

Addis Ababa University

College of Health Sciences

Department of Orthopedics and Trauma Surgery

Measurement of Spinopelvic Parameters in Healthy Ethiopian Adults: A cross-sectional study.

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(MD, Final year Orthopedics and Trauma Surgery Resident)

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December 2025

Addis Ababa, Ethiopia

ADVISOR'S APPROVAL SHEET

This is to certify that the thesis entitled "**Measurement of Spinopelvic parameters in healthy Ethiopian Adults: a cross-sectional study."** is submitted in partial fulfillment of the requirements for the Specialization Certificate in Orthopedic surgery to the department of orthopedics and Trauma surgery, Addis Ababa University college of health science and has been carried out by **Dr Fentahun Bantigegn** under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the Thesis to the Department.

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Abbreviations/ Acronyms

AAU	Addis Ababa University
ASD	Adult Spinal Deformity
BMI	Body Mass Index
CHS	College of Health Science
LL	Lumbar Lordosis
PI	Pelvic Incidence
PT	Pelvic Tilt
SS	Sacral Slope
TASH	Tikur Anbebsa Specialized Hospial
THA	Total Hip Arthroplasty

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Abstract

Background: Spinopelvic alignment plays an important role in understanding spinal biomechanics and planning for surgical interventions to achieve best outcome and avoid complications. Restoration of spinopelvic balance during spinal surgery is very important to ensure a good outcome. Many studies have been conducted on normal range of spinopelvic parameters globally and are found to be population specific. Despite these values known to be different across populations, there was no established normal values for Ethiopian adults. This Study defined normal range of spinopelvic parameters in healthy Ethiopian Adults.

Objectives: This study aimed to determine the normal range of key spinopelvic parameters in healthy Ethiopian adults and to analyze the correlations between these parameters and demographic factors such as age and sex.

Methods: An observational cross-sectional study was conducted on healthy Ethiopian adult volunteers who visited TASH for various reasons other than hip and spine pathologies. It was conducted at TASH from August 2025 to December 2025. Standing single lateral lumbosacral radiograph was obtained under standard conditions after informed consent taken. Two spine surgeons independently measured pelvic incidence, sacral slope, pelvic tilt and lumbar lordosis.

Result: in this study, a total of 102 volunteers participated, of whom 55 males and 47 females with median age of 38. The mean values of PI, SS, PT and LL were 52.8 ± 9.5°, 39.3 ± 7.8°,13.3 ± 7.3° and 42.4 ± 10.4° respectively. Females show higher values in all parameters.PT and PI-LL show correlations with age. Strongest association was noted between LL and SS.

Conclusions: this is the first study that determine normal range of spinopelvic parameters in healthy Ethiopian adults. All parameters were higher in females. PT and PI-LL increase with age. Our spinopelvic parameters values differ across different studies due to ethnic variations as determined by various studies.

Key words; Spinopelvic parameters, normal range, pelvic incidence, sacral tilt, pelvic tilt, lumbar lordosis, Ethiopia

1: Introduction

1.1: Background of Study

Spinopelvic alignment describes the coordinated orientation of the spine and pelvis that enables maintenance of an upright posture within the “cone of economy,” minimizing energy expenditure while preserving sagittal balance(1). The parameters which describe the orientation and alignment of spine relative to pelvis known as spinopelvic parameter are typically evaluated using three parameters which includes pelvic incidence (PI), sacral slope (SS) and pelvic tilt (PT). First described by Legaye et al(2) ,these parameters were used to depict the shape and orientation of the pelvis. PI refers to the angle between the line perpendicular to the midpoint of the sacral endplate and the line from that point to the center of the femoral head.PT is the angle between the line that connects center of sacral endplate to femoral head and the line perpendicular to the ground. SS is the angle between sacral endplate and horizontal line drawn from the posterior superior corner of S1. Lumbar lordosis (LL) also referred to the angle between the upper endplate of L1 and the sacral endplate. PI does not change with position and remains constant after maturation, reflecting inherent pelvic anatomy; therefore, it is a key parameter in planning surgical interventions for deformity corrections, while PT and SS are dynamic positional parameters that allow individuals to compensate for age related, degenerative or structural changes in the spine(2–5). Together, these parameters influence lumbar lordosis, global balance and the efficiency of energy expenditure required to maintain an upright posture(6) . These parameters are geometrically related by the equation PI = PT + SS(7). Historically, the difference between PI and LL has been used as a reliable metric for planning spinal deformity correction(8). Achieving the desired alignment has shown strong associations with postoperative clinical outcomes and health-related quality of life(9–11).

Growing global evidence shows that normative spinopelvic parameters are not universal, with substantial variation based on age, sex, and ethnicity. Reliable interpretation of sagittal spinal alignment requires reference values derived from asymptomatic populations, as individual cohort studies show wide variability related to age, sex and ethnicity. To address this variability, Noshchenko and colleagues performed a systemic review and meta-analysis of

asymptomatic adult and reported pooled normative values for key spinopelvic parameters. In their meta-analysis of asymptomatic adults, Noshchenko et.al reported the pooled means and the optimal ranges of LL (L1–S1), 54.6 (42–67) degrees; PI, 50.6 (39–62) degrees; SS, 37.7 (28–48) degrees and PT, 12.6 (3–22) degrees(12).

1.2. Statement of The Problem

The importance of spinopelvic parameters in the pathogenesis of spinal degenerative disorders is well Kown(13).The prevalence of adult spinal deformity (ASD) in asymptomatic elderly population is more than 60%(14). Regarding ASD, recent studies show that spinopelvic alignment correlated with patient reported outcomes, specifically pain and disability that affected health related quality of life(15,16). Restoration and preservation of spinopelvic balance are important in managing spinal deformities and degenerative spinal diseases to ensure good outcome(17).

It is also recognized that the positional relationship of lumbar spine and pelvis affects acetabular orientation, which is important for hip biomechanics, both for native and replaced hips(18). This relationship among spine, pelvis, and hip recently has gained interest, as patients with spinopelvic pathology have been demonstrated to develop **higher complication** rates, including dislocations following total hip arthroplasty(19,20).

