

Research Paper

Anthropometric weight estimation is less accurate than visual weight estimation in forensic postmortem cases in a Swiss population

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ABSTRACT

When the time since death must be calculated forensic pathologists often consider a calculation based on the Henssge nomogram. This calculation requires an estimated body weight. Previous research has indicated that healthcare workers generally inaccurately guessed patients' body weights. In recent years, weight estimation methods based on anthropometric parameters, such as mid-arm or waist circumference, have been shown to improve estimation accuracy. This study aimed to examine whether anthropometric weight estimation methods could improve weight estimation accuracy compared to visual estimation in forensic pathology.

In 199 cases from a Swiss population, we measured the actual body weight, mid-arm circumference, waist circumference, and body height before autopsy. Additionally, two forensic pathologists visually estimated the body weight. We found mid-arm circumferences to correlate the strongest with actual body weight (Pearson's $r = 0.87$, 95% CI 0.83–0.90). However, all mid-arm circumference-based estimation methods performed worse than those previously described. A statistical bias between -12.3% and -14.5% indicated a systematic weight underestimation. Combined two-physician visual estimation performed significantly better than anthropometric measurements in our population but showed no difference from anthropometric estimation methods previously described in the literature. Further research is needed on novel body weight estimation methods that are currently not applicable for the global population.

1. Introduction

The estimation of time since death is a task that forensic pathologists regularly face when working in crime scenes, and this estimated time range should consequently be as accurate as possible. All cases potentially related to an actual crime or facing other legal repercussions will most certainly undergo further examinations, not the least of which is the proper determination of body weight using a calibrated scale in an institute. However, depending on the country, a preliminary estimation at the crime scene may be a common procedure or even a procedural requirement (as is the case in the authors' country of practice¹).

Establishing the postmortem interval (PMI) usually employs a combination of different methods to narrow the time range and increase accuracy. Using the characteristics of livor mortis and rigor mortis, in combination with supravital reactions and body cooling, is a well-established approach for estimating the time since death in the early

period.²

One essential module for estimating the postmortem interval is body cooling. The calculation based on the Henssge nomogram, which approximates the time since death, ranging from body cooling after death, is assumed to be the most precise.³ It can be performed either on a paper printout or digitally using a computational solution.⁴ The approximation mainly requires the body temperature, room temperature, and body weight, which the physician estimates or measures.⁵ A digital thermometer is always part of a response kit; however, measuring body weight with a scale at the scene is impractical. Therefore, the physician must estimate the body weight to use the Henssge nomogram. An estimation error of only 10 kg can generate a time since death deviation of up to several hours. For example, with an ambient temperature of $-5\text{ }^{\circ}\text{C}$, a rectal temperature of $10\text{ }^{\circ}\text{C}$, and using an empirical correction factor of 1.0, the calculated time since death is estimated to be $20.5\text{ h} + - 3.2\text{ h}$ when body weight equals 70 kg versus $23\text{ h} + - 3.2\text{ h}$ when body weight

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equals 80 kg.

Previous studies have shown that healthcare workers generally poorly estimate body weight and only correctly estimate 50–66 % of cases within a range of ± 10 % of the patient's actual body weight (P10).^{6–13} Additionally, the estimates became significantly less accurate in underweight and obese patients.^{7,9,11} In pediatric emergency medicine, where it is often impossible or impractical to weigh patients and drug doses must be adjusted to the body weight to minimize adverse drug effects, these issues have led to the development of different methods to estimate body weight. However, even body weights determined by physicians using normal scales have been shown to vary significantly from actual body weight.²¹ Conversion formulae based on known or assumed age, which are easy to apply and often mentioned in textbooks, tend to perform poorly because they neglect individual morphological differences.^{14,15} Recently, weight estimation methods have been developed based on anthropometric parameter measurements. Length-based methods with adjustment variables for habitus, such as the PAWPER XL-MAC or Mercy tape, have been shown to be as accurate a weight estimate given by a child's parent (P10 = 79.0 %, 70.9 % and 69.8 %, respectively).^{15,16}

