, collected each data measure from the participants and these sets of data were compared to each other for reliability.

Procedures. IRB approval was obtained prior to the start of the project (Appendix A). Participants were recruited via flyers, list-servs, and by word-of-mouth. Those interested in participating in the study completed a short online survey that determined eligibility by age and ability to stand. If they met these criteria, they were invited and scheduled to come to the Arizona Biomedical Collaborative building for data collections. On the day of their data collection they completed a consent form (Appendix B) prior to data collections. Their weight was recorded, along with their age and gender. For the height measures, all measurements were taken in a separate room. For the purposes of this study, a DEXA table was used as the table the participants laid on. Both investigators received the same training for proper measurement of each variable and practiced on three participants prior to data collections.

The order of measurements were: knee height, arm span, demi span, laser supine, stadiometer, then laser standing measurement. Knee height was taken with a knee height caliper and the participants sat upright and make a 90° angle with their knee, as measured by a goniometer. The caliper's fixed blade was placed on the far end of the calcaneus and the sliding blade on the anterior side of the distal condyles of the femur. Three individual measurements of knee height was taken and averaged. For the arm span measurements, three individual measurements of the span from the tip of the 3^{rd} finger of the right arm to the 3^{rd} finger of the left arm were taken by a measuring tape attached to the wall and averaged. The last estimate measure taken was demi span and was measured by a folding measuring stick from the center of the suprasternal notch to the end of the right middle finger down the outstretched arm. Just as the first three, three individual measurements of demi span was measured and averaged. Laser supine measurements were conducted as follows: the laser was attached to a headpiece and a separate footboard was placed at the participant's feet. The laser pointed above the body of the participant and hit the footboard giving a measurement that was recorded. Three measurements were taken sequentially and averaged. After these supine measurements, the participant was asked to stand and have their height measured three times by a stadiometer and averaged. Lastly, the same laser device used for the supine laser measure was used to measure the standing height. The head-plate made a 90° angle with the wall and had one leveler to ensure that the laser is parallel to the ground. The laser pointed down in front of the participant and took the distance from the top of the participant's head to the floor. Three laser measurements were taken and averaged.

A flow chart of the procedures can be seen in Appendix C. After the first investigator took all height measurements, the first investigator left the room and the second investigator entered the room and performed the same measurements. This was done to statistically examine inter-rater reliability of the laser device. For all height measures a script was followed so that consistency was maintained between the two investigators and with each participant (Appendix D). Pictures are provided to demonstrate how measurements were taken and to show materials used (Appendix E).

Statistical Analysis. Data was assessed by the Statistical Package for Social Sciences (SPSS 22, 2010, Chicago, Illinois). Normality of all variables first was examined. Measures for each of the six measurements (supine laser, knee height, arm span, demi span, standing height with stadiometer, and standing height with laser) was averaged to find a single measure for each of the six measurements. Following proper assumptions, a Pearson correlation was run. Means will be compared using a interdependent t-test. Data will be reported as average mean ± SD.