As sagittal alignment became clinically relevant, normative reference values of these parameters were established in several populations and variable across populations of different genetics(21), ethnicities(5,22–27), age and sex(3,5,17,26,28). Majority of spinopelvic parameters study are conducted in Western and Asian populations. To our knowledge, only one study has provided normative reference values from a Sub-Saharan African cohort(29).Using unrepresentative values for different populations may lead to misclassifications of sagittal alignment and inappropriate surgical targets(30,31). Thus, establishing these local normative reference values helps to avoid these important gaps and facilitate population specific clinical decision making.

Despite the clinical importance of spinopelvic parameters in spinal reconstructive surgery and total hip arthroplasty, normative reference values for healthy Ethiopian adults have not been established. As a result, surgeons in our country frequently rely on non-local data that may not accurately reflect population-specific anatomy and compensatory patterns. All the existing normative data and models which Ethiopian clinicians are using currently are based on western populations, and thus may not take into considerations for anatomic, ethnic and life style difference unique to Ethiopian individuals(21,23,25).This leads to a suboptimal

clinical interpretation, underestimation or overestimation of compensatory changes, and uncertainty in establishing surgical alignment goals(30–32). Absence of population specific normative reference values also creates an obstacle for local based research on sagittal balance and spinal disorders.

Therefore, defining the normative range of spinopelvic parameters in healthy Ethiopian adults is urgently needed.

1.3. Significance of Study

The present study seeks to bridge this gap by defining the first normative spinopelvic parameters in an asymptomatic Ethiopian adult cohort and to examine their variation by age and sex. Establishing these population-specific reference values is intended to improve diagnostic interpretation, optimize surgical planning, and support future spine research in Ethiopia and the broader Sub-Saharan continent. This study is important in that it established data relevant to Ethiopian spine and orthopedic surgeons and thus guide clinical decisions locally. These local normative reference values may help in preparing local guidelines and might also serve as part of comparative regional studies. The radiographs might incidentally detect unrecognized spinal or pelvic pathologies for the participants, after which it would be communicated to the individual and treated accordingly, where necessary.

2. Literature Review

2.1. General overview of Spinopelvic parameters

The key to understanding sagittal alignment is to understand how pelvic morphology shapes spine posture. The three spinopelvic parameters have become the focus of this analysis. PI describes the static anatomic relationship between the sacrum and femoral heads. Because this parameter describes pelvic anatomy rather than posture, it remains constant after skeletal maturity and provides the anatomic reference from which sagittal alignment develops(2). In contrast, PT and SS are dynamic parameters that change with posture or pelvic rotation(33).Together, these parameters describe both the static and dynamic orientation of the pelvis, making them important to understand spinal balance.

2.2. Global Studies and factors affecting spinopelvic parameters.

Globally, many studies have been conducted regarding the relationship between normative spinopelvic values and its variability across different populations(22,24,26,27). A comparative analysis among African American, Caucasian and Asian populations shows that the mean value of PI was greater in African American than Caucasian (57.7° vs. 52.6°, $p = 0.007$), and than in Asian (57.7° vs. 48.7°, $p < 0.001$)(25).A recent systemic review done by Lukas et.al confirmed that ethnicity has a significant effect on the normative values of spinopelvic parameters(34). Ethnic variation of Spinopelvic parameters leads to differences in sagittal alignment patterns. These ethnic and lifestyle based normative spinopelvic differences may lead to misclassifications of sagittal alignment and inappropriate surgical alignment goals which creates significant impact on post operative health related quality of life(10,30,31).

It has been known that PI remains constant after skeletal maturity, however age-related degenerative changes lead to compensatory modifications of PT and SS. The LL decreases with age while PT and PI-LL increases, which subsequently increases risk of spinal malalignment(3,17). Age related changes to spinopelvic parameters occurs differently between men and women, with men exhibiting nonstructural changes and women experiencing structural changes(27,35).

2.3. African Studies

Despite extensive studies conducted worldwide, only one published data is available in Africa(29). When we came to Ethiopia, there is no published study defining normal range of these parameters in healthy adults. Establishing these local reference values will provide

baseline data for physicians in Ethiopia helping with accurate clinical decisions that will improve hip and spine surgery outcomes. therefore, this study aimed at addressing significant and timely needed problems of Ethiopia and possibly the regions by establishing population specific reference values of spinopelvic parameters in healthy Ethiopian adults.

3. Objectives

3.1. General Objectives

To determine normative range of spinopelvic parameters among healthy Ethiopian adults using standardized radiological imaging at Tikur Anbesa Specialized Hospital (TASH), Addis Ababa, Ethiopia in 2025.

3.2. Specific Objectives.

- To measure key spinopelvic parameters including PI, SS, PT and LL using standing lateral lumbosacral radiographs.
- To assess the relationship and variation of these parameters by age and sex.
- To compare results from other reports.

4.Methods

4.1. Study Area and Period

The study was conducted at **TASH**, AAU from August 2025 to December 2025. TASH, situated in the capital city of Ethiopia, Addis Ababa, is the largest referral hospital in the country. The Department of Orthopedics and Trauma surgery comprises 22 staff members, 54 residents, and 5 trauma fellows. The department has 189 active beds, including 14 specifically designated for pediatric patients. The outpatient clinic caters to both trauma and non-trauma orthopedic cases, handling on average 15,000 cases annually.

4.2. Study design

An observational cross-sectional study was conducted among adult volunteers who visit black lion hospital as outpatient for health issues other than hip or spinal conditions or accompanying patients as an attendant

4.3. Source and study population

4.3.1. Source population

Ethiopian Adult individuals who attended TASH as an outpatient for non-spinal conditions or as an attendant during the study period.

4.3.2. Study population

Ethiopian adults aged 18-60 years visited TASH as an outpatient for health issues unrelated to spine or hip conditions or Accompanying patients as an attendant who agreed to participate and underwent appropriate standing lateral lumbosacral images.

4.4. Inclusion and exclusion criteria

4.4.1. Inclusion criteria

- Healthy Ethiopian adult volunteers from 18-60 years
- Good quality standing lateral lumbosacral radiograph
- No spinal or hip pathology.