Weight estimation based on anthropometric parameters has not been extensively studied in adults as in children. Cattermole et al. reported a strong correlation between actual body weight (ABW), mid-arm circumference (MAC), and waist circumference (WC) in adults. They derived four mathematical formulae to estimate actual body weight from the MAC derived from the health data of the American National Health and Nutrition Examination Survey (NHANES) 2011/2012 dataset, and validated these conversion methods on the NHANES 2009/2010 dataset. The most accurate of their conversion methods, a table-based sex-specific MAC-to-weight conversion (named the 'LMS model'), estimated 67.5 % of patients aged at least 16 years within 10 % of their actual body weight.¹⁷

Using anthropometric methods to estimate the body weight of recently deceased persons for a quick and accurate estimation of time since death in the early postmortem interval using the Henssge nomogram would be desirable. We hypothesized that anthropometric weight estimation would be more accurate than visual weight estimation by forensic pathologists.

2. Material and methods

2.1. Data

The study data were collected before routine autopsies at the Institute of Forensic Medicine, Zurich, Switzerland, between July 2020 and December 2021. The designated personnel (data collectors) measured the actual body weight, height, MAC, and WC before autopsy. Weight measurements were obtained using a calibrated autopsy scale with accuracy presumed to be sufficient for the purposes of our study. MAC and WC measurements followed the NHANES Anthropometry Procedures Manual,¹⁸ except that all measurements were taken from the front in the supine position and no markings were made for legal reasons. At the beginning of an autopsy, one junior (1–4 years of experience) and one senior forensic (board certified) pathologist (from a pool of 29 forensic pathologists) were tasked with writing down an estimated body weight and height without knowledge of prior measurements or estimates. These data were forwarded to a data collector who then entered the data into a study dataset (Microsoft Excel).

Autopsies of corpses within 72 h of their assumed or known (for example in-hospital deaths) time since death were included to avoid errors originating from decomposition processes. The exclusion criteria were defined as follows: children and teenager ≤ 17 years of age, unknown assigned sex at birth, signs of decay or decomposition present, missing body parts, and medical conditions affecting habitus.

2.2. Statistical analysis

All statistical analyses were performed using SPSS® (version 27; International Business Machines Corporation (IBM), Armonk, NY, USA). First, to compare the correlation of MAC, WC, and body height with actual body weight between our population and the NHANES population, we determined Pearson's correlation coefficient, r , with 95 % confidence intervals. For each case, the estimated body weight was calculated using the four methods described by Cattermole et al. (sex-specific LMS model, sex-neutral LMS model, regression equation, and simplified equation).¹⁷ Because using the mean of several visual estimates has previously been shown to improve the accuracy of weight estimation, we also calculated the mean value of the junior and senior estimates.¹⁹ Consensus on a specific parameter to compare the estimation accuracy is currently lacking in the literature. Most recent studies expressed accuracies as estimated values within 10 %, 20 %, and 30 % of the measured values (P10, P20, and P30, respectively) and calculated the percentage bias and level of agreement using the Bland–Altman analysis. The significance of agreement was calculated using a one-sample t -test for the percentage bias of each method. The range of agreement was defined as a mean bias of ± 2 SD.

3. Results

3.1. Data characteristics

A total of 199 cases were included in this study (aged 18–99). The proportions of males and females (assigned sex at birth) were 70.4 % and 29.6 %, respectively. Overall, age, actual body weight, MAC, and WC showed an even distribution, whereas the male subgroup tended to be taller, heavier, and younger, as shown in [Table 1](#). Complete visual estimation data were available for 184 participants ($n = 5$, only junior MD; $n = 9$, only senior MD; $n = 1$, no visual estimation).

3.2. Physical parameter correlation in comparison to NHANES

The strongest correlation with actual body weight was found for the MAC (Pearson's r 0.87, 95 % CI 0.83–0.90, [Fig. 1](#)). The WC showed a slightly weaker correlation (Pearson's $r = 0.86$, 95 % CI 0.81–0.89). Body height showed the weakest correlation (Pearson's r 0.62, 95 % CI 0.53–0.70). The degree of correlation between the two cohorts was comparable to the intersecting CI for MAC and WC. The results of the comparison of the values from the NHANES cohort are shown in [Table 2](#).

