Anthropometric variance in humans: Assessing Renaissance concepts in modern applications

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Abstract
Visual analysis of human anatomical and segmental variation are valuable tools for analysing and modifying exercise positions for movement efficiency, health, and safety. The most widely known visual technique for determining whether a body segment is long, short, or normal is based on da Vinci's 1487 Vitruvian Man. In the more than five centuries since, human height has changed. This pilot study explores whether the change in stature affects the validity of da Vinci's original estimations of anthropometry relative to modern populations. The present day data deviated across all Vitruvian segments. Of the nine male and six female subjects, none matched the model, thus indicating the need for further investigation on a larger scale. Male segmental lengths were more different from the Vitruvian standard ($p=0.0002$) than female segmental lengths ($p=0.2457$). However, it was noted that da Vinci's estimations were within one SD of the present means; thus, the model may still be cautiously applied as a guide for health professionals.

KEYWORDS: anthropometry, health, exercise, da Vinci, Vitruvius

Introduction
Teaching and coaching exercise have always carried with them an element of interpretive anatomy with three distinct applications. The most recognised use is the easy selection of appropriate exercises in order to applied controlled stress to the specific anatomical structures in which adaptation is desired; cardiovascular, pulmonary, skeletal, neural, and muscular structures being the most relevant. A second common use is the identification of individuals with anthropometric dimensions associated with success in sport (Pipes 1977; Kansal et al. 1980; Grimston & Hay 1986; Claessens et al. 1998; Bourgois et al. 2000; Crossland et al. 2011). It is commonplace to see sport coaches select potential athletes for a sport or a specific position within a sport based upon physical dimensions. This is most common in school-age and high school sport, where the coach is initially presented with no other means of selection or information other than stature.

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A third application, albeit a less recognised, but likely more significant application, is being able to evaluate an individual's unique anatomical structure and place it in a position that 1) is correct for producing efficient movement through a task-appropriate range of motion and 2) provides a foundation for safety (Kilgore et al. 2009). Both of these points have become poorly attended to in the educational framework that provides the typical gym visitor their expert, personal trainer or coach.

As there is a relative dearth of academic literature related to this topic, it is quite common to find one-size-fits-all approaches to teaching exercise positions in a majority of the authoritative professional literature (American College of Sports Medicine 2006; National Strength & Conditioning Association 2008). It is unfortunate that highly regarded guides for health and fitness professionals do not provide any means for a new clinician, trainer or coach to develop a functional concept of how to adapt exercise positions for individual variations in anthropometry. Indeed, any consideration of anthropometry (other than height, weight, and the derivative Body Mass Index) is absent from virtually all health and fitness curricula. Adding to the informational void are exercise anatomy texts and university courses specifically designed for fitness professionals lacking functional and applied anthropometry instruction relative to movement.

Exacerbating the problem further is the fact that the majority (more than 70%) of practicing health and fitness trainers do not have degrees in health promotion, exercise science, physical education, or other exercise-related degrees (Malek et al. 2002). Despite their lack of education, this group generally refers to the same authoritative academic literature for guidance in practice as do professionals in academia; however, they are much more likely to refer to materials from popular magazines, or word of mouth (Stacey et al. 2010). Consequently, other than learning basic nomenclature from static anatomical representations of the human body, it is unlikely that the average non-university educated health and fitness trainer or coach will be afforded the opportunity to develop an understanding of even the simplest of anatomical applications in exercise. This broadens the problem, affecting both the professional's competency and the quality of teaching and coaching received by the trainee.

The end product of either route to professional practice is that health and fitness professionals are not presented any means to detect anatomical variations or instructions on how to accommodate them. In essence, they will be ill prepared to determine whether someone has longer than normal legs, shorter arms, etc., and how to modify exercise technique to accommodate the identified variations in relatively static exercise (Figure 1). This observation and shortcoming extends to ambulatory exercises, as limb length exerts a powerful influence on gait and velocity transitions (Monteiro et al. 2011).