4.4.2. Exclusion criteria

- Poor quality radiograph
- Previous history of spinal or hip surgery
- Spinal or hip pathology from trauma/neoplastic/inflammatory or infectious history
- Hip/knee/ankle/foot disability that can affect the ability to take appropriate standing radiographs

4.5. Sample size and Sampling technique

4.5.1. Sample size determination

The sample size was calculated to estimate the mean PI with 95% confidence. Based on prior normative global studies, a standard deviation of 10° and a margin of error of 2° were assumed(34).

The sample size was calculated using the following formula:

$$n = \left(\frac{Z_{\frac{\alpha}{2}} \times \sigma}{d} \right)^2$$

Where:

- n = required sample size
- $Z\alpha/2$ = standard normal value at 95% confidence level (1.96)
- σ = standard deviation (10°)
- d = margin of error (2°)

n= $(1.96^2 \times 10^2)/2^2$

n= (3.84×100)/4

n= 96, adding 10% contingency;

Final sample size was ~ 106 participants.

4.5.2. Sampling Technique

All eligible and consenting individuals encountered consecutively during the study period were invited to participate. These were volunteer attendants who came to our clinics accompanying other patients. Consecutive recruitment was used to minimize selection bias.

4.6. Data collection procedures

Participants were recruited during black lion hospital visits for any reason after being screened for eligibility. Informed consent was taken, and important demographic data such as age and sex was collected.

Appropriate standing lateral lumbosacral radiographs were taken in standardized manner; standing upright, arms flexed anteriorly, hips and knees fully extended.

Two fellowship trained spine surgeons measured Spinopelvic parameters using Radiant Dicom twice, and average values were taken.

4.7. Variables

4.7.1. Dependent Variables

Includes **PI, PT, SS, LL.**

4.7.2. Independent variables

Includes **Age, and Sex**

4.8. Operational Definitions:

Healthy Adult: asymptomatic individual with no history or radiographic evidence of spine and hip pathology.

Pelvic incidence: fixed anatomic parameter determined by sacral orientation relative femoral heads.

***Lumbar Lordosis*:** curvature of lumbar spine measured as cobb angle from L1 to S1.

Sacral slope*:* angle between sacral endplate and horizontal.

Pelvic Tilt*:* angle between vertical line and the line connecting femoral heads to sacral endplate.

4.9. Data processing and analysis

Statistical analysis was performed using RStudio version 2024.04.2 (R Core Team, 2024). Normality of continuous variables was checked using the Shapiro-Wilk test. Inter-observer reliability was assessed using a two-way random effects intraclass correlation coefficient for absolute agreement with 95% confidence intervals. Descriptive statistics were reported as mean ± standard deviation for normally distributed variables and as median with interquartile range for non-normally distributed variables. Sex-based differences in spinopelvic parameters were evaluated using two-sample t-tests for normally distributed variables and the Wilcoxon rank-sum test for non-normally distributed variables. Associations between age and spinopelvic parameters were assessed using Spearman's rank correlation coefficient to accommodate the non-normal distribution of age. Simple linear regression was used to examine relationships between pelvic incidence and the other spinopelvic parameters, and multivariable linear regression was used to identify factors associated with lumbar lordosis. A p-value <0.05 was considered statistically significant.

4.10. Data Quality Management

Multiple steps were undertaken during data collection procedure in order to ensure the accuracy and reliability of the findings of this research study.

First, the training was provided to all members of the research team, including radiology technicians and orthopedic trauma and spine surgeons. This allowed us to follow a similar procedure, such as appropriate patient positioning during radiography and at the time of taking measurements. This standardized approach reduced variation and increased reliability.

The machines used for taking radiographs were also checked and calibrated before data collection started. The same equipment and imaging protocol were used in order to avoid any technical differences that might occur and affect the result.

Moreover, before the main study started, a small pilot study was conducted. This enabled us to check its feasibility and see quality of radiograph.

All data entry was done by two different people independently into the database, then was cross-checked to identify any mistakes. Data was reviewed routinely to ensure completeness and accuracy. Two fellowship-trained spine surgeons independently performed the measurements, blinded to the participants' demographic data. We also calculated inter-observer reliability to check the consistency of their work.

4.11. Ethical considerations

The study was carried out with full respect for safety and rights of the participants. The objectives of the research, what the research involved, and any risks to the participant were clearly explained to the participants in a language understood by them before any procedure started. Only those who gave written informed consent were included in this research. All personal information kept confidential. The study involved a single low-dose standing radiograph performed under strict radiation safety standards within safe radiation dose limits. Strictly followed the ALARA (As Low As Reasonably Achievable) principle. The exposure was minimal, non-repetitive, and justified by the lack of existing normative spinopelvic data in the Ethiopian population. The anticipated benefits to clinical practice and future research outweighed the negligible risk associated with the procedure. Ethical approval was obtained from the Department of Orthopedics and Trauma Surgery Research Ethics Review Committee (Ref. no. MF/ORTH/488/2025).

4.12. Dissemination of Results

The study results will be presented as part of a research defense in partial fulfilment of the graduate study.

Results of our study will be disseminated in a number of ways so as to reach both the scientific community and the broader health sector. The study results will be presented at departmental seminars within Addis Ababa University, mainly in departments of orthopedics and Radiology, to enhance academic discussion and integration into everyday clinical practices.

The results of our study will be submitted for presentation at national and regional conferences in orthopedics, spine surgery, and radiology. It will also be prepared for publication in peer-reviewed journals, so that it will allow international comparison and contribution to global knowledge.

The reference values will be shared to clinicians working at Ethiopian health institutions to allow for better evaluation and management of patients in a local context.

The findings will be communicated to national health policymakers and medical curriculum developers to enhance them to develop local clinical guidelines, training materials and other teaching resources for the medical community including residents.

Through these approaches, the present study is aimed at adding to academic knowledge as well as providing practical values for clinicians and decision makers.

5. Results

A total of 106 participants were initially enrolled during the study period. Four cases were excluded from analysis: two due to incidental radiographic spondylolisthesis and the other two due to inadequate visualization of pelvic or spinal landmarks. The final analytic cohort consisted of 102 participants, comprising 55 men and 47 women. Participants' ages ranged from 18 to 60 years, with a median age of 38 years (IQR, 30-50).

