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Review Article

The Cubit: A History and Measurement Commentary

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Historical dimensions for the cubit are provided by scripture and pyramid documentation. Additional dimensions from the Middle East are found in other early documents. Two major dimensions emerge from a history of the cubit. The first is the anthropological or short cubit, and the second is the architectual or long cubit. The wide geographical area and long chronological period suggest that cubit dimensions varied over time and geographic area. Greek and Roman conquests led to standardization. More recent dimensions are provided from a study by Francis Galton based upon his investigations into anthropometry. The subjects for Galton's study and those of several other investigators lacked adequate sample descriptions for producing a satisfactory cubit/forearm dimension. This finding is not surprising given the demise of the cubit in today's world. Contemporary dimensions from military and civilian anthropometry for the forearm and hand allow comparison to the ancient unit. Although there appears no pressing need for a forearm-hand/cubit dimension, the half-yard or half-meter unit seems a useful one that could see more application.

1. Introduction

If we know anything of the cubit today, it probably comes from acquaintance with Hebrew Scripture and/or the Old and New Testaments. People have heard or read about the dimensions of Noah's Ark or Solomon's Temple. Acquaintance with Egyptian history might have brought some awareness from the dimensions given for pyramids and temples. The cubit was a common unit in the early East. It continues today in some locations, but with less prominence having been replaced by modern day units. Early employment of the cubit throughout the Near East showed varied dimensions for this unit. Some variants can be examined easier with reference to biblical passages. Additional variants can also be found in numerous secular documents, but these are less known and less accessible than scripture.

The word cubit (ˈkyü-bət) in English appears derived from the Latin cubitum for elbow. It was *πήχυς* (payˈ-kus) in Greek. The cubit is based upon a human characteristic—the length of the forearm from the tip of the middle finger to end of the elbow. Many definitions seem to agree on this aspect of the unit, yet it does not produce a universal standard for there are many ways to determine a cubit. It can be measured from the elbow to the base of the hand, from the elbow to a distance located between the outstretched thumb and little finger, or from the elbow to the tip of the middle finger. These alternate descriptions further complicate the matter of determining a specific unit measure of the cubit. Hereafter, the latter description, elbow to the tip of the middle finger, will signify the common unit.

The human figure (typically male) has been the basis for many dimensions. The foot is immediately recognized as an example [1]. Less commonly heard is onyx (nail), but onyx remains a medical term. The Old English ynche, ynch, unce, or inch was a thumb-joint breadth. The anthropomorphic basis for many standards supports the statement "man is the measure of all things" attributed to Protagoras according to Plato in the *Theaetetus* [2]. Small wonder the cubit was initially employed for measurement given its omnipresent availability for use. We always possess the unit. Human figure units are arbitrary but universal are especially effective by their bodily reference producing a crude standard that is immediately accessable.

The cubit provides a convenient middle unit between the foot and the yard. The English yard could be considered a double cubit said to measure 12 palms, about 90 cm, or 36 inches measured from the center of a man's body to the tip of the fingers of an outstretched arm [3]. This is a useful way

Table 1: The relative lengths of four common dimensions.

Meter	
Yard	
Cubit	
Foot	

of measuring cloth held center body to an outstretched hand (two cubits), or across the body to both outstretched hands (four cubits as specified in Exodus 26: 1-2, 7-8). The English ell is a larger variant of the cubit consisting of 15 palms, 114 cm, or 45 inches. It is about equal to the cloth measure *ell* of early Scotland. A man's stride, defined as stepping left-right, produces a double cubit, or approximately a yard [1].

The dimensions in Table 1 give the (approximate) relative lengths for meter, yard, cubit, and foot.

The cubit was a basic unit in early Israel and the surrounding Near East countries. It is אמה in Hebrew (pronounced am-mah′), which can be interpreted "the mother of the arm" or the origin, that is, the forearm/cubit. Selected biblical references [4] for the cubit include these five rather well-known selections.

(1) And God said to Noah, I have determined to make an end of all flesh; for the earth is filled with violence through them; behold, I will destroy them with the earth. Make yourself an ark of gopher wood; make rooms in the ark, and cover it inside and out with pitch. This is how you are to make it: the length of the ark three hundred cubits, its breadth fifty cubits, and its height thirty cubits. (Genesis 6:13–15 RSV)

(2) They shall make an ark of acacia wood; two cubits and a half shall be its length, a cubit and a half its breadth, and a cubit and a half its height. And you shall overlay it with pure gold, within and without shall you overlay it, and you shall make upon it a molding of gold round about. (Exodus 25:10-11 RSV)

(3) And he made the court; for the south side the hangings of the court were of fine twined linen, a hundred cubits; their pillars were twenty and their bases twenty, of bronze, but the hooks of the pillars and their fillets were of silver. And for the north side a hundred cubits, their pillars twenty, their bases twenty, of bronze, but the hooks of the pillars and their fillets were of silver. And for the west side were hangings of fifty cubits, their pillars ten, and their sockets ten; the hooks of the pillars and their fillets were of silver. And for the front to the east, fifty cubits. (Exodus 38:9–13 RSV)

(4) And Saul and the men of Israel were gathered, and encamped in the valley of Elah, and drew up in line of battle against the Philistines. And the Philistines stood on the mountain on the one side, and Israel stood on the mountain on the other side, with a valley between them. And there came out from the camp of the Philistines a champion named Goliath, of Gath, whose height was six cubits and a span. (1 Samuel 17:2–4 RSV)

(5) In the four hundred and eightieth year after the people of Israel came out of the land of Egypt, in the fourth year of Solomon's reign over Israel, in the month of Ziv, which is the second month, he began to build the house of The Lord. The house which King Solomon built for The Lord was sixty cubits long, twenty cubits wide, and thirty cubits high. (1 Kings 6:1-2 RSV)

The cubit determined a measure for many aspects of life in Biblical history. A Sabbath day's journey measured 2,000 cubits (Exodus 16:29). This statue proscribed a limit to travel on the Sabbath. The distance between the Ark of the Covenant and the camp of the Israelites during the exodus is estimated at about 914 meters, 1,000 yards, or 2,000 cubits [5].