Identifying a shortcoming within a curriculum of professional preparation is one thing, but how do we approach a solution? Is there a reference standard that can be used in this application? The establishment of body segment length norms has been theorised for at least 5000 years. The ancient Egyptians used two standards; the first was the distance from the ankle to the floor. A human was proposed to have 21.25 of these units in overall height. Later, the measurement unit was changed to the length of the middle finger (digit 3), and human height was stated to be 19 of these units.

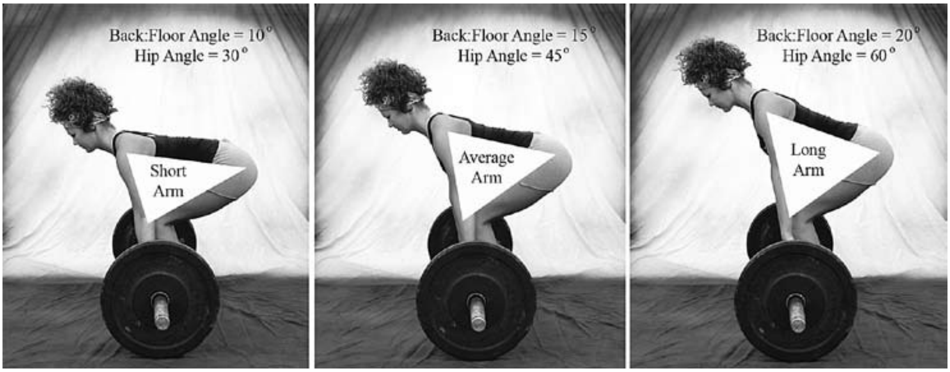

Figure 1: The effect of arm length variation on start position for the deadlift. At the start of the deadlift, the navicular bone, bar, and the most medial and inferior aspect of the scapular spine are aligned in order to produce a straight bar path during ascent. A simple variation in arm length effectively changes the constituent joint angles enabling that position (reprinted with permission from Kilgore, 2010).

Polyclitus, in about the 5th century BC, developed a model of human proportions based on the width of the hand at the metacarpal-phalangeal joints. This enabled production of proportional representations of human in his sculpted works. In this model, the human body was 20 units in overall height. In the first century BC, the Roman architect Vitruvius proposed that the height of the average human was equal to his outstretched arms, fingertip to opposing fingertip. During the Renaissance, the work of Vitruvius was further developed into likely the most persistent and widely recognised descriptive model of human dimensions produced.

One of the most familiar and easiest methods of determining if an individual deviates from 'normal' anthropometry has been to use the historical concept of normal human dimensions created by Leonardo da Vinci (circa 1487). Virtually everyone is familiar with the *Vitruvian Man*, da Vinci's diagram of human proportions, centre of mass, and centre of gravity (Figure 2). It is used symbolically in logos for health and exercise professionals, academic units and medicine around the world. It is a convention used in art instructional programs around the world as a method towards creating proportional representations of the human body.

In application within the exercise arena, by using da Vinci's model, one can simply use an individual's head length as a basis for body segmental analysis and compare the results to those that da Vinci concluded were typical for human dimensions and proportions.

Referencing da Vinci's notes and illustration provide the following dimensional observations:

- from the top of the head to the bottom of the chin is one-eighth of a man's height;
- a man's height is four cubits, which conveniently is eight heads in overall length;
- the length of the outspread arms (wing span or reach) is equal to his height, or eight head lengths;

- the width of the shoulders is a quarter of a man's height, or two head lengths;
- the distance from the elbow to the armpit is one-eighth of a man's height, or one head length;
- the distance from the elbow to the tip of the hand is a quarter of a man's height, or two head lengths;
- the torso, from sternal notch to the level of the hip joint is two-and-a-half head lengths;
- the upper leg is two-and-a-quarter head lengths;
- the lower leg to the ground is two head lengths;
- this widest point of the hips is one-and-a-half head lengths.