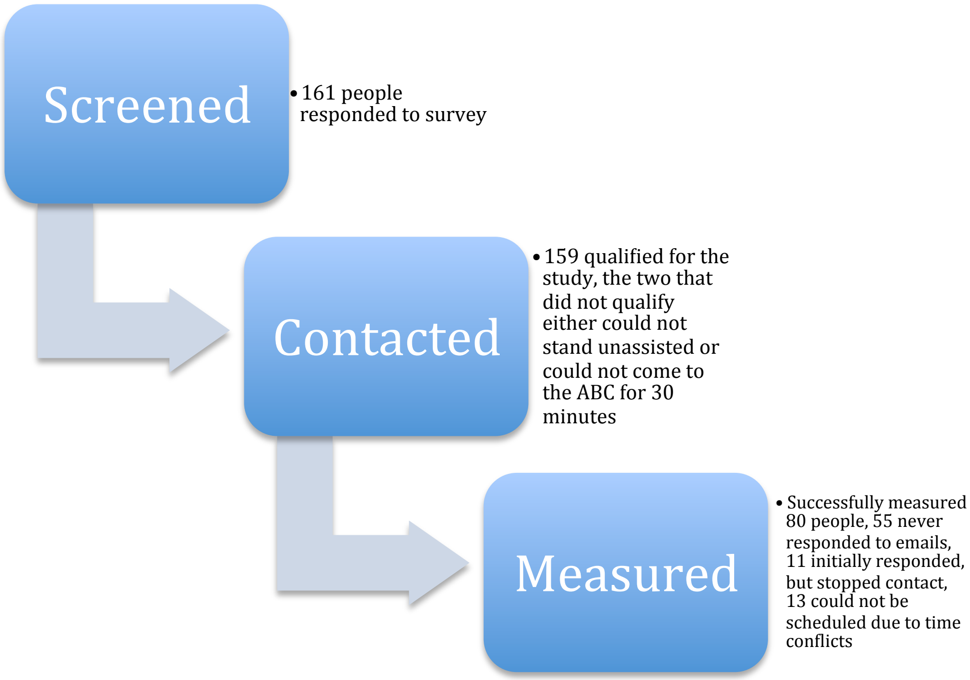
CHAPTER 4

DATA AND RESULTS

Participants

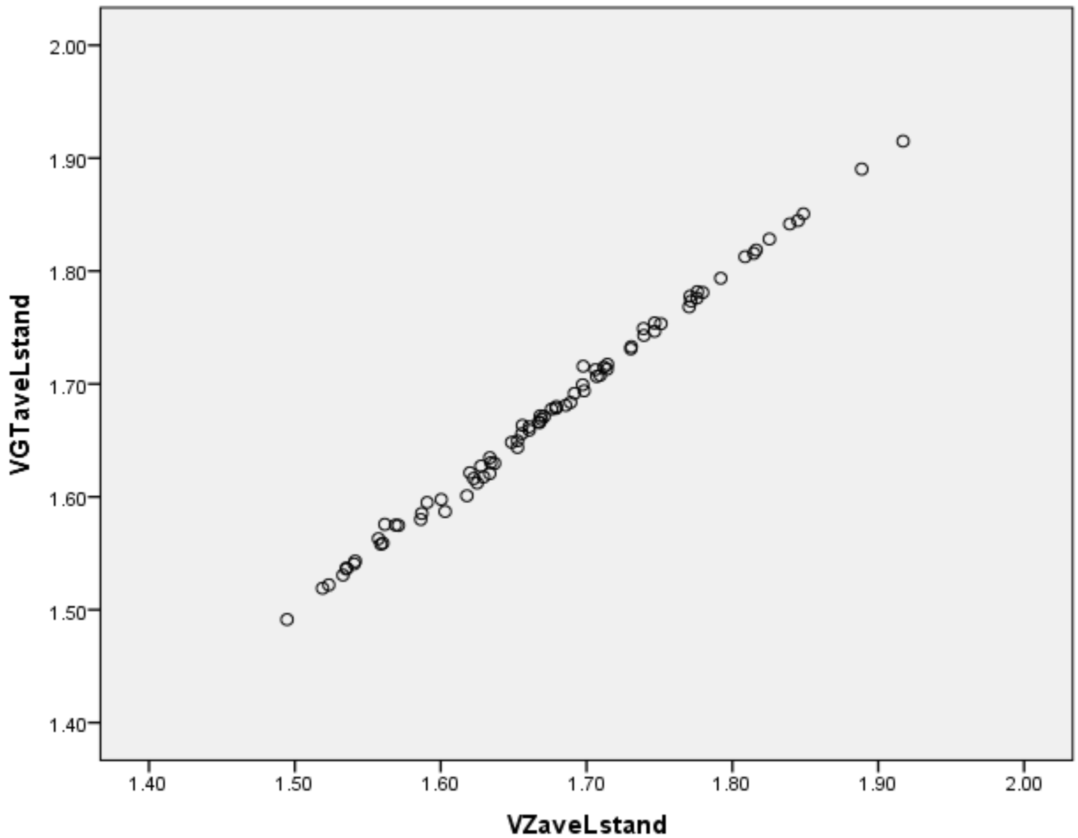
Through various ASU list-serves and word of mouth a total of 161 people were screened to participate in the study. Of the 161 people, 159 were eligible to participate in the study as 2 of the people were either unable to come to the Arizona Biomedical Collaborative building for 30 minutes or were unable to stand unassisted. All 159 of the people were contacted via email to schedule a time, 55 never responded to the emails, 11 initially responded but stopped corresponding, 13 were unable to be scheduled due to time conflicts, and a total of 80 people were successfully measured (Figure 1). Of the 80 participants measured, 32.5% were men and 67.5% were women. Their racial/ethnic demographics were as follows, 62.5% were Caucasian, 20% Hispanic, 8.8% Asian, 3.8% African American, 3.8% as Decline/Other, and 1.3% were Native American. Of the sample 56.4% were students and 43.8% were non-students with the student population consisting of 5% being freshman, 1.3% as sophomores, 8.8% as juniors, 13.8% as seniors, and 27.5% were graduate students. The population of participants came from both Arizona State University and the University of Arizona.

Figure 1. Study population



Inter-rater Reliability. When comparing the mean laser standing measurements taken by the first and second investigator a Pearson Correlation reveals an r-value of $r=0.988$ ($p<0.001$), though an outlier (3 SD from the mean) was present. Removing the outlier, the r-value improved ($r=0.998$), ($p<0.001$) (Figure 2).

Figure 2. Inter-rater reliability: laser-standing measurements of first investigator vs. second investigator.