Inter-rater reliability for all spinopelvic parameters was good to excellent, with intraclass correlation coefficients for each parameter ranging from 0.84 to 0.94. Normality testing demonstrated that SS, PI, and LL were normally distributed, whereas PT showed a right-skewed distribution. Accordingly, SS, PI and LL were summarized using mean ± SD, while PT was expressed as median with interquartile range (IQR). The mean value of PI was 52.8± 9.5°, the mean value of SS was 39.3±7.8 and the mean value of LL was 42.4 ±10.4°. PT showed a median value of 12.3° (IQR 8.3-16.5°) (Table 1).

Table 1: ***Summary of the averaged spinopelvic parameters in the Ethiopian cohort.***

	SS	PT	PI	LL
Mean	39.3	13.3	52.8	42.4
Median (IQR)	39.5 (33.1-45.5)	12.3 (8.3-16.5)	52.4 (46.3-59)	42.6 (35.8-49.3)
Std deviation	7.8	7.3	9.5	10.4
Minimum	16.9	2.1	30	14.3
Maximum	58.7	35	77	69.9

The spinopelvic parameters for male and female sex in the study population were calculated separately and compared. They showed statistically significant differences between males and females. Females showed a higher median SS (41.9 vs 36.9, p=0.07), a higher PT (13.7 vs 11.25, p=0.028), a higher PI (56.4 vs 48.1, p<0.001), and a higher LL (47.4 vs 38.55, p<0.001) (Table 2).

Table 2: ***Comparison of spinopelvic parameters between the two sexes.***

Variable	**Male**	**Female**	**p-value**[¥]
	N = 55[*]	**N = 47**[*]	
SS	36.9 (32.28–41.62)	41.9 (34.45–47.8)	**p = .007**
PT	11.25 (7.62–14.9)	13.7 (10.68–17.68)	**p = .028**
PI	48.1 (42.45–54.47)	56.4 (51.77–62.33)	**p = < .001**
LL	38.55 (34.3–46.33)	47.4 (38.9–53.5)	**p = < .001**

Bold values indicate statistically significant results (P < .05)

[*] Median (Q1, Q3).

[¥] Wilcoxon rank sum test.

Correlation analysis showed a mild positive association between pelvic tilt and age (Spearman's $r_s = 0.29$, $p < 0.05$), and PI-LL and age ($r_s = 0.27$, 100, $p<0.05$)

. No statistically significant correlation was observed between age and sacral slope or lumbar lordosis (Figure 1).

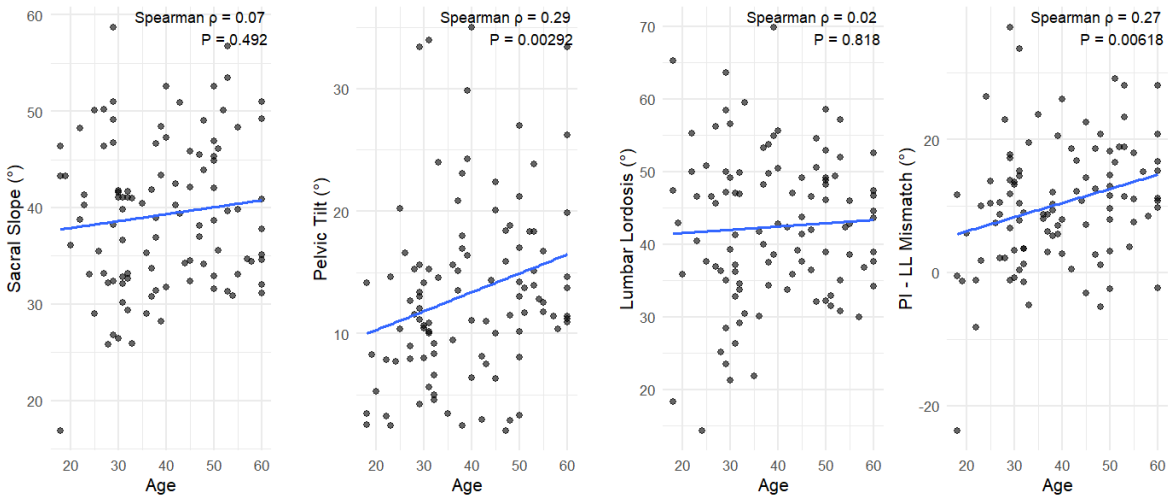


Figure 1: **Spearman's correlation between age and spinopelvic parameters.**

Inter-parameter correlation analysis revealed a strong positive correlation between SS and LL, while PI demonstrated moderate positive correlations with SS, PT, and LL. The association between SS and PT was weak (Table 3).

Table 3: ***Correlation between Spinopelvic parameters.***

Relationships	**Spearman ρ**	**Strength of correlation**	**p-value***
PI ↔ SS	0.56	Moderate	**<0.001**
PI ↔ PT	0.57	Moderate	**<0.001**
PI ↔ LL	0.53	Moderate	**<0.001**
SS ↔ LL	0.67	Strong	**<0.001**
SS ↔ PT	-0.26	Weak	**0.00879**
PT↔ LL	0.03	Very weak	0.752

Bold values indicate statistically significant results (P < .05)

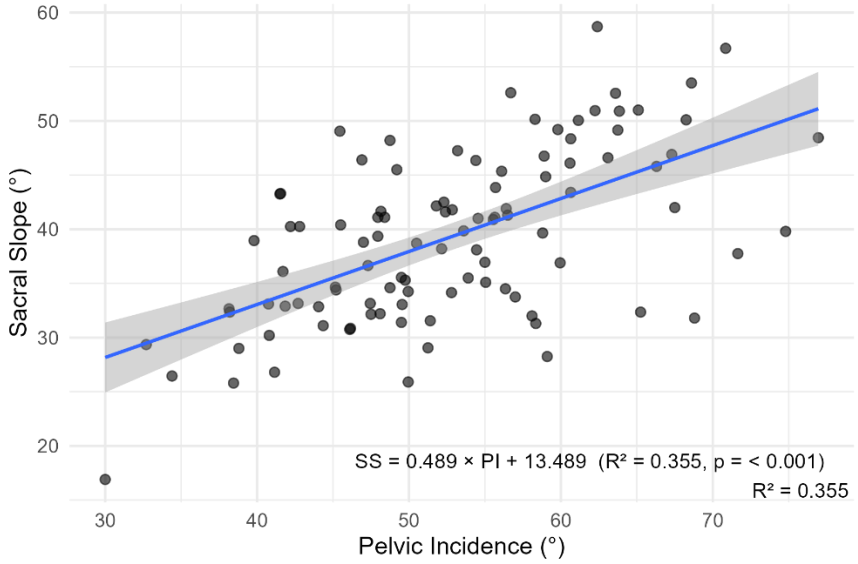
* Spearman's correlation

Bivariate linear regression using PI as the independent variable confirmed that pelvic incidence significantly predicted the other spinopelvic parameters. PI accounted for 35.5% of the variance in SS, 37.3% in PT, and 30.3% in LL (all p < 0.001). The regression equations are (Figure 2):

