Additional information on scale bar position

Corresponding publication (protocol): ArchaeoScale Protocol: Inserting digital scale bars into scientific images – Full step-by-step guideline for anthropological and archaeological specimen photography (DOI: dx.doi.org/10.17504/protocols.io.8epv5j1p6l1b/v1).

Author: Dominik Göldner

Published in 2022

Abstract:

This PDF summarizes a brief experiment to demonstrate the effect of physical scale bar positions on the size dimensions when generating a digital scale bar using the suggested ArchaeoScale protocol published by the author (DG) on protocols.io (DOI: dx.doi.org/10.17504/protocols.io.8epv5j1p6l1b/v1).

Notes on the scale bar position:

As mentioned in the General Notes section above, scale bars should be placed in close correspondence with the feature of interest or the overall subject. This consideration is of utter importance, as the relative position of the physical scale bar along the image depth axis will affect the displayed length of the digital scale bar in the final photograph. To demonstrate this effect, the 5 cm physical scale bar used in this protocol was placed at five different positions (Positions 1 to 5) along the depth axis, whereas the position of the used skull replica was not changed (fig. 17 and 20). An artificial coronal plane through both left and right cranial frontomalare orbitale landmarks (fmo; fig. 17 and 18) that is perpendicular to the ground on which the skull rests was chosen as the reference or base position (here called Position 3).

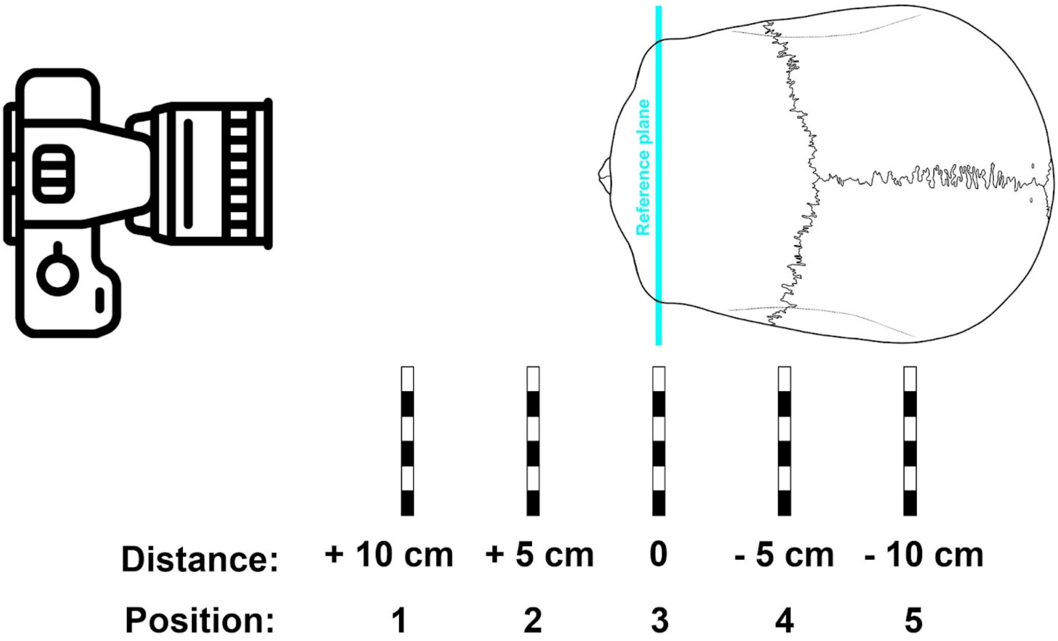

Fig. 17: The following schematic depicts the successive experimental setup used to determine differences in fmo-fmo measurements at various scale bar positions. The distances are measured from Position 3, which serves as a reference plane (the turquoise line) and is parallel to the coronal-craniofacial plane that runs through the left and right fmo landmarks. Illustration created by the author using a single open-source (CC0 license) image of the camera icon (https://www.svgrepo.com/svg/36206/camera-top-view).