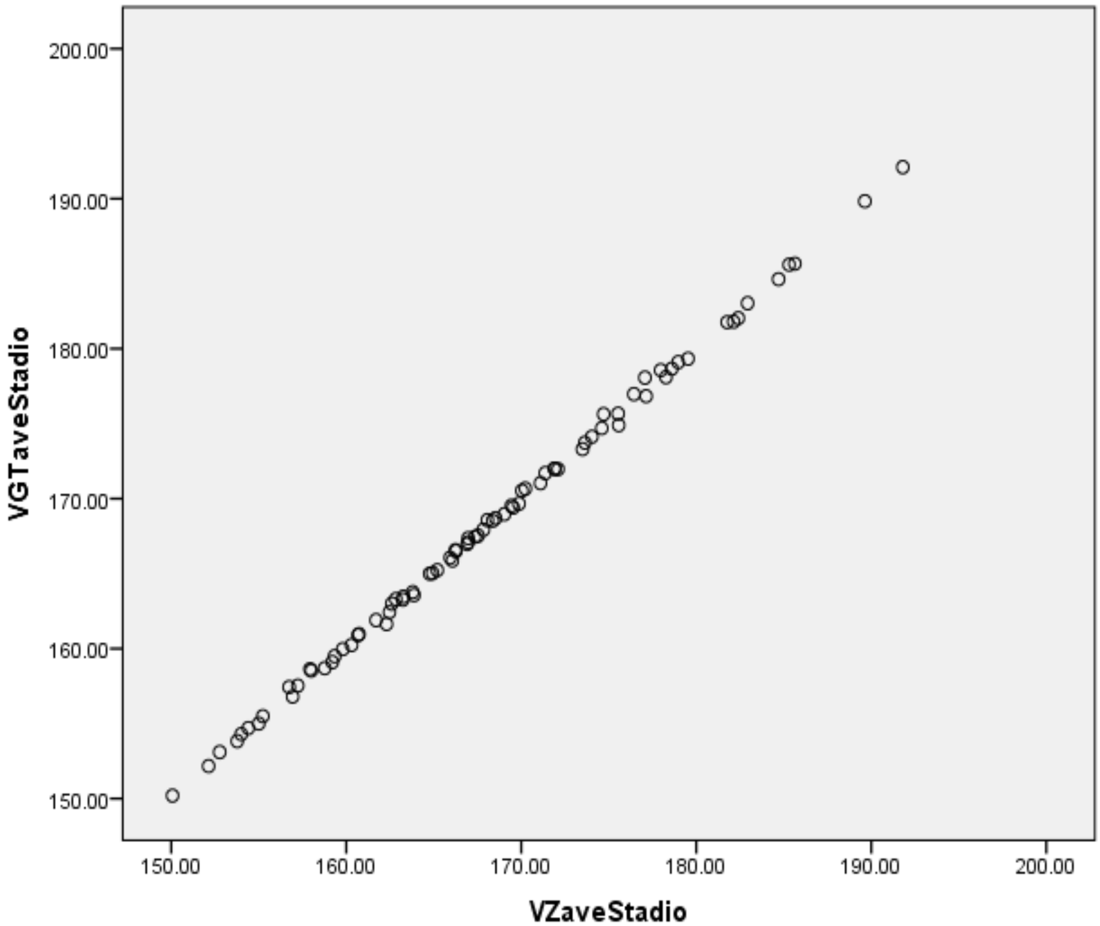
Laser Measurements. The mean standing height of all participants measured by the laser by the first investigator was 167.8cm and the mean standing height measured by the laser by the second investigator was 167.6cm, with a difference of 0.10cm with p=0.358. All alpha levels were α<0.05 (2-tailed). Removing the outlier the new mean standing heights measured by the laser by the first and second investigators were 167.7cm and 167.7cm, respectively, showing no difference (p=0.995) (Table 1). Dividing the participants into genders, the mean standing heights for the males measured by the first and second investigator (excluding the outlier) were 176.3cm and 176.0cm, respectively, with the difference between the two being 0.30cm (p=0.007) (Table 1). For women, the mean standing heights by the first and second investigator were 163.7cm and 163.8cm, respectively, the difference being 0.14cm ($p=0.076$) (Table 1).

Table 1. Mean laser-standing height in centimeters of all participants (except 1 outlier), and divided by genders by the first investigator vs. second investigator.

	N	Mean (in cm)	Standard Deviation
1 (all)	79	167.7	9.6
2 (all)	79	167.7	9.4
1 (men)	25	176.3	8.3
2 (men)	25	176.0	8.4
1 (women)	54	163.7	7.2
2 (women)	54	163.8	7.1

Stadiometer Measurements. Comparing the mean stadiometer measurements taken by the two investigators a Pearson Correlation reveals an r-value of $r=1.00$ ($p<0.001$) (Figure 3).

Figure 3. All stadiometer measurements of first investigator vs. second investigator.



The mean heights of all the participants by the first and second investigators were 168.3cm and 168.2cm, respectively, showing a difference of 0.13cm and $p<0.001$ (Table 2). Dividing into genders, the first and second investigators measured a mean height for men of 176.7cm and 176.6cm, respectively, with a difference of 0.08cm and ($p=0.181$) (Table 2). For women, the first and second investigators measured a mean height of 164.3cm and 164.1cm, respectively, with a difference of 0.15cm and ($p<0.001$) (Table 2).

Table 2. The mean stadiometer heights in centimeters of all the participants and divided by genders by the first investigator and second investigator.

	N	Mean (in cm)	Standard Deviation
1 (all)	80	168.3	9.4
2 (all)	80	168.2	9.4
1 (men)	26	176.7	8.1
2 (men)	26	176.6	8.2
1 (women)	54	164.3	7.0
2 (women)	54	164.1	7.0

Correlations of Laser Supine Measurements Against Standard Measurements. For both the first and second investigator arm span measurements correlated the strongest with the laser supine measurements with a Pearson Correlation of r=0.925 and r=0.908, respectively. The next strongest correlated height estimate with the laser supine measurements was demi-span with a correlation of r=0.922 and r=0.904 for the first and second investigator, respectively. The least correlated, though still considered strongly correlated, were the knee height measurements compared with the laser supine measurements for the first and second investigators (r=0.843 and r=0.810, respectively) (Table 3).