3.3. Comparison of estimation methods

All MAC-based estimation methods produced noticeably lower percentages of estimates within 10 %, 20 %, and 30 % of the actual body weight for our study population compared with the NHANES dataset. The simplified equation method provided the best results in our study

Table 1

Descriptive statistics. The results are rounded to one decimal. Format: Mean \pm SD (Median);¹ assigned sex at birth.

	Overall (n = 199)	Male ¹ (n = 140)	Female ¹ (n = 59)
Age [years]	55.9 \pm 20.1 (55.0)	54.6 \pm 19.9 (54.5)	59.0 \pm 20.3 (57.0)
Body height [cm]	73.9 \pm 10.9 (174.0)	178.3 \pm 8.5 (178.0)	163.4 \pm 8.5 (164.0)
Actual body weight [kg]	80.1 \pm 22.4 (79.0)	85.2 \pm 19.1 (83.5)	68.2 \pm 25.1 (64.0)
Mid-arm circumference [cm]	30.3 \pm 5.2 (30.0)	31.0 \pm 4.4 (31.0)	28.7 \pm 6.4 (28.5)
Waist circumference [cm]	99.6 \pm 12.7 (100)	99.9 \pm 10.9 (100.5)	98.8 \pm 16.1 (99.0)

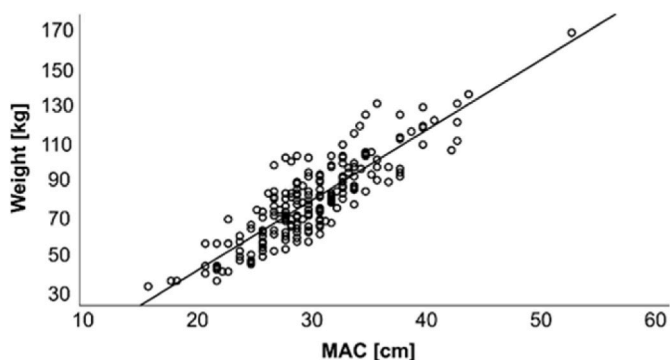


Fig. 1. Distribution of mid-arm circumference (MAC) with weight.

Table 2

Pearson's correlation (95 % CI). The results are rounded to two decimals.

	ZURICH	NHANES (USA)
Mid-arm circumference	0.87 (0.83–0.90)	0.90 (0.90–0.91)
Waist circumference	0.86 (0.81–0.89)	0.89 (0.89–0.90)
Body height	0.62 (0.53–0.70)	0.42 (0.40–0.44)

population, with P10 = 47.7 %, P20 = 75.4 %, and P30 = 93.0 %. In the NHANES dataset, the simplified equation method provided the least accurate results with P10 = 63.5 %, P20 = 92.1 %, and P30 = 98.7 %. All the methods performed substantially better on the NHANES dataset (Table 3).

Bland-Altman analyses showed a significant ($p < 0.001$) bias between -12.3 % (simplified equation method) and -14.5 % (sex-neutral LMS method) in our data (Fig. 2). A negative percentage indicated ABW underestimation for all methods, with the least underestimation using the simplified equation method. The 95 % limits of agreement ranged from -44.9 % to 16.0 % for the sex-neutral LMS method, -43.9 %–16.7 % for the sex-specific LMS method, -44.5 %–16.1 % for the regression equation method, and -43.3 %–18.7 % for the simplified equation method. All methods showed a similar level of disagreement, including clinically relevant discrepancies of up to 45 % of the actual body weight (Table 4).

In visual estimation, accuracy and precision were much better than when applying the methods of Cattermole et al. to our dataset (Fig. 3). Visual estimation did not significantly differ between observers ($p = 0.33$ and $p = 0.90$, respectively). Combined visual estimation by two physicians was associated with improved precision (LOA, -21.9 %–21.1 %) in contrast to single-physician estimation (LOA, -24.8 to 24.6

Table 3

Percentage of estimates within x% of actual body weight (ABW). The results are rounded to one decimal.