Biblical citations and historical archeology suggest more than one standard length for the cubit existed in Israel. In II Chronicles 3:3 the citation may imply cubits of the old standard. Ezekiel 40:5; 43:13 may be indicating the cubit plus a hand. Archeological evidence from Israel [6] suggests that 52.5 cm = 20.67 and 45 cm = 17.71 constitute the long and short cubits of this time and location. To some scholars, the Egyptian cubit was the standard measure of length in the Biblical period. The Biblical sojourn/exodus, war, and trade are probable reasons for this length to have been employed elsewhere.

The Tabernacle, the Temple of Solomon, and many other structures are described in the Bible by cubit measures. These also occur with two different cubits dimensions, the long or royal (architectural) cubit and the short (anthropological) cubit. Scholars have used various means to determine the length of these cubits with some success. The long cubit is given as approximately 52.5 centimeters and the short cubit as about 45 centimeters [4, 5].

The Israelite long cubit corresponds to the Egyptian cubit of 7 hands with 6 hands for shorter one. *Eerdman's Dictionary of the Bible* [7, page 1373] states "... archeology and literature suggests an average length for the common cubit of 44.5 cm (17.5 in.)." This citation also gives a range of 42–48 cm (17–19 in) for the cubit. Range is an important parameter because it indicates the variation operating on this measure. Variation indicates multiple influences.

The English use of *cubit* is difficult to determine. The exact length of this measure varies depending upon whether it included the entire length from the elbow to the tip of the longest finger or by one of the alternates described earlier. Some scholars suggest that the longer dimension was the original cubit making it 20.24 inches for the ordinary cubit, and 21.88 inches for the sacred one, or a standard cubit from the elbow to end of middle finger (20″) and a lower forearm

Table 2: Hebrew linear measures.

Measure	Common scale		Ezekiel's scale	
	Millimeters	Inches	Millimeters	Inches
Cubit	444.25	17.49	518.29	20.405
Span	222.12	8.745	259.14	10.202
Handbreadth	74.04	2.91	74.04	2.91
Finger	18.51	0.72	18.51	0.72

cubit from the elbow to base of the hand (12″). These are the same dimensions for Egyptian measurements according to Easton's *Illustrated Bible Dictionary* [9]. *The Interpreter's Bible* [10, page 154] gives the Common Scale length as 444.25 mm or 17.49 inches and Ezekial's Scale as 518.29 mm or 20.405 inches for the two cubit lengths. Inasmuch as the Romans colonized England the shorter cubit previously mentioned may have been the standard.

A rod or staff is called גמד (gomedh) in Judges 3:16, which means a cut, or something cut off. The LXX (Septuagint) and Vulgate render it "span" which in Hebrew Scripture or the Old Testament is defined as a measure of distance (the forearm cubit), roughly 18 inches (almost 0.5 of a meter). Among the several cubits mentioned is the cubit of a man or common cubit in Deut. 3:11 and the legal cubit or cubit of the sanctuary described in Ezra 40.5 [6].

Barrios [5] gives a summary of linear Hebrew measures (see Table 2).

Barrois [5] indicates the dimension of the cubit can only be determined by deduction and not directly because of conflicting information. He reports the aqueduct of Hezekiah was 1,200 cubits according to the inscription of Siloam. Its length is given as 5333.1 meters or 1,749 feet. Absolute certainty for the length of a cubit cannot be determined, and there are great differences of opinion about this length fostering strong objections and debates. Some writers make the cubit eighteen inches and others twenty, twenty-one inches, or greater. This appears critically important for those seeking to determine the exact modern equivalent of dimensions taken from scripture. Taking 21 inches for the cubit, the ark Noah built would be 525 feet in length, 87 feet 6 inches in breadth, and 52 feet 6 inches in height. Using the standard 20″ cubit and 9″ span, Goliath's height would be 6 cubits plus a span for about 10 feet and 9 inches. With a cubit of 18″ his height is 9 feet 9 inches. The Septuagint, LXX, suggests 4 cubits plus a span, or a more modest 6 feet and 9 inches. There are many implications depending upon which dimension is selected [7]. The story requires young David to slay a giant and not simply an above average sized man! Likewise for many other dimensions and description found in early writings, the larger the dimensions, the better the story. Sacred dimensions require solemn, awe inspiring ones, but this frustrates an exact determination.

