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COMPARISON OF MANUAL GONIOMETRY AND KINOVEA-BASED PHOTOGRAMMETRY FOR INFRASTERNAL ANGLE ASSESSMENT

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ABSTRACT

Background: The infrasternal angle (ISA) has recently gained attention as a potentially relevant clinical and kinematic parameter due to its associations with breathing patterns, abdominal muscle function and thoracic–pelvic interaction. However, the lack of a standardised measurement protocol and the variability of manual techniques limit its broader clinical and research application. Photogrammetry using Kinovea software may represent a practical and objective alternative, although its application to ISA measurement has not yet been systematically investigated. This study aimed to compare manual goniometry and Kinovea-based photogrammetry to assess their agreement for ISA measurement in healthy young adults, assuming a high level of inter-method agreement.

Methods: ISA was measured in 94 healthy young adults using manual goniometry and frontal photographs analysed in Kinovea. Continuous data were summarised using descriptive statistics; normality was assessed via the Shapiro–Wilk test. Systematic differences between methods were evaluated using a paired-samples t-test. Absolute agreement at the individual level was quantified using a two-way single measure intraclass correlation coefficient (ICC). Measurement error was characterised by the standard error of measurement (SEM) and minimal detectable change at the 95% confidence level (MDC95). Agreement was further examined using Bland–Altman analysis.

Results: The ICC (2,1) for absolute agreement was 0.955 (95% CI 0.941–0.970). SEM was 2.54°, and MDC95 was 7.04°. Bland–Altman analysis showed a mean bias of 1.63° with 95% limits of agreement from −4.84° to 8.09° with most values falling within these bounds.

Conclusions: Kinovea photogrammetry demonstrates excellent agreement with manual goniometry with small and consistent inter-method differences that fall below the MDC95 threshold. These findings indicate that Kinovea represents a reliable and methodologically consistent alternative to manual goniometry for ISA assessment, offering advantages such as objective documentation, reduced examiner dependency and suitability for research, education and large-scale data collection.

***Keywords:** Infrasternal angle, goniometry, photogrammetry.*

INTRODUCTION

Infrasternal or subcostal angle (ISA) is anatomically defined by the inferior border of the sternum and the medial margins of the false ribs and in recent literature it has been recognised as a potentially important parameter in the assessment of breathing patterns, abdominal muscle function, and biomechanical interaction between the thorax and pelvis (1,2). From a broader biomechanical perspective, ISA represents a structural and functional interface between respiratory mechanics and trunk stability, making its accurate quantification relevant not only for posture assessment but also for movement analysis, rehabilitation planning and sports performance evaluation. A reliable and reproducible measurement method is therefore a prerequisite for integrating ISA into both clinical reasoning and scientific investigation. Despite growing interest, ISA has not yet become part of standardised clinical assessment, primarily due to the lack of a clearly defined and generally accepted measurement procedure. Existing research identifies two primary methods for ISA measurement: manual goniometry and radiographic analysis. Manual goniometry, although technically simple and widely accessible, is prone to errors arising from anatomical variations, difficulties in palpating the costal margins, inter-examiner variability and limitations related to the construction of the instrument itself. Radiographic studies have demonstrated that ISA width can be reliably quantified (3). However, radiographic assessment is not suitable for routine application due to radiation exposure, financial cost and time requirements. This methodological gap has created space for the application of photogrammetry, which has already been established in biomechanics and sports sciences as an objective, accessible and repeatable method for analysing body angles and positions. Kinovea, a free software for kinematic analysis of two-dimensional images and videos, has been documented to demonstrate very high intra- and inter-rater reliability across various angular parameters. Multiple studies have confirmed the validity of 2D systems compared with reference 3D motion capture systems and standard clinical tools such as manual goniometers and digital inclinometers (4,5). Kinovea measures angular relationships reliably in both static and dynamic conditions, with ICC values most commonly exceeding 0.85–0.95 and low standard error of measurement values (6,7). Furthermore, research suggests that video-based analysis using Kinovea may enable more precise, consistent, and stringent assessment compared to live evaluation, resulting in lower result variability and greater objectivity when specific recording conditions are met (8). Despite the demonstrated reliability of the software in other domains of postural and kinematic analysis, its application in ISA measurement has not yet been systematically investigated. Additionally, there is a lack of validated protocols that would standardise recording conditions, anatomical landmark identification, and digital analysis procedures for ISA assessment within a photogrammetric environment. Given that manual measurement is sensitive to examiner-related error, while photogrammetric methods allow objective and permanent documentation of measurements with the possibility of subsequent analysis (9), it is justified to investigate the degree of agreement between these two approaches and to determine whether Kinovea may represent a reliable alternative or complementary method to manual assessment (10). Therefore, the aim of this study was to compare manual goniometry and photogrammetric ISA measurement using Kinovea software to evaluate their methodological agreement, identify potential systematic differences and examine the feasibility of photogrammetry as a standardised, objective, and reproducible method for infrasternal angle assessment.