Table 3. Correlations of laser-supine measurements against knee-height, arm-span, and demi-span of first investigator vs. second investigator (n=80)*

			Investigator 1				Investigator 2			
			Laser Supine	Ht Knee	Ht AS	Ht DS	Laser Supine	Ht Knee	Ht AS	Ht DS
Investigator 1	Laser Supine	r	1	0.843	0.925	0.922	0.989	0.821	0.927	0.920
		Sig		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Ht Knee	r	0.843	1	0.840	0.796	0.830	0.994	0.844	0.786
		Sig	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Ht AS	r	0.925	0.840	1	0.975	0.904	0.822	0.997	0.978
		Sig	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001
	Ht DS	r	0.922	0.796	0.975	1	0.903	0.773	0.977	0.992
		Sig	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001
Investigator 2	Laser Supine	r	0.989	0.830	0.904	0.903	1	0.810	0.908	0.904
		Sig	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001
	Ht Knee	r	0.821	0.994	0.822	0.773	0.810	1	0.827	0.766
		Sig	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001
	Ht AS	r	0.927	0.844	0.997	0.977	0.908	0.827	1	0.980
		Sig	0.000	0.000	0.000	0.000	0.000	0.000		0.000
	Ht DS	r	0.920	0.786	0.978	0.992	0.904	0.766	0.980	1
		Sig	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

*Ht- height, AS- arm span, DS- demi span; r for Pearson Correlation (Sig- statistical significance 2-tailed)

All references to the first and second investigator were consistent. For both investigators, the means of all the supine heights were closest to the knee height means (Table 4).

Table 4. Means of laser-supine heights, knee-heights, arm-span, and demi-span of first vs. second investigator in cm. (n=80)

		Mean (in cm)	Standard Deviation
Investigator 1	Laser Supine	171.3	9.347
	Knee	171.2	6.584
	AS	167.7	8.787
	DS	178.6	8.346
Investigator 2	Laser Supine	171.0	9.325
	Knee	171.4	6.648
	AS	167.7	8.937
	DS	178.1	8.395

*AS- arm span, DS- demi span

How the Laser Measurements Compare with the Stadiometer Measurements. Lastly, when looking at how the mean measurements between the stadiometer and the laser standing height measurements compare, the laser measurements were ~0.6cm shorter than the stadiometer for both investigators (p=0.878) (Table 5).

Table 5. Mean of differences in centimeters between stadiometer and standing laser heights measurements of first vs. second investigator (n=80)

	Measurement Difference	
Investigator	Mean (in cm)	Standard Deviation
1	-0.569	0.589
2	-0.595	1.433

CHAPTER 5

DISCUSSION

Study Population

As of 2010, the Phoenix population is 65.9% White, 40.8% Hispanic, 6.5% African American, 3.2% Asian, and 2.2% American Indian.[50] Comparing this to the study sample, there is a similarity in the diversity of race and ethnicity, but due to the small sample size the study sample is not a complete representation of the Phoenix population in regards to race/ethnicity. Though enough diversity can be seen in the study sample, and since race/ethnicity does not play a difference in how height is measured, this difference is negligible.

The inter-rater reliability of the device showed to be present through correlation and t-tests, though understanding the type of study participants measured is important in understanding how inter-rater reliability was achieved. When examining the inter-rater reliability data, one outlier was identified and, after re-examining the raw data, did not represent a mistake in data entry. Some participants had a body type that was not conducive for the laser, by having chests or stomachs that protruded enough to obstruct the laser point from hitting the ground. This required the investigators to tilt the laser device away from the body enough for the laser point to clear the obstruction and hit the ground to give a distance measure. These participants (n=4) were noted in the data, but not one of those participants presented as an outlier. There were a few other participants who had the potential to result as outliers, due to hair obstructions or lack of understanding of directions, but these participants did not result as outliers. Possible explanations for the outlier would be a possible mistake when transcribing the measurements during the data collections or perhaps the participant positioned themselves differently for the second investigator than they did for the first investigator. Though, it speaks to the versatility of the laser that even though measurements were taken in less than ideal situations when outliers could have been expected the measurements were consistent as it pertains to inter-rater reliability. However, even with the outlier the correlation is very strong and without the outlier the correlation is even stronger.

Laser Standing Heights

No significant differences were seen between investigator one and two when comparing the laser height measurements supporting that the laser device has inter-rater reliability. When dividing up the participants into genders, males had more of a difference between the measurements than females, giving the impression that the laser device appears to be more consistent for female measurements versus male measurements. The male measurements did show a significant difference between them.

Stadiometer Heights

The stadiometer measurements of the two investigators resulted in a very strong correlation. This suggests that the measurements taken by the investigator one and two were similar, and this supports that the stadiometer has strong inter-rater reliability. However, the differences between investigator one and two for mean height measurements was 0.13cm which was significantly different. Looking at this clinically however, it does not appear to be as meaningful, and this can be seen by calculating caloric needs of a 78kg male through the Mifflin St. Jeor equation and by calculating

BMI using a height that differs by 0.13cm. The chart will describe the differences seen in caloric needs and BMI when the base height is 1.76m and 0.13cm is either added or subtracted from that height.

Height	Caloric Needs based of Mifflin St. Jeor	BMI (kg/m^2)
1.7613m (176.13cm)	780+1,100.8125-150+5 = **1735.8125 kcal**	$78/(1.7613^2)$ = **25.144**
1.76m (176.0cm)	780+1,100-150+5 = **1735.8125 kcal**	$78/(1.76^2)$ = **25.181**
1.7587m (175.87cm)	780+1,099.1875-150+5 = **1734.1875kcal**	$78/(1.7587^2)$ = **25.218**

Notice that it was required to go out to either the ten-thousandths place for meter measurements or to the hundredths place for the centimeter measurements to note the difference that 0.13cm makes, and even more decimal places were needed for the calculations. The resulted in ultimately a 1kcal difference for either adding or subtracting 0.13cm from the base height of 1.76m and as far as BMI goes, even with rounding, no change can be seen. From this example, it can clearly be seen that clinically, a 0.13cm difference that results in statistical significance does not lead to any clinical meaningfulness. However, it will be admitted that there may be a combination of numbers where this difference will lead to a change in BMI, but it would only be in a small percent of the general population.