Rabbi David ben Zimra (1461–1571) claimed the *Foundation Stone* and *Holy of Holies* were located within the Dome of the Rock on the Temple Mount. This view is widely accepted, but with differences of opinion over the exact location known as the "central location theory," some of these differences

Table 3

Great Pyramid at Gizeh, Khufu	20.620 ± −005
Second Khafra	20.64 ± −03
Granite temple	20.68 ± −02
Third Pyramid Menkaura	20.71 ± .02
Peribolus walls	20.69 ± −02
Great Pyramid of Dahshur (?)	20.58 ± −02
Pyramid at Sakkara Pepi	20.51 ± −02
Fourth to sixth dynasty, mean of all	20.63 ± −02

Table 4

Egyptian common cubit	18.24 inches
Egyptian royal cubit	20.64 inches
Great Assyrian cubit	25.26 inches
Beládi cubit	21.88 inches
Black cubit	20.28 inches

result from strong disagreement over the dimension of the cubit. Kaufman [11] argues against the "central location theory" defending a cubit measuring 0.437 meters (1.43 feet). David [12] argues for a Temple cubit of 0.56 meters (1.84 feet).

Differences in the length of the cubit arise from various historical times and geographical locations in the biblical period. These very long time periods and varied geographical locations frustrate determining a more exact length to the cubit. Israel's location between Egypt and Mesopotamia suggest that many influences came into play over the space of hundreds and hundreds of years in this well-traveled area. These influences probably contributed to the varied dimensions encountered over this long time frame. Stories, myths, and drama add their share.

The earliest written mention of the cubit occurs in the Epic of Gilgamesh. The incomplete text is extant in twelve tablets written in Akkadian found at Nineveh in the library of Ashurbanipal, king of Assyria (669–630? BCE). Other fragments dated from 1800 BCE contain parts of the text, and still more fragments mentioning this epic have been found dating from the 2nd millennium BCE. The cubit is specifically mentioned in the text when describing a flood as remarkably similar and predating the flood mentioned in Genesis. Obviously, the cubit was an early and important unit of the Middle East fundamental to conveying linear measures as shown in Tables 2, 3, and 4.

2. Egypt

The Egyptian hieroglyph for the cubit shows the symbol of a forearm. However, the Egyptian cubit was longer than a typical forearm. It seems to have been composed of 7 palms of 4 digits each totaling 28 parts and was about 52.3-52.4 cm in length according to Arnold [13].

The earliest attested standard measure is from the Old Kingdom pyramids of Egypt. It was the royal cubit (mahe). The royal cubit was 523 to 525 mm (20.6 to 20.64 inches) in length: and was subdivided into 7 palms of 4 digits each, for a 28-part measure in total. The royal cubit is known from Old Kingdom architecture dating from at least as early as the construction of the Step Pyramid of Djoser around 2,700 BCE [13–15].

Petrie [15] begins Chapter XX the following. Values of the Cubit and Digit writing.

> *The measurements which have been detailed in the foregoing pages supply materials for an accurate determination of the Egyptian cubit. From such a mass of exact measures, not only may the earliest value of the cubit be ascertained, but also the extent of its variations as employed by different architects.*

Petrie's methods and findings are so clearly and precisely described they can best be quoted as follows.

> *For the value of the usual cubit, undoubtedly the most important source is the King-s Chamber in the Great Pyramid; that is the most accurately wrought, the best preserved, and the most exactly measured, of all the data that are known.*

Arranging the examples chronologically, the cubit used was as shown in Table 3.

Petrie writes the following.

> *For the cubit I had deduced ([16, page 50]) from a quantity of material, good, bad, and indifferent, 20–64 ± .02 as the best result that I could get; about a dozen of the actual cubit rods that are known yield 20–65 ± −01; and now from the earliest monuments we find that the cubit first used is 20–62, and the mean value from the seven buildings named is 20–63 = b .02-. . . . On the whole we may take 20–62 ± −01 as the original value and reckon that it slightly increased on an average by repeated copyings in course of time. (pages 178-179).*

3. Greek and Roman Comparisons

In the writings of Eratosthenes, the Greek *σχοῖνος* (schoe′nus) was 12,000 royal cubits assuming a 0.525 meter. The stade was 300 royal cubits or 157.5 meters or 516.73 feet. Eratosthenes gave 250,000 stadia for circumference of the earth. Strabo and Pliny indicated 252,000 stadia for the circumference and 700 stadia for a degree [13, 17]. Reports of Egyptian construction indicate only a 0.04 inch difference between cubit of Snefru and Khufu pyramids according to Arnold [13] and Gillings [17].

Lelgemann [18, 19] reported the investigation of nearly 870 metrological yard sticks whose lengths represent 30 different units. He argues for the earliest unit, the Nippur cubit, to be 518.5 mm. Lelgemann gives the ancient *stadion* = 600 feet and reports the *stadion* at Olympia at 192.27 meters which he believes is based on the Remen or old Egyptian trade cubit derived from the Egyptian royal cubit (523.75 mm) and old trade cubit = 448.9 mm.

Nichholson [20] in *Men and Measures* devoted a chapter to *The story of the cubit*. His summary (page 30) provided comparative lengths to five cubits as shown in Table 4.

Nichholson proposes a long history of the cubit beginning before the time of the Great Pyramid of Kufu c. 2600 BCE. He claims a measure of 500 common cubits for the base side indicating only a six-inch difference from the base measure made by Flinders Petrie. He fixes the date of the royal cubit at about 4000 BCE. The great Assyrian cubit is dated c. 700 BCE. The Beládic cubit is dated c. 300 BCE. Nichholson fixes the Black cubit as fully realized at around the ninth century of this era which suggests a parallel to the growth and spread of Islam. While his measures for these variants of the cubit appear to dovetail with some of the other estimates given in this paper, there are serious questions about the chronological sequence associated with these variants. Nichholson offers no evidence or support for this sequence. His estimates of the common and royal cubits conform to other estimates, but the other values are less conforming.