SS = 0.489 × PI + 13.489 (R^2 = 0.355, **p = < 0.001**)

PT = 0.467 × PI - 11.341 (R^2 = 0.373, **p = < 0.001**)

LL = 0.600 × PI + 10.760 (R^2 = 0.303, **p = < 0.001**)



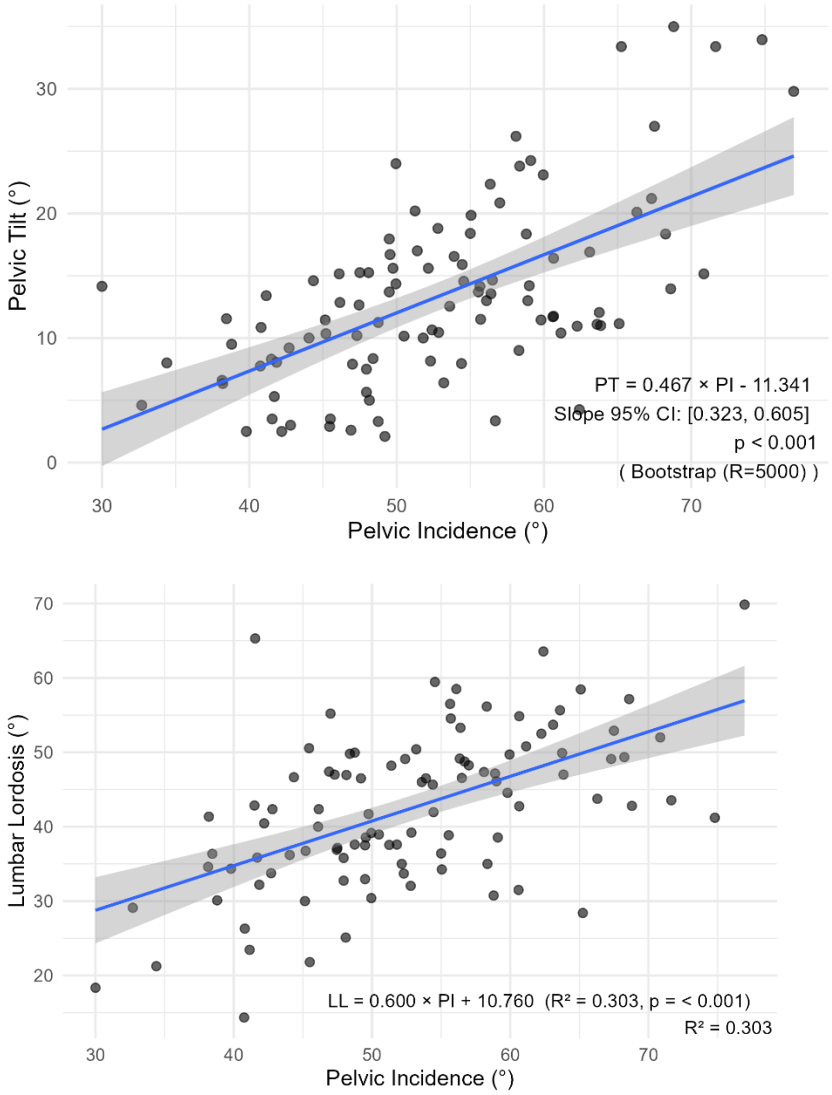


Figure 2: Linear regression model as a function of pelvic incidence.

Multivariate linear regression analysis evaluating predictors of lumbar lordosis showed that PT (β = -0.653, p<0.001) and PI (β = 0.894, p<0.001) were independently associated with lumbar lordosis. Age and sex were not significantly associated with lumbar lordosis. No significant interaction was observed between PI and PT (Table 4).

Table 4: ***Multivariable Linear Regression Predicting Lumbar Lordosis.***

Predictor	**β coefficient (95% CI)**	**p-value**

Age (years)	-0.113 (-0.253, 0.026)	0.110
Sex (female)	2.478 (-0.994, 5.950)	0.160
PI (centered)*	0.894 (0.672, 1.117)	**<0.001**
PT (centered)*	-0.653 (-0.949, -0.357)	**<0.001**
PT × PT	0.002 (-0.019, 0.022)	0.874
R^2	0.466	
Adjusted R^2	0.438	

Bold values indicate statistically significant results (P < .05)

* PI and PT were mean centered prior to inclusion of the interaction term.

Compared with published normative datasets from Africa American, Asia and Europe, (Table 5), this cohort demonstrated similar PI values to European samples. However, the mean LL of 42.4° was lower than all other comparison groups, resulting in a comparatively larger PI-LL mismatch(29,34).

Table 5: ***Comparison of our study with similar studies among other countries.***

Parameters	Ethiopia, Our study (N=102)	African American(25) N=36	China(36) N=546	France(37) N=100
PI	52.8 ± 9.5	57.7 ± 11.5	45.9 ± 8.4	51.7 ± 11.5
SS	39.3 ± 7.8	41.4 ± 9.2	34.0 ± 7.1	39.4 ± 9.3
PT	13.3 ± 7.3	15.9 ± 7.0	11.9 ± 6.6	12.3 ± 5.9
LL	42.4 ± 10.4	57.2 ± 13.2	49.2 ± 10.1	46.5 ± 11.1

6. Discussion

This study provides the first population-specific normative spinopelvic reference values for asymptomatic Ethiopian adults and supports the fundamental biomechanical relationships that govern sagittal alignment. The mean PI of 52.8° ± 9.5°, SS of 39.3° ± 7.8°, and PT of 13.3° ± 7.3° conform to the geometric identity PI = PT + SS and place this cohort within an intermediate PI range compared to previously reported populations(34,38).