When placing a scale bar in this plane, a digitally measured distance in the same plane will reveal the most accurate results. The further away the scale bar is placed from this plane, the higher the error of the obtained (cranio)metric measurements. For each scale bar position, an image with a digital scale bar was generated following the presented protocol. After the digital scale bar was created in ImageJ©, the images were scaled, and it was possible to take digital up-to-scale measurements from the subject within the same software. To evaluate the variation of the scaling between all images, the inner bi-orbital breadth between the left and right frontomalare orbital landmarks (fmo-fmo; Bräuer 1988) was chosen (fig. 18). The measurements were taken in ImageJ© using the Linear Selection Tool after the image had been scaled to all five scale bar positions. The same person (the author) repeated the process of creating the digital scale bar and thus scaling the images as well as taking the fmo-fmo measurements three times at different times on different days for each scale bar position image set to ensure that consistent results were obtained, and that the measurement error remained within acceptable ranges (2 mm). In addition, the same measurement was also taken physically using a digital Vernier caliper (Aickar IP54, accuracy = ± 0.02 mm, resolution = 0.01 mm) on the real skull replica. This measurement was also repeatedly taken on three different occasions. The repetition mean of the physical measurements was used as the gold standard value for all digital measurements.

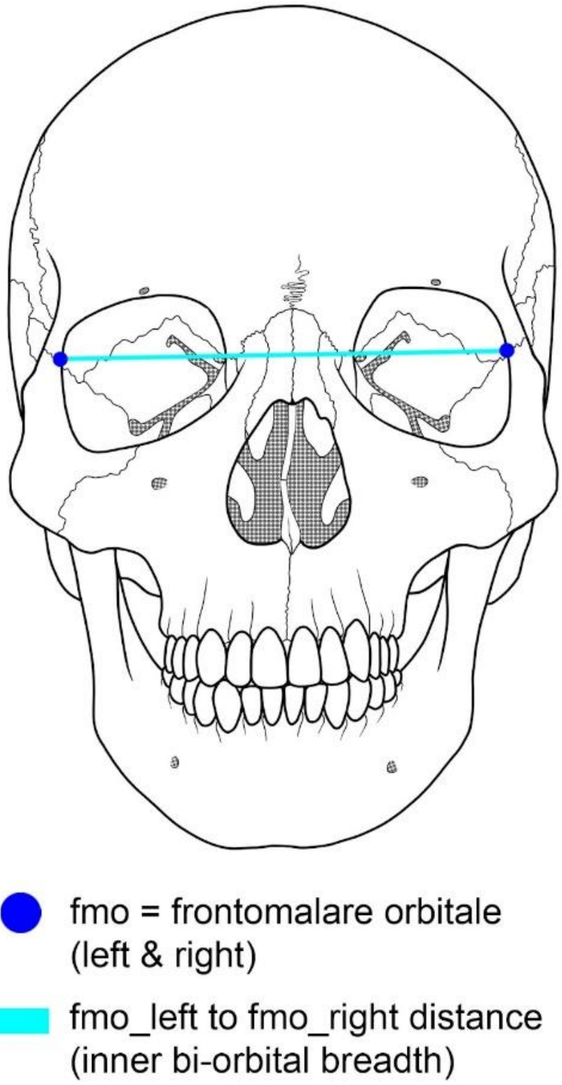

Fig. 18: Inner bi-orbital breadth measurement.

Table 1 summarizes the obtained measurements and the calculated Error Factors and Relative or Percentage Error values. The Error Factor was calculated by dividing the mean of each of the three digital measurement repetitions (M1 to M3) by the mean of the physical measurement. The Relative or Percentage Error represents the difference between the calculated means of the digital measurement repetitions and 1 (i.e., 100% or no difference between measurements). The results were then converted into percentages by multiplying them by 100.

Tab. 1: Measurements of the different scale bar positions.

Position	Distance	fmo_l - fmo_r (mm)				Mean error factor	Mean relative error
		M1	M2	M3	Mean		
Physical		94.77	94.12	95.47	**94.79**	—	—
1	+ 10 cm	71.8	72.1	72.3	**72.1**	0.76	-24%
2	+ 5 cm	82.2	82.3	82.3	**82.3**	0.87	-13%
3	0 cm	94.0	93.1	92.1	**93.1**	0.98	-2%
4	- 5 cm	102.5	102.4	102.7	**102.5**	1.08	+8%
5	- 10 cm	113.6	112.7	113.0	**113.1**	1.19	+19%

Legend: Distance = distance to reference plane at position 3; fmo_l = frontomalare orbitale left, fmo_r = frontomalare orbitale right; M1-3 = measurement 1 to 3.