METHODS

PARTICIPANTS

Measurements were conducted on a sample of 94 healthy participants, consisting of 37 males and 57 females. The target population included students of the University of Applied Health Sciences Zagreb aged between 18 and 25 years. Exclusion criteria comprised congenital and acquired chest wall deformities such as pectus excavatum and pectus carinatum due to their direct influence on angle components, scoliosis greater than 20 degrees according to the Cobb method due to transverse plane rotations and previous pregnancy which is confirmed as alternate factor for infrasternal angle dimensions commonly known as "rib flare". Participants provided written informed consent and were informed of their right to withdraw from the study at any time without consequences and measurement has been approved by The Ethics Committee of the University (KL: 053-01/24-01/76; UB: 25-379-10-24-02).

MEASUREMENT PROCEDURE

Measurement instruments included standard anthropometric equipment such as a stadiometer with a medical scale, a manual goniometer and a measuring tape. Participants were assigned codes consisting of a letter indicating the corresponding group and a number representing the participant's sequential position within that group. Each participant was instructed to assume a neutral (zero) body position, defined as an upright posture with feet together, arms relaxed alongside the body and the head positioned in the Frankfurt horizontal plane. The xiphoid process and medial margins of the costal arches were marked using a dermatographic pencil at the level of the orthogonal projection of the midclavicular line relative to the tenth rib. ISA width was measured using a manual goniometer and additionally assessed via photogrammetric analysis using the Kinovea kinematic softwa re. Particular attention was given to consistent landmark identification and participant positioning, as these factors are known to substantially influence angular measurement accuracy in both manual and photogrammetric assessments. To ensure consistency of examination, palpation, landmark marking and measurement, all procedures were performed by the same examiner. Photographs were acquired using a Sony Cyber-Shot DSC-RX100 VII camera mounted on a tripod with the lens height individually adjusted for each participant to align with the level of the xiphoid process. The camera was positioned at a fixed distance of 2 meters from the participant. Kinovea (0.9.5 version) was downloaded from the official platform (11) and installed on a personal computer. Angular arms were constructed within the software by connecting the previously marked anatomical landmarks and the angle was measured using the built-in goniometer tool (Image 1).

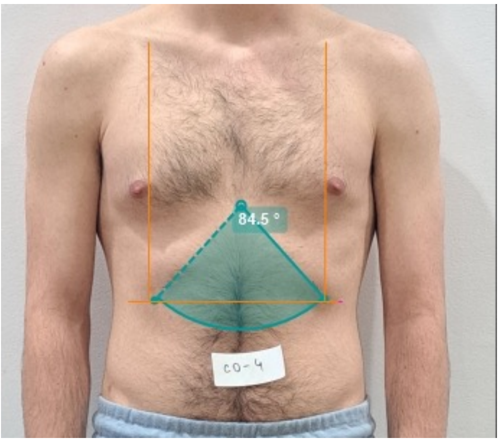

Image 1: ISA marker in Kinovea software (property of the author)

STATISTICAL ANALYSIS METHODS

Descriptive statistics were used to summarise participant characteristics and ISA outcomes. Continuous variables are presented as mean and standard deviation (SD) alongside median and interquartile range (IQR). Normality of continuous data was assessed using the Shapiro–Wilk W test and visual inspection of Q–Q plots and density plots.

To evaluate systematic differences between measurement methods, ISA obtained by manual goniometry and Kinovea photogrammetry were compared using a paired-samples t-test. This analysis was intended to determine whether a consistent mean offset (systematic bias) existed between methods.