PI behaved as a fixed anatomical parameter and significantly predicted SS, PT, and LL, accounting for approximately 30–37% of the variance in these dynamic variables. This magnitude of association aligns with prior work, indicating that pelvic morphology is an important but not exclusive determinant of sagittal alignment(25). The persistence of unexplained variance emphasizes the multifactorial regulation of sagittal alignment.

Sex differences were observed across all spinopelvic measures, with females demonstrating higher PI, SS, PT, and LL. These findings are consistent with the recent reports by Nakano et al (2025)(35).

The effects of age were relatively modest. While the PT and PI-LL mismatch showed a mild increase with age, the SS and LL measurements did not exhibit significant age-related trends in this asymptomatic cohort. However, the observed rise in PI-LL mismatch with age can serve as a sensitive marker for a decrease in lumbar lordosis, given that individual values for pelvic incidence remain constant after skeletal maturity(9). These findings suggest that age-related spinal changes in this population are actively masked by an increase in pelvic tilt, preserving sagittal balance, consistent with patterns observed in other asymptomatic populations(39,40).

The strong correlation observed between SS and LL, in our cohort, reinforces their close biomechanical coupling and supports the chain of balance concept advocated by Dubousset(40,41).The inverse relationship noticed between SS and PT further supports their complementary roles in maintaining global sagittal alignment(33).

In multivariable regression analysis, PI and PT remained independently associated with LL, whereas age and sex were no longer significant predictors after adjustment. Inclusion of PT significantly improved model performance, increasing the adjusted R^2 from 0.32 to 0.44, with a significant nested model comparison ($F = 22.86$, $p < 0.001$). This finding indicates that PT provides meaningful explanatory value beyond fixed pelvic morphology, supporting its role as a functional compensatory parameter rather than a redundant correlate of PI.

The relatively lower mean LL observed in this cohort compared with many published normative studies may reflect a population-specific sagittal alignment profile (Table 5)(29,34). Potential explanations include differences in habitual posture, occupational load, and activity patterns; however, these factors were not measured in this study and should be considered hypothesis-generating and investigated directly in future work.

From a surgical perspective, restoration of LL proportional to PI remains a cornerstone of deformity correction, as discussed by Le Huec(42). The mean PI-LL mismatch in our asymptomatic cohort was 10.3°, which exceeds the widely accepted ideal threshold of < 10° proposed by the Schwab-SRS classification(9). If a surgeon strictly applies the Schwab PI–LL < 10° rule to this population, nearly half of asymptomatic Ethiopian adults would be

incorrectly classified as having a sagittal plane deformity. Therefore, reliance on LL reference values derived from other populations may lead to inappropriate alignment targets, potentially affecting surgical planning and postoperative outcomes(10,30). Future biomechanical and ethnographic studies are required to determine whether habitual load carriage, as is common in this region, influences sagittal alignment in this population. The present dataset provides an initial local reference to inform surgical planning, but surgeons should interpret small deviations cautiously.

7. Strength and Limitations of Study

7.1. Strengths

The study was restricted to a strictly asymptomatic adult population, allowing characterization of normative spinopelvic parameters without confounding from prior surgery or advanced degeneration. Additionally, to our knowledge, this study provides the first population-specific normative spinopelvic reference data for healthy Ethiopian adults. Finally, measurements were performed independently by two fellowship-trained spine surgeons, and the inter-rater reliability was good to excellent, supporting methodological rigor.

7.2. Limitations

This study used a consecutive sample of clinic attendants at a single tertiary center rather than a population-based sample, which may affect external validity. The presented percentiles should therefore be viewed as clinic-based normative references pending validation in population-based cohorts. Additionally, BMI, occupation, and activity level were also not collected for all participants and, therefore, were not included in adjusted models. These factors are known potential confounders of pelvic parameters and should be recorded in future population studies. Another limitation is that we have only examined static standing films and have excluded patients over 60 years with the intention of degenerative changes might affect normative ranges.

8. Conclusions and recommendations

8.1. Conclusions

Asymptomatic Ethiopian adults exhibit comparable PI, SS, and PT values to various non-Asian cohorts, although they have a lower mean LL and a borderline PI-LL mismatch. This normative data serves as an important local reference for clinical evaluation of the spine and surgical planning of hip and spine surgery. However, given the single-center design and the lack of participants above the age of 60, we advise caution in interpreting these results.

8.2. Recommendations

Based on the findings of our study, population-specific normative values should be considered when interpreting spinopelvic alignment in Ethiopian adults. Clinicians evaluating sagittal balance should avoid direct application of reference values obtained from other populations without considering population-based variations.

Pelvic incidence should be part of radiographic evaluation of spinopelvic alignment and surgical planning, as it remains the main determinant of sagittal alignment and lumbar lordosis.

Alignment targets that consider individual pelvic morphology and lumbar curvature result in more physiological correction and improve outcomes.

Future studies should include multicenter cohorts to identify regional and ethnic variability within the Ethiopian population and improve generalizability. Additionally, future studies should also consider age stratification of data to clearly note age related changes of these parameters. Demographic factors including height, weight and BMI should also be part future studies as these variables may act as confounding factors. If possible, dynamic studies should also be part of consideration of future studies.

Finally, this normative data can serve as a reference framework for comparative studies, outcome evaluation following spinal or hip surgery, and the development of region-specific guidelines for sagittal alignment assessment.

9. References

1. Roussouly P, Pinheiro-Franco JL. Sagittal parameters of the spine: biomechanical approach. European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society. 2011. p. 578–85. doi:10.1007/s00586-011-1924-1 PubMed PMID: 21796394.

2. Legaye J, Duval-Beaupère G, Hecquet J, Marty C, Duval-Beaupère · G, Hecquet · J, et al. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J. 1998. Report.