4. Greek/Roman Periods

The Greek *πῆχυς* (pay′-kus) was a 24-digit cubit. The Cyrenaica cubit measured about 463.1 mm with the middle cubit about 474.2 mm making them roughly 25/24 and 16/15 Roman cubits. Other Greek cubits based on different digit measures from other Greek city-states were also used. The Greek 40-digit-measure appears to correspond to the Latin gradus, the step, or half-a-pace [21].

It shows that the Greeks and Romans inherited the foot from the Egyptians. The Roman foot was divided into both 12 unciae (inches) and 16 digits. The uncia was a twelfth part of the Roman foot or pes of 11.6 inches. An uncia was 2.46 cm or 0.97 of our inch. The cubitas was equal to 24 digiti or 17.4 inches. The Romans also introduced their mile of 1000 paces or double steps, with the pace being equal to five Roman feet. The Roman mile of 5000 feet was introduced into England during the occupation. Queen Elizabeth, who reigned from 1558 to 1603, changed the statute mile to 5280 feet or 8 furlongs, with a furlong being 40 rods of 5.5 yards each. The furlong continues today as a unit common in horse racing.

The introduction of the yard as a unit of length came later, but its origin is not definitely known. Some believe the origin was the double cubit. Whatever its origin, the early yard was divided by the binary method into 2, 4, 8, and 16 parts called the half-yard, span, finger, and nail. The yard is sometimes associated with the "gird" or circumference of a person's waist, or with the distance from the tip of the nose to the end of the thumb on the body of Henry I. Units were frequently "standardized" by reference to a royal figure.

The distance between thumb and outstretched finger to the elbow is a cubit sometimes referred to as a "natural cubit" of about 1.5 feet. This standard seems to have been used in the Roman system of measures as well as in different Greek systems. The Roman ulna, a four-foot cubit (about 120 cm), was common in the empire. This length is the measure from a man's hip to the fingers of the outstretched opposite arm. The

Table 5: Middle East names and dimensions for the cubit and related measures.

		Egypt	
Digit, zebo	1/28 royal cubit	0.737″	18.7 mm
Palm, shep	1/7	2.947″	75 mm
Royal foot	2/3	13.95″	254 mm
Royal cubit	unit	20.62	524
Ater, skhoine	12,000 royal cubits	3.9 miles	6.3 km
		Hebrew	
Finger, ezba	1/24 cubit	0.74″	19 mm
Palm, tefah	4 fingers, 1/6 cubit	2.9″	75 mm
Span, zeret	3 palms, 1/2 cubit	8.8″	225 mm
Royal cubit	7/6 standard cubit	20.7	525 mm
Pace	2 cubits	35.4″	900 mm
Stadion	360 cubits	528″	162 meters
		Greek	
Palm	4 fingers	3.0″	77 mm
Span	12 fingers	9.1″	231
Cubit	24 fingers	18.2″	463 mm
Stade		604 feet	185 meter

Roman cubitus is a six-palm cubit of about 444.5 mm about 17.49 inches [17].

5. Other Near East Dimensions

Over time and the geographic areas of the Middle East various cubits and variations on the cubit have been recorded: 6 palms = 24 digits, that is, ~45.0 cm or 18 inches (1.50 ft); 7 palms = 28 digits, that is, ~52.5 cm or 21 inches (1.75 ft); 8 palms = 32 digits, that is, ~60.0 cm or 24 inches (2.00 ft); and 9 palms = 36 digits, that is, ~67.5 cm or 27 inches (2.25 ft) [1]. Oates [22, page 186] writing of mesopotamian archeology states "measures of length were based on the cubit or "elbow" (very approximately 0.5 m)."

The Histories of Herodotus [23, page 21] described the walls surrounding the city of Babylon as "fifty royal cubits wide and two hundred high (the royal cubit is three inches longer than the ordinary cubit)." An accompanying note to the text provides the information given in parentheses, and the end note reports these values as "exceedingly high" raising questions about the height of these walls which would be well over three-hundred feet high if the royal cubit of 20 inches is implied, or 100 meters if the royal cubit is 50 cm. For comparison, the great pyramid of Khufu is listed as originally 146.59 meters [24, page 895]. The credibility of Herodotus has often been questioned, and these dimensions might be suspect also or subject to the same exaggerations found elsewhere in his reportings.

In 1916, during the last years of Ottoman Empire and during WWI, the German Assyriologist Eckhard Unger found a copper-alloy bar during excavation at Nippur from c. 2650 BCE. He claimed it to be a measurement standard. This bar, irregular in shape and irregularly marked, was claimed to be a Sumerian cubit of about 518.5 mm or 20.4 inches. A 30-digit cubit has been identified from the 2nd millennium BCE with a digit length of about 17.28 mm (slightly more than 0.68 inch). The Arabic Hashimi cubit of about 650.2 mm (25.6 inches) is considered to measure two French feet. Since the established ratio between the French and English foot is about 16 to 15, it produces the following ratios: 5 Hashimi cubits ≈ 10 French feet ≈ 128 English inches. Also, the length of 256 Roman cubits and the length of 175 Hashimi cubits are nearly equivalent [16].