Dividing the stadiometer measurements into genders, as done in laser measurements, the opposite effect is seen where there is less difference with the mean stadiometer measurements for males when compared to the differences of the mean female stadiometer measurements. The female mean stadiometer differences showed to be statistically significant. This suggests that stadiometers measure male heights more consistently than female heights. This is an interesting pattern, that for females the laser appears to be more consistent and with males the stadiometer appears to be more consistent. In the sample more females are represented versus males, though this does not appear to explain this difference. The only possible explanation is that perhaps due to male ego and perceptions and previous understanding of stadiometer protocol, males might have stood more consistently for stadiometer measurements, despite the use of the script by investigators.

Laser Supine Heights Against Standard Measures

Pearson correlations show that the arm span measurements correlated the most with the laser supine heights for both investigators. Though, investigator one had a higher correlation to arm span than investigator two. Demi-span measurements were the next strongly correlated with the laser supine measurements for both investigators, though the same is true that investigator one had a stronger correlation than investigator two. The knee height measurements correlated the least with the laser supine measurements, though still a strong correlation. As before, investigator one had a higher correlation than investigator two. Previous studies state that as height increases the reliability of knee height decreases, and this study supports that because the knee heights correlated the least when compared to laser supine height [24].

When comparing the means of the laser supine measurements to the means of arm span, demi-span, and knee-height, the mean knee-height measurements are the closest to the laser supine measurements, disputing what was seen with the correlations. The arm span had the next nearest mean compared to the laser supine measurements. Past studies show that arm span gives a greater height estimate when compared to recumbent length (which is the most comparable to how laser supine heights were measured) though this was not found with the current study because the mean arm span measurements were shorter than the mean laser supine measurements and not as close in measurement with knee height means [2]. This is an interesting observation, and clinically how the means compare should be more important than how they correlate because the means represent the actual numbers measured rather than how the numbers compare to each other, as seen in correlations.

Laser Measurements Compared to Stadiometer Measurements

Past studies show that laser measurements are usually 0.8cm shorter than the stadiometer measurements for ages 2+, however the current study showed the first investigator and second investigator having a laser measurement difference of 0.6cm, with the laser measuring shorter [5,6]. In the Mayol-Kreiser et al. study, the 0.8cm difference was found when combining all of the age groups, though, looking more closely at the study, the adult mean differences between the laser and stadiometer measurements was 0.5cm [5]. This is consistent with the findings in this study, furthering the validation of using a laser to measure human height for adults.

As discussed previously with the stadiometer heights, putting the 0.6cm of difference into a clinical context will give the proper perspective of whether this difference is clinically meaningful. As before, a chart will be used to show a baseline height of 1.76m (176cm) and how either adding or subtracting 0.6cm to it affects caloric calculations based from the Mifflin St. Joer formula and BMI calculations of a 78kg male.

Height	Caloric Needs based of Mifflin St. Jeor	BMI (kg/m^2)
1.766m (176.6cm)	780+1,103.75-150+5 = **1738.75 kcal**	78/(1.766^2) = **25.010**
1.76m (176.0cm)	780+1,100-150+5 = **1735.8125 kcal**	78/(1.76^2) = **25.181**
1.754m (175.4cm)	780+1,096.25-150+5 = **1731.25 kcal**	78/(1.754^2) = **25.353**

Unlike as before, not as many decimal places were needed to see the difference that 0.6cm makes on measurements. For caloric calculations a difference of either 3kcal when 0.6cm was added to the base height, or a difference of about 5kcal for when 0.6cm was subtracted from the base height. These differences are more prominent than the 0.13cm difference seen before, however, these differences would still not be considered clinically meaningful differences. Especially when looking at the BMI, very small differences can be seen. For some of the population that could be borderline BMI, this 0.6cm difference could make more of a distinction, which is something to be considered.

Laser Device

In the previous study by Mayol-Kreiser et al. the head plate of the laser was found to be too short for all body types [5]. The laser device used in the present study had an extended head plate (of 3 inches) and an added back plate that allowed the laser device to rest against the wall and eliminated the need for one of the previous levelers. One leveler was still needed to ensure that the laser device did not tilt, but was parallel to the floor. With the previous study with Mayol-Kreiser et al. the leveler was placed above the head plate requiring a stool to be stood upon to read it. This was changed in the newer modification as the leveler was placed below the head plate so it could be read without the need of a stool. The laser device is made with a lightweight metal, and the laser itself is lightweight only weighing 0.4lbs.[51]

Doing a quick Google search of portable stadiometers, their cost ranges of from about $150-$300. This is exclusively for portable stadiometers, because height "rods" can cost as little as $50 to as much as $200. The laser used for this study cost ~$80 (though this is a more technical laser, a more simple laser could be used), plus the cost of materials and labor to build the head plate and a box in which to place the laser in would give the cost of the laser to be about $150. This reaches the lower end of the portable stadiometer costs, making the laser more cost effective.

As far as any safety concerns, the laser device is considered a class 2 laser, which the FDA identifies as being similar to barcode scanners and to quote the hazard the laser presents the FDA says, "Hazard increases when viewed directly for long periods of time. Hazard increases if viewed with optical aids."[51,52] The FDA also clarifies the possible radiation that lasers in general present, "In general, laser radiation is not in itself harmful, and behaves much like ordinary light in its interaction with the body. Laser radiation should not be confused with radio waves, microwaves, or the ionizing x-rays or radiation from radioactive substances such as radium."[52] Understanding this, there should be no health concern by using this laser device as long as the laser is used properly.