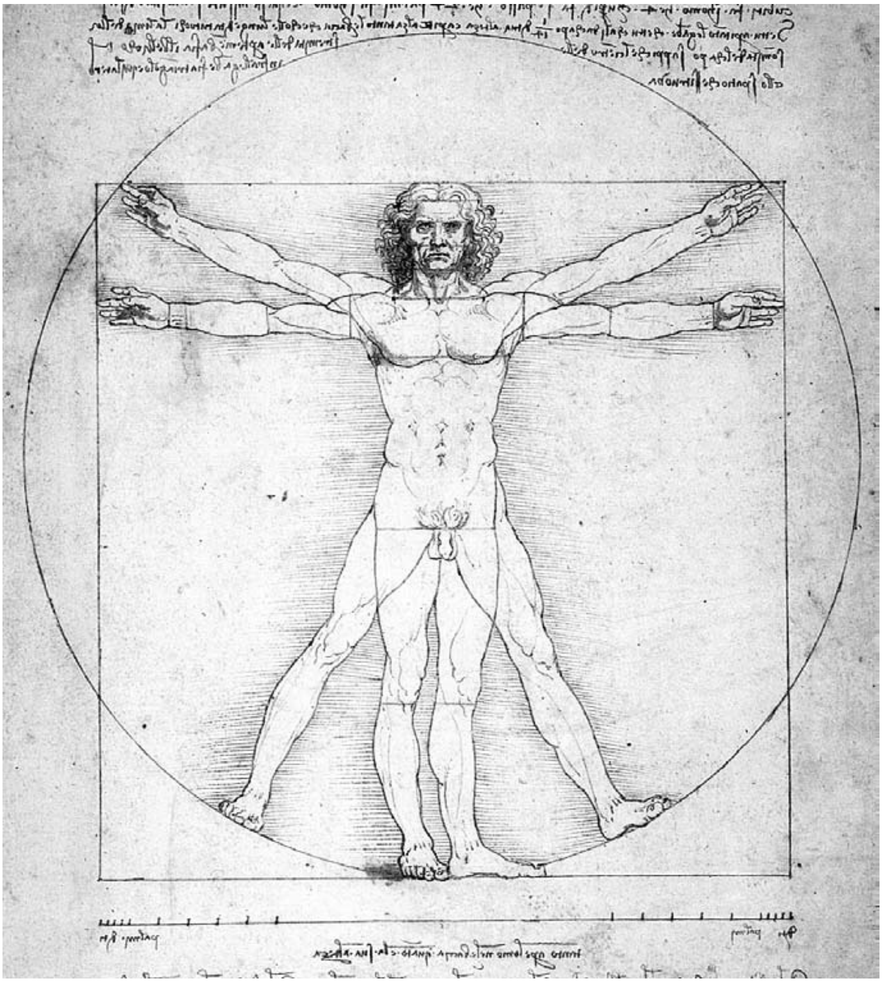

Figure 2: da Vinci's Virtuvian Man (Uoumo Vitruviano). From the collection of the Gallerie dell'Accademia, Venice, Italy.

Using the Vitruvian diagram, a field practitioner can visually, and rapidly, determine if a body segment is different from da Vinci's prototypical human male. The ability to make such rapid assessments is valuable. However, while da Vinci's works are genius and legendary, do five-hundred-year-old assessments of human dimensions apply today as they did during the Renaissance? It is commonly known that Westerners (Caucasian/European) have been becoming progressively taller. From the Renaissance to as late as the 1800s, average male height was likely between 5'6" and 5'8" or 167.6 and 172.7 cm (Steckel 2004). The dimensions of the 19th century male were estimated in a study of five male subjects to be 5'8" or 172.7 cm (Harless 1858). The contemporary male is approximately 5'9'–5'11" or 175.3–180.3 cm (Ogden et al. 2004; Sveriges Officiella Statistik 2007; Corbett et al. 2008). Therefore, a central question is whether the changes in body stature since da Vinci's original estimations of segmental dimensions remain valid in modern populations.