The guard cubit (Arabic) measured about 555.6 mm; 5/4 of the Roman cubit producing 96 guard cubits ≈ 120 Roman cubits ≈ 175 English feet. The Arabic nil cubit (or black cubit) measured about 540.2 mm. Therefore 28 Greek digits of the Cyrenaica cubit ≈ 25/24 of a Roman foot or 308.7 mm, and 175 Roman cubits ≈ 144 black cubits. The mesopotamian cubit measured about 533.4 mm, 6/5 Roman cubit making 20 Mesopotamian cubits ≈ 24 Roman cubits ≈ 35 English feet. The Babylonian cubit (or cubit of Lagash) measured about 496.1 mm. A Babylonian trade cubit existed which was nine-tenths of the normal cubit, that is, 446.5 mm. The Babylonian cubit is 15/16 of the royal cubit making 160 Babylonian trade cubits ≈ 144 Babylonian cubits ≈ 135 Egyptian royal cubits. The Pergamon cubit 520.9 mm was 75/64 of the Roman cubit. The Salamis cubit 484.0 mm was 98/90 of the Roman cubit. The Persia cubit of about 500.1 mm was 9/8 of the Roman cubit and 9/10 of the guard cubit. Extending the geographic area still further produces more names and values for the cubit [16, 18, 19, 25, 26].

From the Encyclopedia Britannica [24] section on Weights and Measures given in Volume 23, the unit specifications for the Middle East cubit are shown in Table 5.

From a table in A. E. Berriman's Historical Metrology [8] we find his summary of cubit standards in Table 6.

If one assumes the values from Berriman's table to be reasonable estimates, then the descriptive statistics from the data in Table 7 offer a summary of these varied dimensions.

The estimates in Berriman's table for Greek and Roman cubits align reasonably well with the Egyptian short cubit

Table 6: Cubit dimensions from Berriman [8].

Cubit	Inches	Meter
Roman	17.48	0.444
Egyptian (short)	17.72	0.450
Greek	18.23	0.463
Assyrian	19.45	0.494
Sumerian	19.76	0.502
Egyptian (royal)	20.62	0.524
Talmudist	21.85	0.555
Palestinian	25.24	0.641

Table 7: Descriptive statistics for A. E. Berriman's table.

	Inches	Meter
Mean	20.04	0.51
Median	19.61	0.50
Standard deviation	2.57	0.07
Range	7.76	0.20
Minimum	17.48	0.44
Maximum	25.24	0.64

suggesting an average of approximately 18 inches. This dimension is about two inches shorter than the overall mean in Table 7. The full range of values is about eight inches from 17.5 to 25. The varied origins for these data and previous values suggest considering a family of cubits accumulated from many geographic areas over many different times rather than view these differences as suspects of one exact dimension. Such variants may not be simple differences, or differences around an exact unit, but rather a composite of dimensions accumulated over a large chronological period from many geographical locations that cannot be disentangled. These multiple dimensions suggest local applications rather than simply differences about a single standard which frustrates greater accuracy.

A rounded value of 18″ seems common for this period. The Hellenistic cubit appears in line with what has been identified as the short cubit. Standardization of the cubit began during Hellenism coinciding with Alexander's conquests in the Middle East. Its standardization was probably increased greatly under the Roman Empire from the influences of war, travel, and trade. These influences contributed to bringing the cubit into a more standard operational unit. Roman engineers in viaduct, bridge, and road construction brought standardization throughout the empire.

Cubits were employed through Antiquity to the Middle Ages and continue even today in some parts of the East. Continued usage prevailed for measuring textiles by the span of arms with subdivisions of the hand and cubit in less industrialized countries.

Moving forward to Da Vinci (1452–1519) we have his specifications and commentary on Vitruvius Pollio (1st century BCE) for the human figure and its dimensions [1]. They can be summarized as fractions of a 6-foot man as given in Table 8.

Table 8: Human dimensions relative to the six-foot male.

Unit	Inches
Finger	0.75
Palm	3
Foot	12
Cubit	18
Height	72
Pace	72

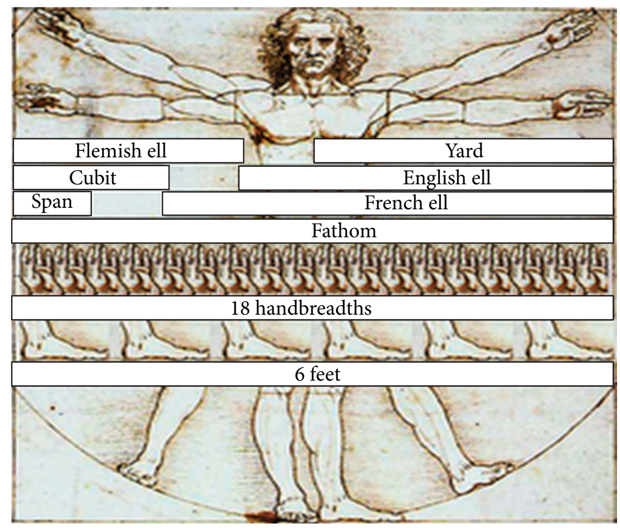

Figure 1: Vitruvian Man.

Figure 1 gives the famous picture associated with these dimensions. The unit given shows one more example of the dimension of the cubit [1].

The figure of the Vitruvian Man by Leonardo da Vinci depicts nine historical units of measurement: the yard, the span, the cubit, the Flemish ell, the English ell, the French ell, the fathom, the hand, and the foot. The units depicted are displayed with their historical ratios. In this figure the cubit is 25% of the 6′ individual and about 18 inches. We are reminded once more of the importance of the human figure for establishing units of measure.