Limitations

One limitation to the study was that the laser device still does not seem to be long enough for some of the general population. Only adults were used in this study, so none of the results can be generalized to children or adolescents. The footboard used as part of measuring the supine height was not rigid enough and often participants could bend by the footboard simply by resting their feet on it. Participants were asked to keep their feet flexed to avoid this problem, but there is still possibility that this might have affected the data. Another limitation to the study was there was some learning involved between the measurements of the first investigator and the second. Measurements from the first and second investigator happened consecutively so participants were more aware of how to position themselves for the second investigator after their experience from the first investigator. A possible limitation to the study is that after the measurements with the first investigator participants could also have been more stretched resulting in longer measurements, such as for arm span. The inverse could also be true that the participants might have been exhausted from the first set of measurements that when the second investigator measured their fatigue could have affected their posture.

It could be said that a laser may be more difficult to use than a stadiometer because it requires a person to need to learn how to use the laser device. However, to use the laser properly requires training, just as using the stadiometer takes training. The laser does require a person to hold the laser in place, so if someone has issues holding their arm up, using the laser may present a problem. Though, to properly take stadiometer measurements a person needs to be able to lift their arm to place the headpiece of the stadiometer on the head of the person being measured. Both the laser and stadiometer requires similar arm usability. Also, the laser device used for the study is a prototype and is best use as it is would be in the rural setting. For clinical settings, a permanent laser device could be placed in the ceiling of an office for daily use. Though these developments will be discussed further.

Future Directions

Studies continue to support the laser device to be a valid height measuring tool. Further studies could be done specifically in pediatrics, where accurate height measure is critical. Since the nutritional status of children is partly based on their height, the importance of having an accurate height measure for children can more clearly be seen because without an accurate measure children could be missed in being classified as malnourished.[39] The variability of currently used practices to measure height can be seen more clearly with adults because adults' heights should be constant, where with children their growth changes and the inaccuracy of how they are being measured cannot be seen so clearly. Understanding this and what this current study shows gives reason why lasers now need to be studied more closely in pediatric populations. Clinical studies should also be done to see how well the laser device works in clinical settings. Such as to see how well clinicians could use the laser in daily use and how practical having a laser would be, though some modifications to the current design of the laser device would be needed, as discussed later. Similar studies should be done to see how well the laser device works in rural settings. The design of the laser would work well in rural settings because it is so portable and light, especially when compared to the portable stadiometer.

The laser would require no assembly, and can be held in one hand and easily placed in a bag the size of a typical handbag for storage and travel. For clinical use, the laser concept would work best if somehow permanently mounted on the wall. Or even more advanced, would be if the laser could be mounted in the ceiling and would calculate the displacement distance a person creates when standing underneath the laser relative to the ground, thereby giving a height measure. This would take virtually no office space and technology could be developed, perhaps in the form of an app that would allow the height measurement to be inputted directly into the patient's electronic medical file. This would replace the need to transcribe the measurement, further taking away any chance of human error. In addition, the place where a person would stand to get their height measured could have a weight scale so that a person's weight and height could be measured at the same time. There are large potential advancements using the laser to measure height can bring.

The laser shows potential for other applications in the health field. Height is considered an anthropometric measurement, and there are many other anthropometric measurements that the laser could maybe apply to, such as being used to measure waist-to-hip ratio.

CHAPTER 6

CONCLUSION

The laser is a competent device to measure human height. We can come to three conclusions, based on what was hypothesized and revealed by data. First, the laser device has strong inter-rater reliability, meaning various persons can operate it and the measurements should still be accurate. Second, the laser measurements for supine-height were compared to the standard heights estimates taken in clinical settings, arm span, demi span, and knee height. Results showed that the measurements of supine height measured by the laser correlated strongly with all three height estimates, also meaning that the laser is a validated tool to measure supine height. Thirdly, the laser is consistent in measuring about 0.5cm shorter for adult height when compared to stadiometer heights, as seen in previous studies [5]. The laser is consistent in showing that it is an accurate and reliable tool that has many possibilities for clinical use.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

ASU Knowledge Enterprise Development

APPROVAL:CONTINUATION

Sandra Mayol-Kreiser
SNHP: Nutrition
602/496-1862
Sandra.Mayol-Kreiser@asu.edu

Dear Sandra Mayol-Kreiser:

On 10/9/2015 the ASU IRB reviewed the following protocol:

Type of Review:	Modification and Continuing Review
Title:	Validation Study of a Laser as a New Tool for Height Measurement
Investigator:	Sandra Mayol-Kreiser
IRB ID:	1309009687
Category of review:	(4) Noninvasive procedures, (7)(b) Social science methods, (7)(a) Behavioral research
Funding:	Name: SNHP: Nutrition
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• IRB-Child Assent Forms Laser.pdf, Category: Consent Form; • verbal script, Category: Recruitment Materials; • Consent Form, Category: Consent Form; • online survey, Category: Recruitment Materials; • IRB-Parent-Child permission form.pdf, Category: Consent Form; • Laser Validation Study, Category: IRB Protocol; • procedures for modification, Category: IRB Protocol;

The IRB approved the protocol from 10/9/2015 to 10/7/2016 inclusive. Three weeks before 10/7/2016 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 10/7/2016 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Carol Johnston
Vanessa Garcia-Turner
Ginger Hook
Carol Johnston
Cassandra Smith

APPENDIX B

CONSENT FORM

Validating a Laser to Measure Standing and Supine Height in Free Living Adults

My name is Vanessa Garcia-Turner and I am a graduate student under the direction of Dr. Carol Johnston in the College of Health Solutions at Arizona State University. I am conducting a research study to validate a laser for measuring standing and supine height in adults.