A pilot study was designed and carried out to examine this question and determine the need and feasibility of attempting a larger scale examination.

Materials and methods

Subjects

Nine adult Caucasian males and six adult Caucasian females volunteered to participate in this pilot study. The males averaged 24.2 years of age (± 13.9), the females 31.0 years of age (± 13.9). Male height was 182.4 cm (± 7.3). Female height was 164.2 cm (± 9.6).

Methods

First, head height was determined by measurement from the base of the chin to the highest point on the crown of the head of each subject. This distance formed the base unit of analysis. Each individual's head length was used in assessment of their segmental lengths. The methodology was approved by the relevant institutional review board and the following measurements were then taken:

- *Overall body height* – measured in a standing position, from the inferior calcaneous at the floor to the highest point of the skull;
- *Wing span* – measured with the arms outstretched parallel to the floor, the tip of digit three (middle finger) to the opposing digit three;
- *Shoulder width* – measured from acromio-clavicular joint (point of the shoulder) to acromio-clavicular joint across the breadth of the back;
- *Hip width* – measured at the widest point at the level of the acetabulum (hip joint);
- *Upper arm* – measured from the acromio-clavicular joint to the point of the elbow (olecranon);
- *Elbow to finger tip* – measured from the olecranon to the distal end of the third digit;
- *Torso* – measured from the suprasternal notch to the level of the acetabulum;
- *Upper Leg* – measured laterally from the acetabulum to the middle of the knee joint;
- *Lower leg* – measured laterally from the middle of the knee joint to the floor.

Analysis

The data was analysed through simple descriptive statistics (means and standard deviations). The resulting group means were compared to the values derived from da Vinci's original descriptions and illustration. A paired t-test was performed on the segmental lengths (in cm) between those derived from the Vitruvian Man diagram and those measured in the subjects of the present study.

Results

The data clearly demonstrates a variance in overall body and segmental dimensions relative to those derived from the Vitruvian man diagram. Beginning with the base measurement unit, the head, it is obvious that cranial dimension has changed in the past five centuries. da Vinci's model provides an average head height of 20.96 cm (167.6 cm in body height divided by 8 head lengths in body height). The males in the present study had an average head height of 23.9 cm (± 1.71). Female head height was 21.4 cm (± 1.71). If da Vinci's original model's scaling method is still applicable, the change in skull dimensions should not alter the other dimensional relationships.

Table 1: Male mean height and segmental dimensions in centimeters

Measure	Male		SD	Female		SD	da Vinci
Height	182.46	±	7.31	164.25	±	9.59	167.68
Wing span	189.22	±	18.71	167.64	±	10.30	167.68
Shoulder width	54.72	±	11.98	41.91	±	3.94	41.92
Upper arm	37.80	±	6.05	20.96	±	6.96	31.44
Elbow to finger tip	49.74	±	5.17	36.67	±	3.31	41.92
Torso	61.68	±	13.05	52.39	±	5.74	52.4
Upper leg	47.75	±	7.17	47.15	±	7.16	46.11
Lower leg and foot	50.74	±	10.34	41.91	±	4.38	41.92
Hip width	43.77	±	11.17	31.43	±	6.63	31.44

As anticipated, the females were smaller in all values with the exception of the upper leg, which had nearly identical measures. The segmental measures differed between males and females (Tables 2 and 3) and both experimental sets of observations deviated from those proposed by da Vinci. No single subject, male or female, conformed precisely to the Vitruvian dimensions (Table 4).