	P10		P20		P30	
	Study	NHANES	Study	NHANES	Study	NHANES
Sex-neutral LMS model	43.2	65.2 %	71.9	93.3 %	92.0	99.0 %
Sex-specific LMS model	44.7	67.5 %	74.4	94.9 %	93.5	99.3 %
Regression equation	43.2	64.8 %	71.4	93.4 %	92.5	99.1 %
Simplified equation	47.7	63.5 %	75.4	92.1 %	93.0	98.7 %
Senior MD visual estimation	63.2		87.6		94.8	
Junior MD visual estimation	61.4		89.4		99.5	
Mean visual estimation	67.9		93.5		98.9	

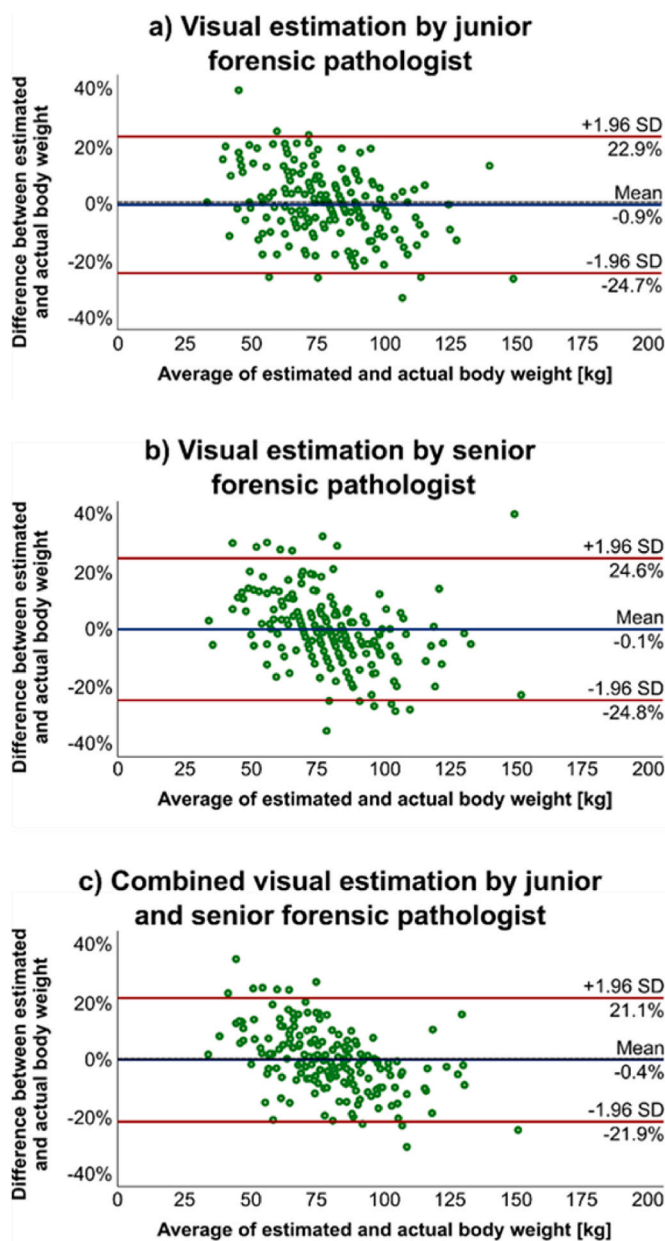


Fig. 2. a – c: Bland-Altman plots of anthropometric estimation methods.

% and -24.7 %–22.9 % for senior and junior MD estimation, respectively). The combined visual estimation showed results comparable to the application of the sex-specific LMS model to the NHANES dataset. It also showed the highest P10 among all methods and datasets (67.9 %, Table 3). For P20, only the sex-specific LMS model in the NHANES dataset provided a higher percentage than that of the combined visual estimation method (94.9 % vs. 93.5 %). For P30, the combined visual estimation did not improve the performance of the single-physician visual estimation.

In the visual estimation, we observed a clear tendency to overestimate lightweight bodies (body mass index below 18.5 kg/m², n = 11, 5.5 %) and underestimate heavyweight bodies (body mass index 30 kg/m² and above, n = 46, 23.1 %), as linear studies often tend to be less accurate at the extremes of the scale. A study focusing on outliers would be beneficial.

Table 4

Bias and Level of Agreement (LOA), in %. The results are rounded to one decimal.