Another example from this period comes from the *Autobiography* [27] of Benvenuto Cellini (1500–1571). In describing his casting of Medusa, Cellini's narration uses cubit to illustrate length as casually as we might use foot or yard. At least in this context, if not others, the cubit appears of common usage. How more generalized a cubit dimension prevailed through this time period is not known exactly. By the time of the French Revolution the Committee of Weights and Measures had abandoned the cubit among other dimensions in favor of the metric system.

6. The Human Cubit

The history of metrology provides interesting data on the varied dimensions of the cubit. Metrology first utilized the human figure in establishing dimensions. History to this

Table 9: Frequency of left cubit measure by inches.

Stature by inches	Under 16.5	Under 17	Under 17.5	Under 18	Under 18.5	Under 19	Under 19.5	Above 19.5	
71+	0	0	0	1	3	4	15	7	30
70	0	0	0	1	5	13	11	0	30
69	0	1	1	2	25	15	6	0	50
68	0	1	3	7	14	7	4	2	38
67	0	1	7	15	28	8	2	0	61
66	0	1	7	18	15	6	0	0	47
65	0	4	10	12	8	2	0	0	36
64	0	5	11	2	3	0	0	0	21
−64	9	12	10	3	1	0	0	0	35
Total	**9**	**25**	**49**	**61**	**102**	**55**	**38**	**9**	**348**
Inches	16.5	17	17.5	18	18.5	19	19.5	19.5	
Frequency	9	25	49	61	102	55	38	9	

point suggests that a value of about 17-18″ seems average and most common.

Sir Francis Galton (1822–1911) offers data gathered from the investigations he conducted. Galton deserves recognition as one of the first investigative anthropometrists. He was a scientist producing some of the first weather maps for recording changes in barometric pressure [28] and strategies for categorizing fingerprints [29]. Galton stands out for his investigations involving thousands of subjects. Some investigations were conducted at the International Health Exhibition in London held 1884-85 and at other field locations. Galton had earlier made an analysis of famous families from which he compiled *Hereditary Genius* [30] and later in *Natural Inheritance* [31]. He maintained a life-long interest in determining the physical and mental characteristics of groups of individuals.

Not only did Galton collect data from his laboratory on human subjects, he investigated statistical techniques for analyzing tables, graphs, and plots of data. In doing so he created the origins for what is now recognized as correlation and regression analysis. Correlation became more formally developed by Pearson [32] as the product moment correlation coefficient. It has become the most known and used statistical procedure of our time. Other statisticians, especially Sir Ronald Fisher [33–35] and Tukey [36], have criticized the correlation coefficient for its abuse arising from simplistic applications and dubious interpretations. Nevertheless, the correlation coefficient remains a popular analytic technique. Pearson [37] also produced three volumes on the life, letters, and works of Galton.

Galton's data for the cubit of his day is given in Table 9. It was taken from Stigler [38, page 319] *The History of Statistics*. Its original source is Galton [39] whose investigation gives data gathered from about 130 years ago on the forearm or cubit. Stigler [38, page 319] indicated three of Galton's row totals were summed incorrectly. These sums were corrected in Table 9.

Figure 2 summarizes the relative frequency of forearm/cubit lengths from Galton's data on 348 subjects given in Table 9.

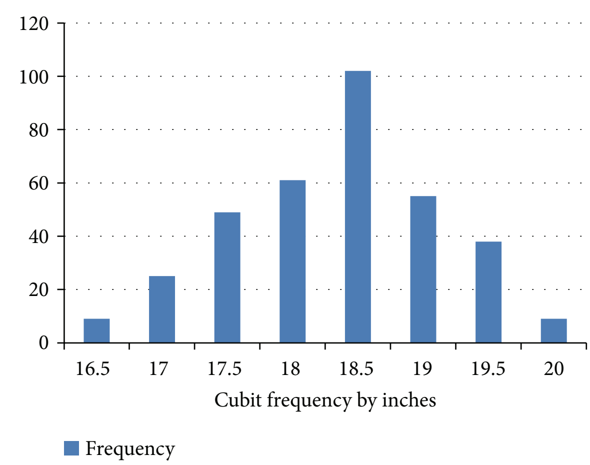

Figure 2: Cubit frequency by inches for 348 subjects.

Figure 2 indicates the modal category of forearm/cubit measures for Galton's sample was 18.5 inches. The frequency distribution of forearm measurements is somewhat balanced. This might be expected given that these measures would be determined by chance through heredity. This was Galton's viewpoint and emphasis. Consequently, his attention derived from this data and other data moved his interest to eugenics. Many other English scientists and statisticians shared this interest; Fisher, Pearson, Haldane, Cattell, and others [40]. Galton (and the others) received considerable criticism for taking this position. However, it was as a scientist and compiler of human data that led Galton to draw his inferences. His pronouncements [30, 31, 41] concerning eugenics do not smack of a political or personal agenda. One may disagree, but it is important to understand that Galton's work was focused upon data and methodology as the basis for forming his conclusions.

The mean for the Galton sample of 348 persons in Table 9 was almost 18 inches bringing estimates of a center location (i.e., mode, median, and mean) in sync with an approximate normal distribution as shown in Table 10.

TABLE 10: Millimeters and inches of the left cubit.