I am inviting your participation, which will involve you lying on a table while your height is measured with a laser then measured to calculate height estimates. After you will be asked to stand to have your standing height measured by the same laser device and then your height will be measured by a stadiometer. The laser tool will, at no time, be directed toward the body. After the first investigator, a second investigator will enter the room and repeat the measuring protocol. This will take about 20 minutes of your time. You have the right not to answer any question, and to stop participation at any time.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. You should be at least 18 years or older to participate.

Possible benefits of your participation are validating a new tool to measure height that can improve efficacy in health care. There are no foreseeable risks or discomforts to your participation.

Every measure collected will in no way be identifiable thereby maintaining your anonymity. Your responses will be kept confidential. The results of this study may be used in reports, presentations, or publications but your name will not be used. However, only statistical results will be reported in publications, no raw data will be released.

If you have any questions concerning the research study, please contact the research team at: carol.johnston@asu.edu or at (602) 827-2265. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Please let me know if you wish to be part of the study.

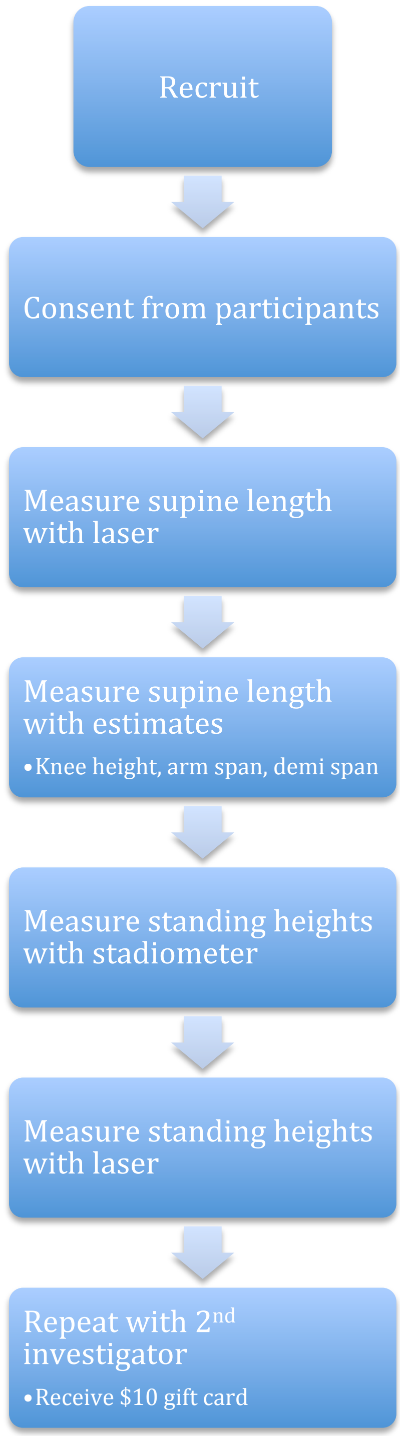
By signing below you are agreeing to be part of the study.

Name:

Signature: Date:

APPENDIX C

METHODS FLOW CHART


Recruit
Consent from participants
Measure supine length with laser
Measure supine length with estimates
•Knee height, arm span, demi span
Measure standing heights with stadiometer
Measure standing heights with laser
Repeat with 2nd investigator
•Receive $10 gift card

APPENDIX D

SCRIPT

Participant enters

"Hello, anytime during this study you are welcome to ask any questions that you would like. During the study I will be touching parts of your knee, arms, neck and head- is this going to be okay?"

"Please take off your shoes and stand on the scale"

-Take weight-

Knee height

INSTRUCTIONS: Make sure the center of goniometer is on the distal condyle of knee. Place caliper against knee, then measure knee. Make sure heel is touching the back (the paper ream).

"You may now sit down in that chair. I will be measuring the angle of your left knee with this [goniometer] to make sure your knee is at 90°. Once your knee is at 90° I will measure your knee height with this knee caliper. To adjust the angle of your knee I will place various layers of plywood underneath your foot to make sure that your knee is at 90°. I will measure your knee height three times. Between each time I will remove the knee caliper and replace it to measure it again. Do you have any questions? Please lift your left heel"

-Measure knee height and record-

"Please extend your leg forward and we are going to repeat the measurement. Do you have any questions?"

INSTRUCTIONS: Make sure the center of goniometer is on the distal condyle of knee. Place caliper against knee, then measure knee. Make sure heel is touching the back (the paper ream).

-Measure knee height and record-

"Please extend your leg forward and we are going to repeat the measurement one last time. Do you have any questions? I want to press down with similar pressure, how does that feel?"

Make sure the center of goniometer is on the distal condyle of knee. Place caliper against knee, then measure knee. Make sure heel is touching the back (the paper ream).

-Measure knee height and record-

Arm Span

INSTRUCTIONS: Make sure that their feet are always touching the wall, that the shoulders are back and touching the wall, and that their pelvis is tilted forward. Make sure the leveler is level before reading measurement.

"Please stand over there underneath the green square against the wall. Please make sure your shoulder blades and heels are touching the wall and tilt your pelvis forward, to not stick out your butt. Do this to the best of your ability. Now, raise your right arm **as straight as you can, with your palm out. I need your right middle finger to be touching this device, please slide as I instruct. I need to make sure your arms are at a 90° with your body, I will use the goniometer again to measure this, allow me to adjust your arms please."