	ZURICH		NHANES (USA)	
	Bias (%)	LOA (%)	Bias (%)	LOA (%)
Sex-neutral LMS model	-14.5	-44.9 to 16.0	-1.0	-22.5 to 20.6
Sex-specific LMS model	-13.6	-43.9 to 16.7	-1.0	-21.6 to 19.5
Regression equation	-14.2	-44.5 to 16.1	-0.8	-22.4 to 20.7
Simplified equation	-12.3	-43.3 to 18.7	1.4	-20.4 to 23.1
Senior MD visual estimation	-0.1	-24.8 to 24.6		
Junior MD visual estimation	-0.9	-24.7 to 22.9		
Mean visual estimation	-0.4	-21.9 to 21.1		

4. Discussion

In this study, we tested the hypothesis that anthropometric weight estimation would estimate body weight more accurately than visual weight estimation by forensic pathologists. We could not confirm this hypothesis, as no MAC-based estimation method showed a higher weight estimation accuracy than visual estimation in our study population. All MAC-based calculation methods systematically underestimated body weight by 10–15 %, although the correlation between MAC and actual body weight was comparable to that of the NHANES population. When comparing descriptive statistics for the derivation population of the MAC-based calculation methods (NHANES 2011/2012 dataset), the mean and median actual body weights were 15 kg and 13 kg higher, respectively, whereas the MAC did not differ substantially. Potential causes for this difference might be the higher prevalence of comorbidities associated with central obesity in the forensic medicine population, or morphological differences between the Swiss and US populations. A study by Opdam et al. observed a similar tendency for higher actual body weight in a Dutch geriatric population; similarly, Cattermole’s regression model might only be valid for the US population but not for a European population and suggested that country- (and population)-specific datasets should be used.²⁰

The visual estimation by a single physician was within the range of accuracy reported in previous studies.^{6–13} We observed no significant difference in visual estimates between junior and senior physicians, while a combined visual estimation by two providers (junior and senior) still improved estimation accuracy. Because medical personnel are often not alone on the scene, we think routine team estimation may be an easy way to increase the accuracy of weight determination for more accurate time of death analysis. We assume that the accuracy could be further improved if physicians, medicolegal or other trained personnel working the scene were made aware of the tendency to overestimate lightweight bodies and underestimate heavyweight bodies. To take matters further, one could design and perform weight-estimation training and then test the outcomes. However, obtaining a close relative’s (e.g. spouses’ or parents’) weight estimate might remain a low-cost alternative with comparable accuracy, as already proven in the pediatric population.¹⁴

A major limitation of this study was the inclusion of only the local population. As previously mentioned, we assumed that anthropometric parameters had high interpopulation variability. The results were specific to the Swiss population examined at our institute. The use of our anthropometric estimation methods could be more or less accurate when applied to regions with a different population affinity. Furthermore, our study group included more males than females, which is representative of the average population of our institute. In addition, this study only focused on the four MAC-based methods proposed by