3. Rezaee H, Bahadorkhan G, Ehsaei M, Ganjeifar B, Keikhosravi E, Pishjoo M. Spinopelvic parameters among healthy volunteers in Iran. Archives of Bone and Joint Surgery. 2020 Sep 1;8(5):620–4. doi:10.22038/abjs.2020.40734.2106

4. Evaluation of spinoplvic parameters in spinal arthrodesis.

5. Zhu Z, Xu L, Zhu F, Jiang L, Wang Z, Liu Z, et al. Sagittal alignment of spine and pelvis in asymptomatic adults: Norms in Chinese populations. Spine (Phila Pa 1976). 2014 Jan 1;39(1). doi:10.1097/BRS.0000000000000022 PubMed PMID: 24270931.

6. Hasegawa K, Dubousset JF. Cone of Economy with the Chain of Balance—Historical Perspective and Proof of Concept. Spine Surgery and Related Research. Japanese Society for Spine Surgery and Related Research; 2022. p. 337–49. doi:10.22603/ssrr.2022-0038

7. Kim HJ, Yang JH, Chang DG, Suk S Il, Suh SW, Song KS, et al. Adult Spinal Deformity: Current Concepts and Decision-Making Strategies for Management. Asian Spine J. 2020;14(6):886–97. doi:10.31616/ASJ.2020.0568

8. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V. Adult Spinal Deformity-Postoperative Standing Imbalance How Much Can You Tolerate? An Overview of Key Parameters in Assessing Alignment and Planning Corrective Surgery. SPINE. Report.

9. Schwab FJ, Blondel B, Bess S, Hostin R, Shaffrey CI, Smith JS, et al. Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: A prospective multicenter analysis. Spine (Phila Pa 1976). 2013;38(13). doi:10.1097/BRS.0b013e318292b7b9

10. Zhou H, Liang Z, Li P, Shi H, Liang A, Gao W, et al. Correlation analysis of surgical outcomes and spino-pelvic parameters in patients with degenerative lumbar scoliosis. Front Surg. 2023;10. doi:10.3389/fsurg.2023.1319884

11. Thijs D, Kashtiara A, Beldé S, Van de Kelft E. Surgical Management of Lower Back Pain: Is Optimizing Spinopelvic Alignment Beneficial for Patient Outcomes? Life. Multidisciplinary Digital Publishing Institute (MDPI); 2025. doi:10.3390/life15060833

12. Noshchenko A, Hoffecker L, Cain CMJ, Patel V V., Burger EL. Spinopelvic Parameters in Asymptomatic Subjects Without Spine Disease and Deformity. Clinical Spine Surgery. Lippincott Williams and Wilkins; 2017. p. 392–403. doi:10.1097/BSD.0000000000000533 PubMed PMID: 28368866.

13. Le Huec JC, Faundez A, Dominguez D, Hoffmeyer P, Aunoble S. Evidence showing the relationship between sagittal balance and clinical outcomes in surgical treatment of degenerative spinal diseases: a literature review. International Orthopaedics. Springer Verlag; 2015. p. 87–95. doi:10.1007/s00264-014-2516-6 PubMed PMID: 25192690.

14. Schwab F, Dubey A, Gamez L, Benchikh A, Fegoun E, Hwang K, et al. Adult Scoliosis: Prevalence, SF-36, and Nutritional Parameters in an Elderly Volunteer Population. SPINE. Report.

15. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F. The Impact of Positive Sagittal Balance in Adult Spinal Deformity. SPINE. Report.

16. schwab2013.

17. Asai Y, Tsutsui S, Oka H, Yoshimura N, Hashizume H, Yamada H, et al. Sagittal spino-pelvic alignment in adults: The Wakayama Spine Study. PLoS One. 2017 Jun 1;12(6). doi:10.1371/journal.pone.0178697 PubMed PMID: 28586366.

18. Verhaegen JCF, Innmann M, Alves Batista N, Dion CA, Horton I, Pierrepont J, et al. Defining Normal Static and Dynamic Spinopelvic Characteristics: A Cross-Sectional Study. JBJS Open Access. 2022 Jul 5;7(3). doi:10.2106/JBJS.OA.22.00007

19. Heckmann N, McKnight B, Stefl M, Trasolini NA, Ike H, Dorr LD. Late dislocation following total hip arthroplasty: Spinopelvic imbalance as a causative factor. Journal of Bone and Joint Surgery - American Volume. 2018;100(21):1845–53. doi:10.2106/JBJS.18.00078 PubMed PMID: 30399079.

20. Esposito CI, Carroll KM, Sculco PK, Padgett DE, Jerabek SA, Mayman DJ. Total Hip Arthroplasty Patients With Fixed Spinopelvic Alignment Are at Higher Risk of Hip Dislocation. Journal of Arthroplasty. 2018 May 1;33(5):1449–54. doi:10.1016/j.arth.2017.12.005 PubMed PMID: 29310920.

21. Chen HF, Zhao CQ. Pelvic incidence variation among individuals: Functional influence versus genetic determinism. Journal of Orthopaedic Surgery and Research. BioMed Central Ltd.; 2018. doi:10.1186/s13018-018-0762-9 PubMed PMID: 29554920.

22. Sangondimath G, Mallepally AR, Marathe N, Salimath S, Chhabra HS. Radiographic Analysis of the Sagittal Alignment of Spine and Pelvis in Asymptomatic Indian Population. Asian Spine J. 2022;16(1):107–18. doi:10.31616/ASJ.2020.0301

23. Dave BR, Anil A, Dave MB, Agrawal SS, Mayi SC, Krishnan A, et al. Normative Values for Spinopelvic Sagittal Parameters in the Asymptomatic Indian Population. Cureus. 2025 Sep 6. doi:10.7759/cureus.91734

24. Zárate-Kalfópulos B, Romero-Vargas S, Otero-Cámara E, Correa V, Reyes-Sánchez A. Differences in pelvic parameters among Mexican, Caucasian, and Asian populations: Clinical article. J Neurosurg Spine. 2012 May;16(5):516–9. doi:10.3171/2012.2.SPINE11755 PubMed PMID: 22385086.

25. Arima H, Dimar JR, Glassman SD, Yamato Y, Matsuyama Y, Mac-Thiong JM, et al. Differences in lumbar and pelvic parameters among African American, Caucasian and Asian populations. European Spine Journal. 2018 Dec 1;27(12):2990–8. doi:10.1007/s00586-018-5743-5 PubMed PMID: 30143898.