All measurement repetitions display only small errors (< 2 mm) and can therefore be considered overall consistent and reliable. The mean of the physically measured fmo-fmo distance is 94.79 mm and 93.1 mm for its digital counterpart, where the scale bar was placed in the approximately same plane of this distance measurement (Position 3). The error between the digital and physical references is -2% with an error factor of 0.98. Positions 1 and 2 have Relative Error rates of -24% and -13% in the positive direction, i.e., towards the lens. In the negative direction, toward the image background, the Relative Errors are +8% and +19% for positions 4 and 5, respectively.

The experimentally collected results briefly show the influence of the scale bar position on the obtainable fmo-fmo distance measurements. As expected, the further away the scale bar was placed from the camera, the larger the measurements became, and vice versa. Overall, a clear linear trend can be observed, which highly correlates with the distance of the bar to the camera (fig. 19), i.e., the larger the distance of the scale to the camera, the smaller the scale bar, and the larger the obtained measurements, the Error Factor and Relative Error. This means that as you move away from the camera, the scale bar's measurable dimensions shrink. This observation is, of course, not at all surprising, but it demonstrates well the effect of the position of the physical scale bar on the outcome. Based on this alone, images with (or without) scale bars should not be used to take measurements, as it can, in most cases, not be guaranteed that the scale bars were placed in the exact same plane as the (mostly three-dimensional) features or distance measurements of interest. Furthermore, the effect of lens distortion should be considered if this is not corrected. Each different lens has a unique distortion factor that is more prominent toward the image edges. As the subject or feature of interest is usually positioned in the center of the image and scales towards the edges, this might have an influence that should also be considered. Furthermore, scale bars that are incorrectly positioned relative to the camera and to the region of interest can appear blurry in the final image.