–Measure right arm angle-

[Gently slide to your right until you are touching the instrument]

-Measure right arm angle-

"Now please raise your left arm, keeping your arms against the wall the best of your ability. I am going to measure the angle of your left arm and then I will take your arm span measurement. Please hold this position as best you can."

–Take measurement-

"You may drop your arms. We are going to repeat this two more times. Please lift your right arm..."

-Take measurement-

"You may drop both of your arms" –record data-

INSTRUCTIONS: Make sure that their feet are always touching the wall, that the shoulders are back and touching the wall, and that their pelvis is tilted forward. Make sure the leveler is level before reading measurement. Check the arm angle between each measurement.

–Repeat instructions starting from ** and take two more measurements-

Demi Span

INSTRUCTIONS: Make sure that their feet are always touching the wall, that the shoulders are back and touching the wall, and that their pelvis is tilted forward. Measure from center of their sternal notch.

"Now we are going to perform a similar measurement, but we are only going to measure from the tip of your left middle fingertip to your chest. **I am going to measure the angle of your arm again to make sure it is at a 90°. I am going to ask you to hold the measuring stick on your chest while I take the measurement."

–Place the measuring stick-

"Please hold this here with your left hand, during this time please hold your arm up as best you can."

–Take the measurement; bring their hand forward to the stick to measure-

"We are going to repeat this 2 more times" –Measure two more times, starting at **-

<u>Supine Laser Measure</u>

INSTRUCTIONS: Make sure they are looking straight up at the ceiling (check), that their feet are flexed, that all the tapes are lined up and that they

"Now we are going to move over here."

"Please lie flat on your back, looking up at the ceiling above you, with your head on that side and please try to lie in the center as best you can. <u>Focus on the sticker that is on the ceiling.</u> Flex your feet and please keep them flexed while measurements are being taken. I am going to place this footboard here against your feet. Are you comfortable? Please allow me to adjust your head to make sure you are looking straight up. I want this to touch your head, but not compress. Please restrain from moving while measurements are being taken. I am going to take 3 measurements again, but you will not have to move, other than lifting your head when I ask. Any questions?"

–Take the measurement-

"Please lift your head"

Remove the headpiece and replace. Check that their head is level and looking straight up. Ask to make sure the headpiece is compressing with the same pressure.

-Take the measurement-

Remove the headpiece and replace. Check that their head is level and looking straight up. Ask to make sure the headpiece is compressing with the same pressure.

Standing height with Stadiometer

INSTRUCTIONS: Make sure that their feet are always touching the wall, that the shoulders are back and touching the wall, and that their pelvis is tilted forward.

Please stand up straight with your feet and heels together. Please ensure your heels are against the back of the stadiometer, that your shoulders are back, and pelvis is tilted forward. Allow your arms to hang loosely at your sides with your palms facing inward. Please look straight ahead, focus on the sticker in front of you and allow me to lightly position your head. I want this to touch your head, but not compress too hard. How does this feel? Hold still please.

-Ensure that the head is at a right angle to the stadiometer and is on the right plane-

-Take measurement-

"Please stand off and come right back on"

-Ensure that the head is at a right angle to the stadiometer and is on the right plane and make sure that their feet are always touching the wall, that the shoulders are back and touching the wall, and that their pelvis is tilted forward. -

-Take measurement and have them get off and come back on-

-Ensure that the head is at a right angle to the stadiometer and is on the right plane and make sure that their feet are always touching the wall, that the shoulders are back and touching the wall, and that their pelvis is tilted forward. -

Standing height with laser device

INSTRUCTIONS: Make sure that their feet are always touching the wall, that the shoulders are back and touching the wall, and that their pelvis is tilted forward and that the device is against the wall. CHECK THE LEVELER BEFORE RECORDING MEASUREMENT.

"Please move to stand under the green sticker again and stand up straight with your feet and heels together. Please ensure your shoulder and heels are against the back of the wall and allow your arms to hang loosely at your sides with your palms facing inwards and your pelvis is tilted forward. Please look straight ahead, focus on the sticker, and allow me to lightly position your head. Hold still please.

-Ensure that the head is at a right angle with the laser device and on the Frankfurt plane-

-Take measurement, CHECK LEVELER, record data, then remove device, have them relax, then replace device-

Make sure that their feet are always touching the wall, that the shoulders are back and touching the wall, and that their pelvis is tilted forward. Check that the device is against the wall. CHECK THE LEVELER BEFORE RECORDING MEASUREMENT.

"Please ensure your shoulder and heels are against the back of the wall and allow your arms to hang loosely at your sides with your palms facing inwards and your pelvis is tilted forward. Please look straight ahead, focus on the sticker, and allow me to lightly position your head"

-Take measurement, CHECK LEVELER, record data, then remove device, have them relax, then replace device-

Make sure that their feet are always touching the wall, that the shoulders are back and touching the wall, and that their pelvis is tilted forward. that the device is against the wall. CHECK THE LEVELER BEFORE RECORDING MEASUREMENT.

"Please ensure your shoulder and heels are against the back of the wall and allow your arms to hang loosely at your sides with your palms facing inwards and your pelvis is tilted forward. Please look straight ahead, focus on the sticker, and allow me to lightly position your head"

APPENDIX E

PICTURES


ASU
Exercise & Sport
Research Institute
FIRE


BOSCH
Professional