Absolute agreement between methods was quantified using a two-way random-effects intraclass correlation coefficient for single measurements (ICC (2,1)). Measurement error was further characterised by calculating the standard error of measurement (SEM) and the minimal detectable change at the 95% confidence level (MDC95). SEM was computed using the formula:

$$\mathrm{SEM} = \mathrm{SD} \times \sqrt{1 - \mathrm{ICC}}$$

where SD represents the overall variability of ISA; in this study, SD was taken from the total sample variability of the averaged ISA measure. The MDC95 was calculated as:

$$\mathrm{MDC}_{95} = 1.96 \times \sqrt{2} \times \mathrm{SEM}$$

indicating the smallest inter-method difference that likely exceeds measurement error.

Agreement was additionally examined using Bland–Altman analysis. The mean difference (bias) and 95% limits of agreement (LoA) were calculated as:

$$\mathrm{Bias} = (\mathrm{X} - \mathrm{Y});\quad \mathrm{LoA} = \mathrm{Bias} \pm 1.96 \times \mathrm{SD}_{\mathrm{diff}}$$

with corresponding 95% confidence intervals for the bias and for the lower and upper LoA reported. The Bland–Altman plot displayed the individual method differences against the method means, the bias line, the upper and lower LoA, and the confidence interval bounds for these estimates to facilitate evaluation of agreement and potential proportional bias.

All tests were two-sided with the type I error rate set at 5% (α = 0.05). Analyses were performed in jamovi (version 2.6.44.0.).

RESULTS

Table 1. Descriptive statistics of basic anthropometric variables by sex.

Variable	Sex	Mean	Median	SD	IQR
Age	*Men*	*19.65*	*19.00*	*1.27*	*1.00*
	Women	*19.40*	*19.00*	*1.18*	*0.00*
Body mass	*Men*	*82.06*	*83.10*	*14.75*	*20.00*
	Women	*64.86*	*63.00*	*11.27*	*19.00*
Height	*Men*	*1.82*	*1.81*	*0.07*	*0.09*
	Women	*1.68*	*1.68*	*0.06*	*0.09*
BMI	*Men*	*23.38*	*22.79*	*4.47*	*4.84*
	Women	*23.77*	*23.34*	*3.77*	*5.28*

Participants were young adults; men showed the expected greater height and body mass than women, with similar BMI distributions across sexes (Table 1).

ISA summaries were consistent across methods and showed higher values in men than women, providing descriptive context for the strong inter-method agreement and the small systematic difference observed in the primary analyses (Table 2).

Table 2. Key descriptive statistics for ISA overall and by sex.

Variable	Sex	Mean	Median	SD	IQR
ISA manual [°]	*Total*	*83.71*	*86.00*	*12.23*	*18.75*
	Men	*87.84*	*90.00*	*11.03*	*14.00*
	Women	*81.04*	*81.00*	*12.32*	*20.00*
ISA photogrammetry [°]	*Total*	*82.09*	*83.45*	*11.96*	*18.65*
	Men	*85.62*	*86.40*	*10.48*	*13.20*
	Women	*79.79*	*79.80*	*12.38*	*20.80*
ISA (averaged) [°]	*Total*	*82.90*	*84.15*	*11.98*	*19.23*
	Men	*86.73*	*88.15*	*10.61*	*14.75*
	Women	*80.41*	*80.40*	*12.25*	*20.45*

ISA measured with the goniometer was slightly higher than ISA measured with Kinovea, with a small but statistically significant mean difference of 1.63° (95% CI 0.95–2.30; $p < 0.001$), indicating a modest systematic offset between methods (Table 3).

Table 3. Paired samples t-test comparing ISA measured by goniometer and Kinovea.

Comparison	*Manual vs photogrammetry*
t	*4.78*
p	*< 0.001*
Mean difference	*1.63°*
95% CI	*0.95° – 2.30°*

The ICC for absolute agreement was 0.955, indicating excellent agreement between goniometer and Kinovea at the individual level. Based on the overall variability of ISA, the estimated standard error of measurement (SEM) was approximately 2.54°, with a minimal detectable change at the 95% confidence level (MDC95) of about 7.04°, suggesting that differences smaller than ~7° may fall within measurement error (Table 4).