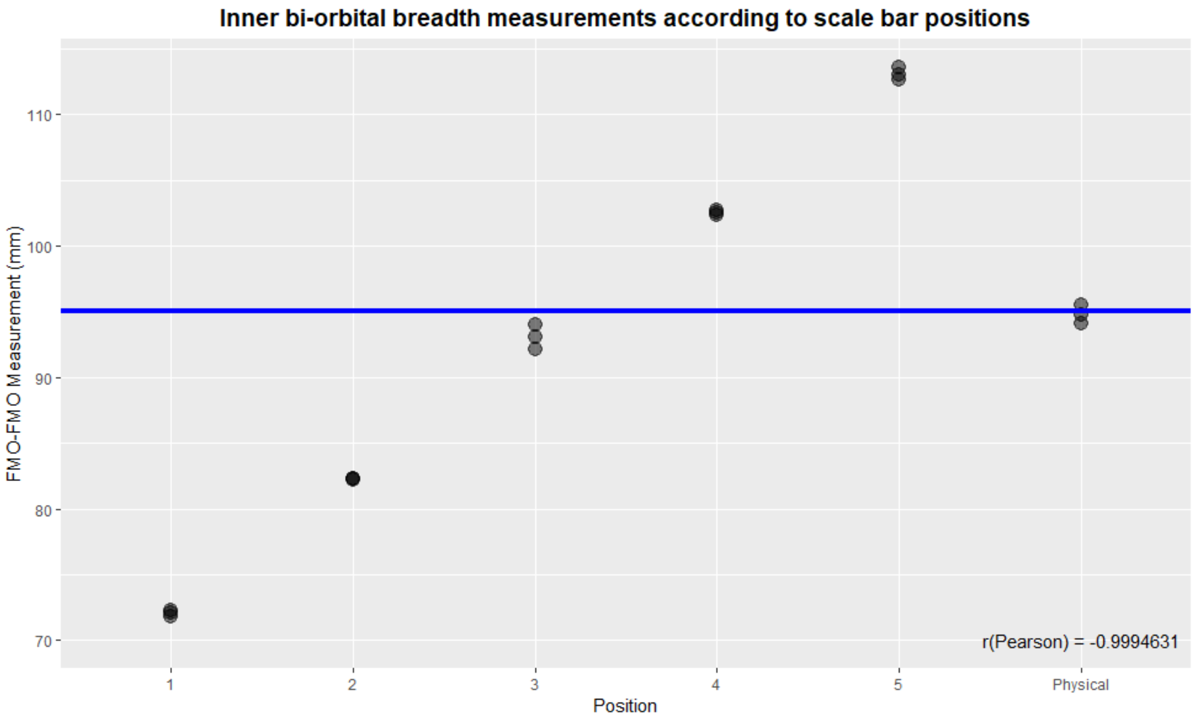

Fig. 19: This graph shows the differences between the fmo-fmo measurement at different scale bar positions along the image depth axis. ImageJ was used to take digital measurements at Positions 1 to 5. The last position ("Physical") represents the physical measurement obtained from the real skull replica. The blue horizontal line represents the reference line according to the physical measurement at around 95 mm. Each measurement was taken three times. The plot was generated using RStudio (version 2022.07.2) and the ggplot2 plugin (version 3.6.6). R code and raw data (as presented in tab. 1) are reported below.

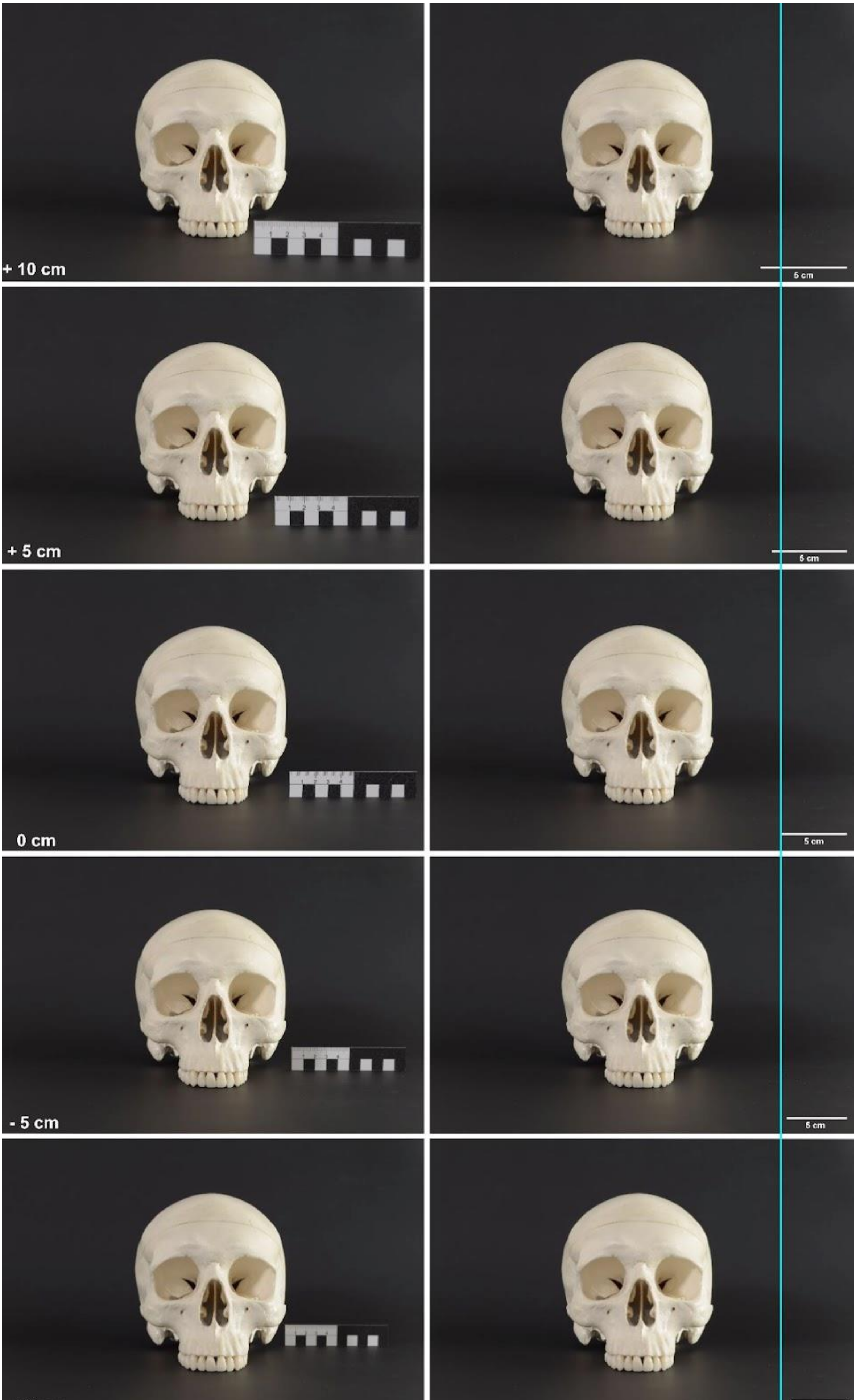
+ 10 cm
5 cm
+ 5 cm
5 cm
0 cm
5 cm
- 5 cm
5 cm
- 10 cm
5 cm