	Millimeters	Inches
Mean	67.06609	17.83621
Standard error	0.126798	0.042699
Median	67	18
Mode	67	18
Standard deviation	2.365384	0.796541
Sample variance	5.595043	0.634478
Kurtosis	−0.9142	−0.42833
Skewness	−0.09243	−0.16653
Range	8	3.5
Minimum	63	16
Maximum	71	19.5
Sum	23339	6207
Count	348	348

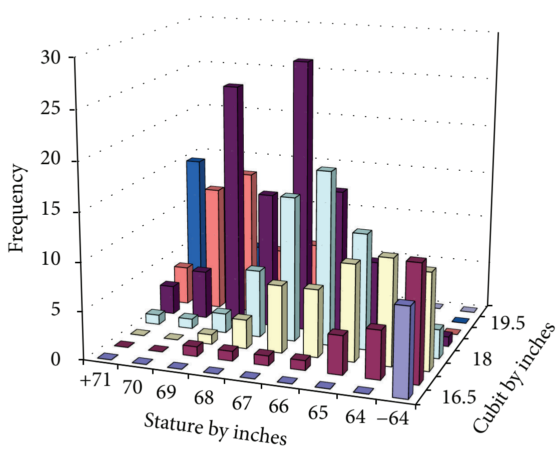

FIGURE 3: A three-dimensional view of Galton's data.

From Galton's data summarized in Figure 2 and Tables 9 and 10 about 2% had forearms at 16.5″ or less and 2% had forearms greater than 19.5″. Approximately 63% or 218 persons and close to two-thirds of the 348 person sample are within one-half inch + or − the mean of 18.3 inches or almost 18.5″ if rounded off. About 95% vary less than an inch above and below the mean estimate. Rounding from these frequencies makes these values approximate, but they still provide a generally useful summary from his sample. Skewness and kurtosis appear as minimal influences on the distribution further confirming a balanced distribution.

Figure 3 provides a three-dimensional view of Galton's data. It usefully shows the clustering of values along the center diagonal from the upper left to lower right. Galton's figures were not shown as three-dimensional, but he recorded the frequencies at each intersection of his two-way table which were used to produce this three-dimensional figure. Pondering his data gave rise to Galton's work on association/correlation for which the word regression has now evolved being derived from his efforts to interpret what this and other data express. See Stigler [38] for more details on Galton's

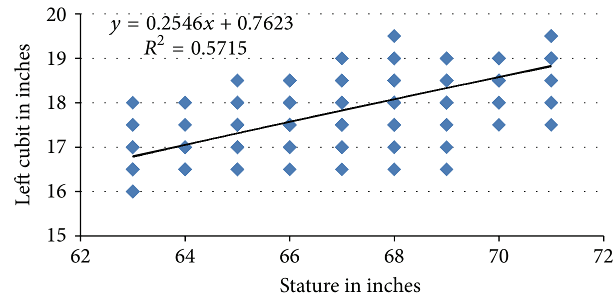

FIGURE 4: Plot of left cubit to stature.

analytic methods. These matters are not directly connected to the issues of cubit length and therefore not discussed here. However, the relationship of cubit to stature is useful and it can be compared to Da Vinci's estimate.

Stigler [38, page 319] indicated "Galton's ad hoc semi-graphical approach gave the correlation value $r = 0.8$." This was Galton's approach prior to the Pearson product moment correlation which when calculated for his data gave $r = 0.75$.

Figure 4 is a plot of data from Table 9 with a linear regression line and showing the variation in forearm/cubit at each level of stature. It is very important to note the wide variation of left cubit measures (vertical) for each indication of stature (horizontal). Individual differences in the cubit/forearm are clearly evident at each point of stature thwarting anything more specific than a generalized indication for the forearm/cubit from Galton's data. The shared variance between stature and cubit is about 57% suggesting these two variables are related but not completely.

Several questions emanate from Galton's data regarding forearm length or the cubit.

(1) How representative is this sample of the general population?

(2) How much change, if any, in human dimensions has occurred from ancient times and over the one hundred plus years from Galton's sample to the present day?

(3) Is there any gender difference or other sources of influence and bias?

From what we know of Galton's methods there appears no indication of outright bias. Stigler [38] in chapters 8, 9, and 10 of his book raised no questions when describing Galton's data and methods for analysing data. Galton's samples were large and often in the thousands. This cubit sample is moderate in scope. Galton was aware of gender differences and utilized 1.08 as a correction factor for male/female differences [38].

However, there is little information regarding sample representation. It appears that Galton was generally fastidious in his investigations. He utilized gatherings of the general population from which to procure his samples and make his measurements. Given that right handedness predominates, Galton measured the left hand to avoid what might result from possible environmental influences upon the mostly

Table 11: Forearm percentiles for an unidentified British population.

Percentile	5	50	95
Male	440	475	516
Female	400	430	460

dominant right hand. Volunteering could be a potential source of bias, but volunteering probably allowed a larger sample of individuals. He paid individuals a modest amount to participate not unlike what is sometimes done today.

Johnson et al. [42] reviewed and reanalyzed Galton's original data. They report on mean scores, correlations of the measures with age, correlations among measures, occupational differences in scores, and sibling correlations. A correlation of cubit/forearm to stature indicated the former was about 25–27% of stature. Nothing further is added to a knowledge of forearm/cubit dinemsion by their work.

Relevance of the forearm/cubit length in more recent times comes from anthropometric dimensions utilized in industrial psychology and applications to the clothing industry. Data from Mech [43] gives more recent data of human dimensions including the forearm. Forearm lengths reported for percentiles 5, 50, and 95 are given in Table 11.