Table 4. Intraclass correlation for ISA measured by goniometer and Kinovea.

Model	*Two-way*
Type	*Agreement*
Unit	*Single*
ICC	*0.955*
95% CI	*0.941–0.970*
p	*< 0.001*
SEM	*2.54°*
MDC95	*7.04°*

The Bland–Altman analysis confirmed a small systematic difference between methods that was already evident in the paired t-test. The mean bias was 1.63° (95% CI 0.95 to 2.30), indicating that ISA measured by goniometer tends to be slightly higher than Kinovea on average. The 95% limits of agreement ranged from □4.84° to 8.09°, meaning that for an individual participant, the goniometer value could be up to ~5° lower or ~8° higher than the Kinovea value. The plot shows most points within these limits, supporting overall good agreement, with a slight upward trend suggesting a possible mild proportional bias, meaning that differences may increase somewhat at higher ISA values.

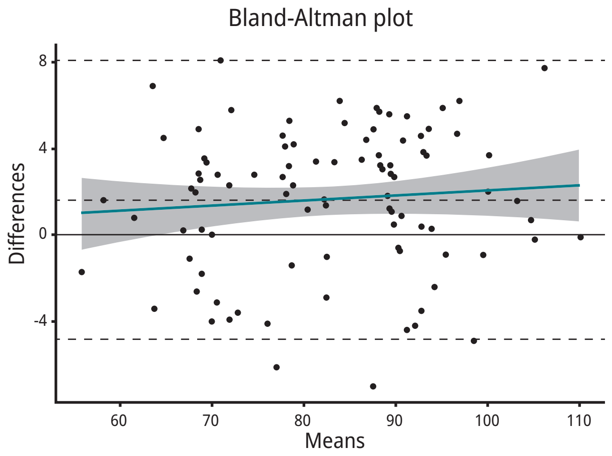

Figure 1. Bland–Altman plot of agreement between ISA measured by manual goniometry and Kinovea photogrammetry.

DISCUSSION

The comparison of manual goniometry and photogrammetric measurement of the infrasternal angle (ISA) using Kinovea software in this study revealed several important methodological and practical considerations with direct implications for measurement selection in both research and clinical contexts. Our results indicate that the manual method yields slightly higher ISA values on average compared to photogrammetric assessment, with a statistically significant difference. However, overall agreement between the methods was very high and consistent with findings reported in previous methodological comparison studies. The mean bias and limits of agreement obtained through Bland–Altman analysis, combined with relatively low SEM (2.54°) and MDC95 (7.04°), confirm a stable relationship between methods and indicate that while differences exist, they are small in magnitude and consistent across participants. In practical terms, this suggests that the two methods do not behave identically, but the differences are sufficiently predictable to support their acceptable agreement under controlled conditions. From a clinical and preventive perspective, the MDC95 value may help distinguish true changes in the ISA from measurement variability. Changes exceeding this threshold may indicate potentially meaningful adaptations, while smaller differences are likely within measurement error. The stable inter-method difference supports the use of photogrammetry for longitudinal monitoring when consistent protocols are applied.

The advantages of photogrammetry become particularly evident when considering the nature of ISA itself. As an angle determined by anatomical prominences of ribs VIII–X, manual ISA measurement relies heavily on examiner experience, palpation quality, and precise goniometer positioning. This reliance on examiner skill makes manual goniometry more susceptible to variability, especially in populations with increased adiposity or pronounced individual anatomical variation. In contrast, photogrammetric analysis enables measurement based on visually marked landmarks on a two-dimensional image, eliminating the need for repeated palpation during each assessment. This reduces potential sources of instrument- and examiner-related error and enhances reproducibility, as reflected in the high ICC values observed in this study. Participants can be photographed within a short time frame, while analyses can be conducted independently and without their presence, thereby increasing scheduling flexibility and overall study feasibility. Although Kinovea is often described as a "low-cost and accessible" method (12), this characterization should be interpreted with a grain of salt. While the software itself is free, minimal equipment such as a camera, tripod, and computer, as well as a controlled recording environment, are required. However, it should be noted that all these are one-time costs. Generally, in clinical screening contexts where rapid assessment is essential, manual goniometry remains more practical due to minimal equipment requirements and the absence of post-processing. Photogrammetry should therefore not be viewed as a replacement for clinical examination, but rather as a complementary method in scenarios requiring higher precision, documentation, and quality control. Standardisation of recording procedures represents another critical aspect. While photogrammetry offers greater control over measurement conditions, it requires strict adherence to protocols defining camera distance, height, marker visibility, and body positioning. Certain adjustments, such as adapting camera height to participant stature, are unavoidable but can be systematically controlled. This aligns with findings from biomechanical and kinesiological research demonstrating that photogrammetry is most reliable when recording conditions are strictly standardised and uniform; otherwise, perspective distortion and out-of-plane movement may compromise accuracy (13,14). In the present study, the importance of standardisation is reflected in the relatively narrow limits of agreement and low SEM values, suggesting that the recording and analysis procedures were sufficiently consistent to minimise technical variability. The systematic tendency of manual measurements to produce slightly higher values may be partially explained by subjective placement of goniometer arms on bony landmarks and differences in perceived rib margins compared to clearly marked points on photographs.