Fig. 20: A comparative overview of all scale bar positions along the image depth axis, i.e., variable distances of the physical scale bar from the camera lens. The original photographs are shown on the left, along with the physical 5 cm scale bars. The right images show the original pictures, which do not include the physical scale bars but the generated and inserted digital 5 cm bars. On the right, positions or distances from the physical scale bar from the lens are indicated. Positive values represent bar positions closer to the lens, while negative values represent positions further away. The middle images at 0 cm represent the reference position at which the scale bar is located at its optimal place, i.e., where it aligns with the coronal craniofacial plane. The turquoise-colored line that crosses the digital scale bars vertically shows differences in the length of the digital bars. This reference line is aligned with the reference plane at position 0 cm.

Raw data (screenshot):

The table below shows the raw data used to generate the plot shown in fig. 19. It is the same data as summarized in tab. 1.

Position	Distance	M	Measurement
1	10	M1	71.8
1	10	M2	72.1
1	10	M3	72.3
2	5	M1	82.2
2	5	M2	82.3
2	5	M3	82.3
3	0	M1	94.0
3	0	M2	93.1
3	0	M3	92.1
4	-5	M1	102.5
4	-5	M2	102.4
4	-5	M3	102.7
5	-10	M1	113.6
5	-10	M2	112.7
5	-10	M3	113.0
Physical	0	M1	94.77
Physical	0	M2	94.12
Physical	0	M3	95.47

R Studio Code for Figure 19:

Used R Studio version: 2022.07.2

Used packages: ggplot2 (version: 3.3.6)

Code:

```
# Load required packages ------------------------------------------------

library(ggplot2)


# Set working directory ------------------------------------------------

setwd("F:/…")


# Read data -------------------------------------------------------------

Data <- read.table("Data.csv", header = T, sep = ";", dec = ".")    #read dataset

View(Data)                                                             #view data


# Calculate Pearson correlation ------------------------------------------

Data2 <- Data[-c(16:18),]                          #remove physical measurements from dataset

str(Data2)                                         #check vector levels of the dataset

Data2$Distance <- as.numeric(Data2$Distance) #change distance variable vector level

cor(Data2$Distance, Data2$Measurement, method = c("pearson"))

#calculate correlation using the Pearson method


# Generate scatter plot  ------------------------------------------------

Plot <- ggplot(Data, aes(x = Position, y = Measurement)) +
geom_point(size = 4, alpha = 0.5, show.legend = FALSE) +
geom_hline(yintercept = 95, color = "blue", size = 1.5) +
ggtitle("Inner bi-orbital breadth measurements according to scale bar positions") +
labs(y = "FMO-FMO Measurement (mm)") +
 theme(plot.title = element_text(hjust = 0.5, size = 14, face = "bold")) +
annotate("text", x = 6, y = 70, label = "r(Pearson) = -0.9994631")              #define plot


Plot              #to show the final plot
```