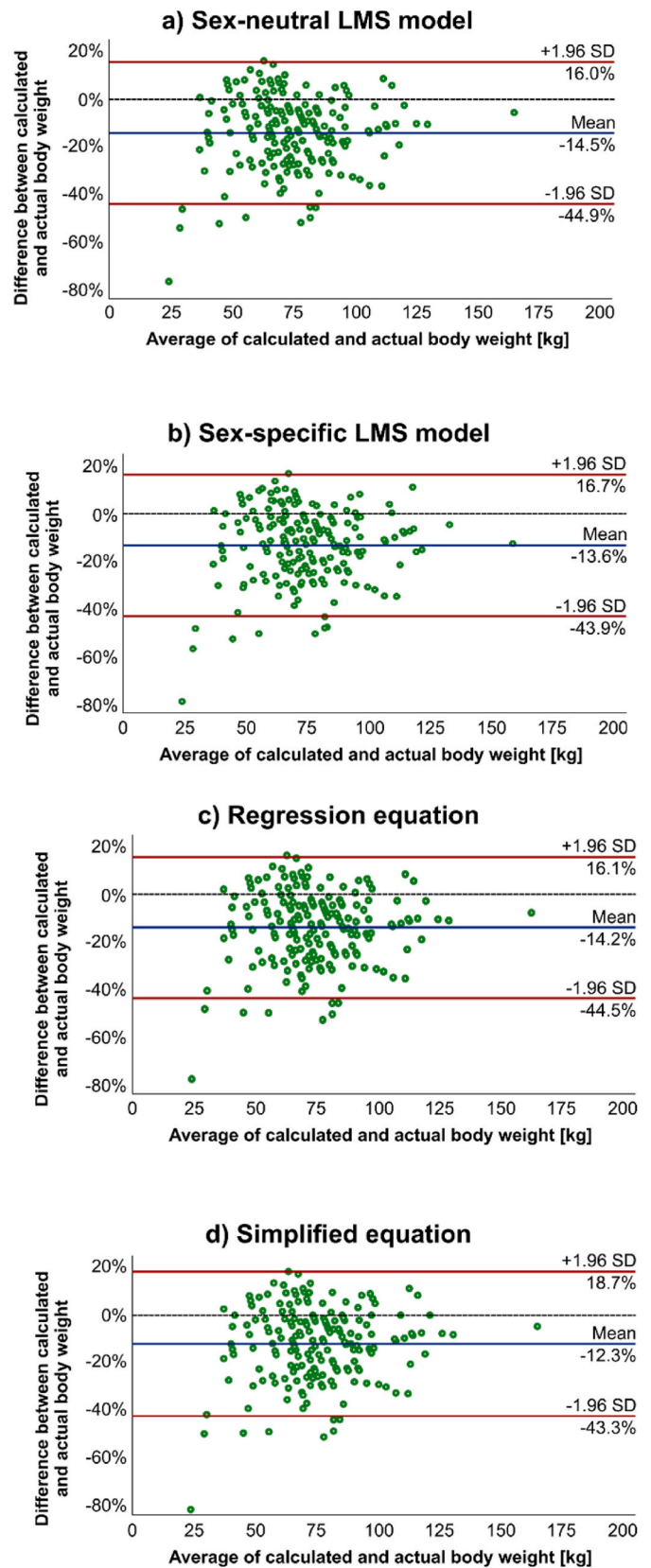


Fig. 3. a-d: Bland-Altman plots of visual estimation methods.

Cattermole et al. Another recent study that compared weight estimation methods for emergency medical care showed that the Lorenz method, a formula based on body height, waist circumference, and hip circumference initially designed to calculate dosages of thrombolytic agents in patients with stroke, could provide even more accurate estimates when applied to the NHANES 2017/2018 dataset (P10 = 86.8 %, P20 = 99.4 %).²¹ This method is limited because it is time-consuming to calculate and, thus, not the optimal method in emergency medicine; therefore, it might prove to be a superior alternative in forensic applications. Finally, the method is limited to bodies without missing body parts with an unambiguous sex.

We suggest that further studies should evaluate a wider array of anthropometric estimation methods. Combinations of anthropometric measurements with visual adjustment for habitus, as seen in the PAWPER XL-MAC tape, have been shown to improve the estimation accuracy in children. In a recently published study by Wells et al., a modified PAWPER XL-MAC tape for adults estimated a P10 of 86.4 % of actual lean body weight.²² In contrast to emergency medicine, weight estimation methods can be performed without time pressure. Therefore, emphasis should be placed on the most accurate methods, even if they are more complex or slow to calculate. These methods should be validated in multiple populations. Furthermore, we suggest a consensus on expressing the weight estimation accuracies as P10 and P20 values for comparability in future studies. Last but not the least, increasing numbers for any postmortem computed tomography scanning (PMCT) for the purpose of better forensic triage will also route these bodies through the respective facility, where the bodies can easily be weighed, without any extra time invested into what will always remain to be inherently lossy methods.²³

4.1. Conclusion

Although weight estimation based on anthropometric parameters has shown the potential to be more accurate than visual estimation, this study could not reproduce previous findings comparing MAC-based weight estimation with forensic pathologists' visual estimation in a postmortem setting. While other formulae based on different anthropometric measurements have recently been shown to potentially improve estimation accuracy, which might clearly surpass visual estimation accuracy, these formulae first need validation in different local populations. For the time being, we recommend weighing bodies on a scale for the best weight estimation.

Statements and declarations

Declaration of interest: None. This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics approval

According to the Swiss law on human research, this study was granted exemption from requiring ethical approval by the cantonal ethics committee of Zurich (KEK ZH-Nr. 15-0686 and BASEC-Nr Req-2022-01446).

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