The issue of participant anticipation is also noteworthy. In practice, participants may respond to manual palpation of the rib cage with changes in muscle tone or trunk posture, potentially affecting rib configuration and ISA width. Photographic recording, particularly when performed without direct physical contact, reduces these reactions and may yield a more natural representation of thoracic morphology. Moreover, photogrammetric assessment may minimise anticipatory responses in measurements involving thoracic parameters influenced by breathing patterns, particularly during spontaneous inspiration and expiration (15). This further supports the potential utility of photogrammetry in studies examining respiratory mechanics and trunk biomechanics. In addition to methodological agreement, photogrammetric assessment offers several advantages that make it particularly suitable for research purposes. In studies involving larger samples, key considerations include time efficiency, reduced participant burden, and the ability to ensure quality control throughout the data collection process. Photogrammetry enables rapid acquisition of measurement data, while the analytical phase can be conducted independently of the recording session, eliminating the need for repeated participant involvement. This separation of data collection and analysis significantly enhances feasibility in large-scale or multi-session research designs. An additional advantage of photogrammetry lies in its objectivity and permanence of documentation. Each image constitutes a lasting record of the measurement, allowing for retrospective verification, reanalysis or evaluation by multiple raters. This reduces the need for a larger number of examiners during data collection and is particularly beneficial in studies with larger sample sizes, where photogrammetry enables significantly more efficient logistics. Furthermore, the availability of permanent digital records allows for repeated analyses of the same material, which is especially valuable in research settings where inter- and intra-rater reliability testing, secondary analyses, or methodological refinement are required. From a preventive and public health perspective, Kinovea-based photogrammetry enables rapid image acquisition with subsequent offline analysis, making it suitable for larger cohorts in educational, sports, or research settings. The permanent digital record allows quality control, independent re-analysis, and longitudinal comparison under standardized conditions. This approach may be particularly useful in studies examining thoraco-abdominal morphology in relation to breathing patterns, trunk stability, and posture-related parameters, as well as in monitoring ISA changes during structured intervention programs when recording protocols are consistently applied. Importantly, the method should be viewed as a research and monitoring tool rather than a diagnostic instrument.

LIMITATIONS

Several limitations should be acknowledged. A primary limitation relates to examiner-related error and extrinsic factors influencing measurement precision. Notably, in the female subsample, sports bras posed an obstacle to precise marking of the xiphoid process. Additionally, increased adiposity in the thoracic region may impair accurate identification of anatomical landmarks. With these limitations in mind, future measurements should ideally be conducted without clothing covering the thoracic area. Future research should aim to validate standardised ISA photogrammetry protocols across diverse populations, including clinical groups, older adults and individuals with postural or respiratory dysfunctions. Additionally, comparisons with three-dimensional motion capture or imaging techniques would further strengthen the evidence base for photogrammetric ISA assessment.

CONCLUSIONS

The results of this study indicate that Kinovea-based photogrammetric assessment is a reliable and metrically stable alternative to manual goniometry for measuring the infrasternal angle. Although a minimal systematic offset exists, it is predictable and can be easily accounted for during result interpretation. Kinovea offers a practical and efficient option in research and educational settings, while manual goniometry remains the preferred method in clinical practice.

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