Table 2: Male subjects segmental dimensions expressed in head lengths

Subject	Height	Wing span	Shoulder width	Upper arm	Elbow to fingertip	Torso	Upper leg	Lower leg	Hip width
1	7.50	7.75	1.75	1.25	1.75	2.25	1.75	2.25	1.50
2	8.50	7.25	2.25	2.00	2.50	3.75	2.50	3.00	2.00
3	8.10	8.40	1.50	1.75	2.00	2.25	2.25	2.25	1.25
4	7.60	7.80	1.75	1.75	2.00	2.25	2.00	2.25	1.25
5	8.00	7.75	2.25	1.50	2.00	3.00	1.50	2.00	2.00
6	7.25	7.50	3.25	1.25	2.00	3.00	2.25	1.50	2.75
7	9.00	9.50	2.25	1.75	2.25	2.75	2.00	2.75	1.75
8	7.50	7.75	2.25	1.50	2.25	2.50	2.00	2.25	1.50
9	7.00	7.25	2.00	1.75	2.00	2.00	2.25	2.00	1.75
Mean	7.83	7.88	2.14	1.61	2.08	2.64	2.06	2.25	1.75
STD	0.57	0.70	0.50	0.25	0.22	0.55	0.30	0.43	0.47

Table 3: Female subjects segmental dimensions expressed in head lengths

Subject	Height	Wing span	Shoulder width	Upper arm	Elbow to fingertip	Torso	Upper leg	Lower leg	Hip width
1	7.50	8.00	1.75	1.75	2.00	2.00	2.00	2.00	1.50
2	7.00	7.00	1.75	1.25	1.75	2.00	1.50	2.00	2.00
3	8.25	8.25	2.00	1.75	2.25	2.50	2.25	2.25	2.25
4	7.00	7.25	1.75	1.25	2.00	2.00	2.25	2.00	1.50
5	8.00	8.00	2.00	2.00	2.00	2.50	2.00	2.50	1.75
6	8.50	7.50	1.50	1.25	2.00	2.50	2.50	2.00	1.50
Mean	7.71	7.67	1.79	1.54	2.00	2.25	2.08	2.13	1.75
STD	0.64	0.49	0.19	0.33	0.16	0.27	0.34	0.21	0.32

Table 4: Comparison of experimental observations to Vitruvian dimensions (data presented in head lengths)

Dimension	da Vinci	Males	Females
Overall body height	8.0	7.7	7.7
Wing span	8.0	7.9	7.7
Shoulder width	2.0	2.3	1.8
Hip width	1.5	1.8	1.8
Upper arm	1.0	1.5	1.5
Elbow to fingertip	2.0	2.1	2.0
Torso	2.5	2.6	2.3
Upper leg	2.2	2.0	2.1
Lower leg	2.0	2.1	2.1

Statistical evaluation with a paired t-test between the segmental lengths from da Vinci's illustration and the modern male mean values for the same segments demonstrated a significant difference (p=0.0002). Similar statistical treatment of the present female data suggests that there is not a statistical difference between da Vinci's male model and these female values (p=0.2457). As one would expect, a comparison of segmental means between males and females was significantly different (p=0.0002).

Discussion

A partial description of normal human anthropometric variation has been sporadically examined in large scale studies (Daniels 1952; Gordon et al. 1988; Yao et al. 1991, Park et al. 2011). Most of such studies have had specific intents relative to military occupational needs or were part of correlative studies examining potential contributing or detracting anthropometric variables relative to health. A complete description of segmental anatomy was not part of these studies. It has been previously noted that there has not been a systematic or comprehensive evaluation of civilian anthropometry (Kroemer et al. 1988). In the author's literature research in preparation for this manuscript, there was no available research or theoretical manuscripts that were current and directly addressed normal segmental construction in a format similar to that presented by da Vinci. The most similar parallel data was that of Harless, who performed an analysis of five males to produce a set of average dimensions (Harless 1858). There were also no academic or professional articles regarding segmental recognition techniques for use by allied health or fitness professionals relative to the teaching of exercise.