These percentiles are from an unidentified British sample ages 19 to 65. Lacking more information one can only compare and contrast these dimensions to previous samples discussed earlier. These males had a median cubit measure of 475 mm or ~18.7 inches. Females measured a slightly shorter median measure of 430 mm or ~16.9 inches. Mech [43] indicated a median value close to that given in Table 9 for Galton's data or ~18.7 to ~18.3.

The Lean Manufacturing Strategy reports a forearm mean = 18.9′, standard deviation = 0.81′, minimum = 15.4′, and maximum = 22.1′ based on data from McCormick [45]. Nothing further is given regarding this sample and its characteristics.

There are numerous sites and organizations providing carefully determined dimensions for the human body. However, these dimensions are developed to serve the clothing industry and furniture design adding nothing to a knowledge of the contemporary forearm/cubit dimension [46].

The anthropometry database ANSUR [47] obtained from http://www.openlab.psu.edu/ gives a table of percentiles for the horizontal measure made "from the back of the elbow to the tip of the middle finger with the hand extended," that is, cubit. The sample was comprised of unidentified male army recruits.

The ANSUR data sample [47] in Table 12 provides descriptive statistics for the right male forearm plus extended hand in millimeters. The mean for this quite large contemporary sample is about one inch greater than the short cubit reported much earlier. So is the median although the mode is slightly less. The sample appears reasonably balanced, but the variation indicated by the standard error, standard deviation, and range show this human dimension to vary. Variation has been encountered before in the reporting of earlier samples.

Table 12: Elbow-fingertip length percentile distribution in millimeters.

(a)

1st	2.5th	5th	10th	25th	50th	75th	90th	95th	97.5th	99th
435	442	448	455	468	483	499	515	523	532	542

(b)

Mean	484.04	(19.05 inches)
Standard error	0.55	
Median	483	(19.01 inches)
Mode	472	(18.58 inches)
Standard deviation	23.32	
Sample variance	544.09	
Kurtosis	0.43	
Skewness	0.22	
Range	192	
Minimum	386	
Maximum	578	
Count	1774	

7. Discussion

The varied dimensions for the historical cubit of ancient times and places speak to a variation in the dimension itself. Two major units predominate; one estimate centers around 18 inches and the other around 20 inches. There are other variations, some smaller and some much greater. There is too wide a geographical area and too great a chronological time period to consider any of these latter variations normative. Each variant was more likely to be locally relevant rather than widely prominent. Only in the Greek and Roman empires through war, trade, and construction did these values coalesce to somewhat of a standard.

How has the human physique changed over time? Roche [48] reported that rates of growth during childhood have increased considerably during the past 50–100 years. He indicated increases in rates of growth and maturation for all developed nations, but not evident in many other countries. There were recorded increases in length at birth in Italy and France, but little change in the United States. An increase in childhood stature was given for about 1.5 cm/decade for 12-year-old children. The increase in stature for youth was about 0.4 cm/decade in most developed countries. The changes in body proportions during recent decades were reported as less marked than those in body size. Leg length increased more than stature in men but not in women. Roach further indicated that changes in nutrition alone could not account for the trends which exceed the original socioeconomic differentials. In the United States, Roach reported there have been per capita increases in the intake of protein and fat from animal sources, decreases in carbohydrates and fat from vegetable sources, and some changes in caloric intake. It is not clear that these changes constitute better nutrition stimulating growth. The trends could reflect environmental improvements, specifically changes in health practices and living conditions leading to improvements for mortality rates and life expectancy [44]. Nutrition varies even in developed countries. Roche [48] reported genetic factors play a small role in causing trends. However, the data speaks to considerable variation among contemporary samples as also noted in Galton's data.

Overall, it seems unwise to be overly fastidious about any contemporary value for the cubit when such samples are vaguely described. For any comparison of contemporary dimensions reported there are few characteristics given by which to judge sample representation. The contemporary estimates appear somewhat close together and suggest at least for these samples no great change has occurred over the years, but we cannot be sure lacking valid data. Without more sample definition, any fastidious analysis appears unwarranted. The Galton values are likely to have been local and relevant to a British sample. Nowadays samples are more likely to reflect the role of immigration with whatever additional effects this might bring to bear on determining national human dimensions. In general, Europeans are taller than Asian/Middle East peoples and Americans are taller than Europeans. These are generalizations from gross estimates. Komlos and Baten [49] have made a comprehensive analysis of stature over centuries. The striking feature of their tables is the intravariation of values for each time period. Individual variation was also observed in Galton's data. However, systematic sampling and sample details must accompany any data before estimates can be more than gross general indications.

A variety of circumstances address the cubit, but most of them offer little specific information beyond what has already been presented. These biased sites typically serve some agenda, often religious or personal. Overall, even these sites typically report the two major dimensions for the cubit at 18 inches or 20 inches.

The cubit as a dimension remains useful. We take the cubit (hand and foot) wherever we travel. Knowing personal dimensions can sometimes prove useful for making quick albeit gross estimates. The 18$''$ ruler is a very handy device whenever measures just beyond a foot ruler are required, especially when it is necessary to draw straight lines for a length just beyond twelve inches. Tape measures are a boon, but not for drawing lines.

It appears that we might content ourselves with a cubit length of 18 inches as a somewhat consistent dimension for the cubit. Even as the foot evolved from a specific albeit arbitrary personage, any assemblage of them leads to an abstract dimension, so the cubit could justify more application as a 0.5 yard and/or a 0.5 meter. Further prominence of either or both these units might prove more useful than first surmised.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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