26. Bhosale S, Pinto D, Srivastava S, Purohit S, Gautham S, Marathe N. Measurement of spinopelvic parameters in healthy adults of Indian origin – A cross sectional study. J Clin Orthop Trauma. 2020 Sep 1;11(5):883–8. doi:10.1016/j.jcot.2019.07.013

27. Kürşad Bayraktar M. SAGITTAL SPINOPELVIC PARAMETERS IN THE YOUNG ADULT TURKISH POPULATION. The Journal of Turkish Spinal Surgery. 2019. Report.

28. Karapınar BO, Acer N, Susar Güler H, Tokpınar A, Görkem SB. Examination of Age and Gender-Related Changes in Spinopelvic Parameters in Children and Adolescents Using Computed Tomography Images. Medical Records. 2024 May 16;6(2):212–8. doi:10.37990/medr.1458990

29. HSOA Journal of Orthopedic Research and Physiotherapy. Report.

30. Tan L xian, Du X kang, Tang R min, Rong L min, Zhang L ming. Effect of spinal-pelvic sagittal balance on the clinical outcomes after lumbar fusion surgery. BMC Surg. 2023 Dec 1;23(1). doi:10.1186/s12893-023-02240-y PubMed PMID: 37914985.

31. Pizones J, Hills J, Kelly MP, Alavi F, Nuñez-Pereira S, Smith JS, et al. Alignment Goals in Adult Spinal Deformity Surgery. Global Spine J. 2025 Jul 1;15(3):108S-122S. doi:10.1177/21925682251331048

32. Cho Y, Jo DJ, Hyun SJ, Park JH, Yang NR. From the Spinopelvic Parameters to Global Alignment and Proportion Scores in Adult Spinal Deformity. Neurospine. Korean Spinal Neurosurgery Society; 2023. p. 467–77. doi:10.14245/ns.2346374.187

33. Duval-Beaup~re G, Schmidt C, Cosson P. A Barycentremetric Study of the Sagittal Shape of Spine and Pelvis: The Conditions Required for an Economic Standing Position. Annals of Biomedical Engineering. 1992. Report.

34. Lukas KJ, Verhaegen JCF, Livock H, Kowalski E, Phan P, Grammatopoulos G. The effect of ethnicity on the age-related changes of spinopelvic characteristics: a systematic review Aims. Bone Joint Res. 2023;12(4):231–44. doi:10.1302/2046-3758.124.BJR

35. Nakano T, Oyama T, Wada K, Wada K, Kumagai G, Nitobe Y, et al. Sex differences in factors affecting spinopelvic sagittal alignment and balance: a cross-sectional observational study in a Japanese community. Sci Rep. 2025 Dec 1;15(1). doi:10.1038/s41598-025-02735-z PubMed PMID: 40404836.

36. Zhou S, Sun Z, Li W, Zou D, Li W. The Pelvic Incidence Stratified Sagittal Spinopelvic Alignment in Asymptomatic Chinese Population With Different Age Groups. Global Spine J. 2022 Oct 1;12(8):1821–6. doi:10.1177/2192568221989647

37. Vaz G, Roussouly P, Berthonnaud E, Dimnet J. Sagittal morphology and equilibrium of pelvis and spine. European Spine Journal. 2002;11(1):80–7. doi:10.1007/s005860000224 PubMed PMID: 11931071.

38. Dionne AC, Gorroochurn P, Miller R, Katiyar P, Bennion S, Bonsignore-Opp L, et al. Normative Thoracic, Lumbar, Pelvic, and Global Sagittal Alignment Parameters for Asymptomatic Adults A Systematic Review and Meta-Analysis of > 35,900 Volunteers. Spine (Phila Pa 1976). 2025 Sep 1;50(17):1188–200. doi:10.1097/BRS.0000000000005274 PubMed PMID: 40407040.

39. Barrey C, Roussouly P, Perrin G, Le Huec JC. Sagittal balance disorders in severe degenerative spine. Can we identify the compensatory mechanisms? European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society. 2011. p. 626–33. doi:10.1007/s00586-011-1930-3 PubMed PMID: 21796393.

40. Hasegawa K, Okamoto M, Hatsushikano S, Shimoda H, Ono M, Watanabe K. Normative values of spino-pelvic sagittal alignment, balance, age, and health-related quality of life in a

cohort of healthy adult subjects. European Spine Journal. 2016 Nov 1;25(11):3675–86. doi:10.1007/s00586-016-4702-2 PubMed PMID: 27432430.

41. stagnara1982.

42. Le Huec JC, Aunoble S, Philippe L, Nicolas P. Pelvic parameters: origin and significance. European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society. 2011. p. 564–71. doi:10.1007/s00586-011-1940-1 PubMed PMID: 21830079.

10. Annex

Annex-1; English Version consent form

I, _____, agree to share my personal information for this research study. I know the researchers might publish the information in scientific journals or other academic places. I understand my name will not appear in any publication. However, my anonymity may not be entirely guaranteed. I understand that the results of this research, including reports or academic presentations, might end up online for anyone to read, free of charge. I have also been told these findings could show up on different websites, in print, or even in other languages.

By signing below, I am saying I know all this, and I understand that taking part does not affect my personal rights.

Name:_____

Date:_____

Signature: _____

Name of person obtaining consent:_____

Date:_____

Signature: _____

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የሚወጣው መረጃ ስም እንደማይጠቅስ ተገልፆልኛል ነገር ግን ሙሉ ለሙሉ ማንነቴን ላይደብቅ ይችላል::

የሚወጣው የፅሁፍ ስራ ፣ የራጅ ግብአቶች ያለምንም ክፍያ የኢንፎርሜሺን መረብ ላይ ለሁሉም ተጠቃሚ እንደሚወጣ ተገልፆልኛል ::

እነኝህ ግባአቶች ከምርምር መፅሔቱ ውጪ በሌሎች የኢንፎርሜሺን መረብ ገፆች ወይም በህትመት ደረጃ ሊወጡ እንደሚችሉ እና ወደ ሌሎች ቋንቋዎች ሊተረጎሙ እንደሚችሉ ተገልፆልኛል ::

ይህን ቅፅ ለመፈረም መስማማቴ የግላዊ መብቴን አይሸርም ::

ስም _____

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