There has been changes in human segmental dimensions since the time of da Vinci (Table 5). Although the present data is different, it remains within one standard deviation of da Vinci's proposed values. While different from the Vitruvian Man, the present data remains crudely similar. This suggests that da Vinci's model may still be a valid approximation of segmental proportions for artistic reference in the creation of depictions of the human body. It may also serve as a health or fitness practitioner's rudimentary mental image, or template, of what "normal" can look like and enable the modification of exercise technique to accommodate detected variations in segment lengths. It is therefore prudent to consider the inclusion of this model in health and fitness professional preparatory materials for students in academic programs and presentation of the model in the popular exercise media in order to reach those fitness professionals who rely on those magazines for guidance.

However, the Vitruvian Man does not accurately describe the modern human body's dimensional lengths and relationships; therefore, further analysis is warranted. Gender was not considered in da Vinci's model, and the present data indicates that scaled female segmental lengths follow a similar pattern as males with the exception of a more narrow shoulder dimension, and are in fact fairly close to the values suggested by da Vinci.

Although the present study is based on a larger subject pool than in previous similar works, a much larger subject pool is needed for verification of all findings of this preliminary study.

Table 5: Comparison of the present data to that of Harless (1858) and to da Vinci's Vitruvian Man model

Subject set	Height	Wing span	Shoulder width	Upper arm	Elbow to fingertip	Torso	Upper leg	Lower leg	Hip width
Present data	182.4	189.2	54.7	37.8	49.7	61.7	47.8	50.7	43.8
Harless (1858)	172.7	-	-	36.4	50.2	64.5	44.9	48.9	-
da Vinci (1487)	167.6	167.6	41.9	21	36.7	52.4	47.1	41.9	31.4

This paper is intended to be an exploratory evaluation of da Vinci's model as a functional tool for health and fitness professionals. In application, the deviations seen here suggest that it will be commonplace to see from a quarter to half a head's length segmental variance between individuals throughout the axial and appendicular anatomy. Not a single subject in this study possessed the dimensional relationships put forth by da Vinci. This strongly suggests that practitioners must become competent in adjusting exercise positions on an individual basis in order to maximise exercise efficiency and safety. It also indicates that consideration of a single exercise position as correct for all individuals is likely to be a flawed approach, consideration of anatomical orientations and external physical influences must be taken into account.

The small subject pool pilot data presented here, along with the scarcity and discontinuity of related anthropometric research, underscores the value of conducting a larger scale evaluation of human dimensions in order to update the Vitruvian concept to modern dimensions. Such an endeavour will lead to a better understanding of the visual analysis of human segmental variation and provide clinical and field practitioners an objective comparative tool for use in the field to aid in teaching and analysing exercise technique and movement.

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Povzetek

Vidna analiza človeške anatomske in segmentalne variacije so pomembna orodja za analizo in modifikacijo vadbenih položajev, ki izboljšujejo učinkovitost gibanja, vidike zdravja in varnosti. Najbolj znana vidna tehnika za določanje kratkosti, dolgosti ali normalnosti telesnih segmentov temelji na da Vicijevi skici vitruvijskega moškega iz leta 1487. V več kot petih stoletjih pa se je višina ljudi povečala. Ta pilotska študija proučuje, ali je ta razlika v telesni višini vplivala na veljavnost da Vincijevih izvornih antropometrijskih ugotovitev na sodobnih populacijah. Sodobni podatki so pokazali na odklone na vseh vitruvijskih segmentih. Nihče izmed devetih moških in šestih ženskih merjencev ni ustrezal modelu, kar nakazuje potrebo po nadaljnjem raziskovanju na večjem vzorcu. Segmentalne dolžine moških so se od vitruvijskega standard razlikovale bolj (p=0.0002) kot segmentalne dolžine žensk (p=0.2457). Vseeno pa je opazno, da so bile da Vincijeve ocene znotraj enega standardnega odklona od trenutnega povprečja, zaradi česar bi lahko model z omejitvami še vedno služil kot merilo strokovnjakom na področju zdravstva.

KLJUČNE BESEDE: antropometrija, zdravje, vadba. da Vinci, Vitruvius

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