



Peri-pubertal Skeletal Age Determination using Sauvegrain's Method in Indian Population

Ishdeep Singh Oberoi^{1*}, Virender Kumar Gautam², Prateek Rastogi³, Manoj Kumar Nandkeoliar⁴

¹Senior Resident, Department of Orthopedics, Sharda Hospital & Sharda Care, Greater Noida, Uttar Pradesh

²Professor & Senior Consultant, Department of Orthopedics, Sharda Hospital & Sharda Care, Greater Noida, Uttar Pradesh

³Associate Professor, Department of Orthopedics, Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh

⁴Professor Emeritus, Department of Biochemistry, School of Medical Sciences and Research, Sharda University, Greater Noida, Uttar Pradesh

*Corresponding Author: Ishdeep Singh Oberoi

(Received: 16 January 2026

Revised: 25 February 2026

Accepted: 17 March 2026)

KEYWORDS

Skeletal age, Sauvegrain method, Greulich & Pyle, peri-pubertal children, reliability, bone age.

ABSTRACT:

Background: Skeletal age estimation provides a more accurate measure of biological maturation than chronological age, particularly during puberty when growth accelerates. The Greulich & Pyle (GP) method, though widely used, becomes less reliable in peri-pubertal children. The Sauvegrain method, based on elbow radiographs, has been proposed as a more precise alternative, but data on its applicability in Indian children are limited.

Aim: To evaluate the reliability and validity of the Sauvegrain method for peri-pubertal skeletal age determination in Indian children and compare it with the conventional GP method.

Methods: A cross-sectional observational study was conducted on 106 peri-pubertal children (53 boys, 53 girls) aged 9–15 years attending a tertiary teaching hospital (May 2023–November 2024). Skeletal age was assessed using elbow radiographs (Sauvegrain method) and wrist radiographs (GP method). Inter- and intra-observer reliability were evaluated. Correlation between skeletal age and chronological age was assessed using Pearson's correlation coefficient.

Results: The mean chronological age was 13.21 ± 1.42 years in boys and 10.71 ± 1.39 years in girls. The Sauvegrain method consistently provided higher skeletal age estimates than the GP method. In boys, Sauvegrain scores correlated strongly with chronological age ($r = 0.85-0.89$), while in girls correlation was slightly lower ($r = 0.78-0.82$). The GP method showed a tendency to underestimate skeletal maturity. Reliability analysis confirmed excellent reproducibility, with interobserver intraclass correlation coefficients ranging from 0.89–0.91 and intraobserver coefficients from 0.87–0.91 ($p < 0.001$).

Conclusion: The Sauvegrain method demonstrated strong correlation with chronological age and superior reliability compared to the GP method, making it a valuable tool for peri-pubertal skeletal age determination in Indian children. Its structured scoring system minimizes observer variability and enhances accuracy, especially during pubertal growth. Larger, multicentric, and longitudinal studies are recommended to further validate its clinical utility.

Introduction

Skeletal maturity assessment provides a more reliable indicator of biological development than chronological age, particularly during the peri-pubertal phase when rapid growth and hormonal changes occur. Accurate

estimation of skeletal age is essential in clinical practice, including the management of growth disorders, planning surgical interventions, and monitoring orthopedic conditions such as slipped capital femoral epiphysis. It also plays a crucial role in endocrinology, sports medicine, and forensic age estimation¹.



The most widely used methods for skeletal maturity assessment are the Greulich-Pyle (GP) and Tanner-Whitehouse (TW) techniques, both based on hand and wrist radiographs. However, these methods become less reliable during puberty, when ossification changes in the hand are minimal. To overcome this limitation, Sauvegrain et al.⁴ proposed an alternative method using elbow radiographs, which has been shown to provide more precise evaluation of skeletal maturity during the peri-pubertal years⁵.

India, with its diverse genetic, nutritional, and socioeconomic background, presents unique growth patterns that necessitate population-specific validation of skeletal age assessment methods. While GP and TW methods have been widely studied in Indian children, research on the applicability of the Sauvegrain method remains limited. Given the distinct ossification patterns of the elbow, this method offers a promising alternative for improving accuracy in the assessment of Indian adolescents⁷.

The present study aims to evaluate the applicability of the Sauvegrain method for peri-pubertal skeletal age determination in the Indian population. It seeks to establish normative data for elbow ossification stages, assess the reliability and validity of this method in comparison with existing techniques, and analyze the influence of gender, socioeconomic, and regional factors on skeletal maturity.

Material & Methods

Study Design and Duration

This was a cross-sectional observational study conducted in the Department of Orthopedic Surgery at a tertiary care teaching hospital from May 2023 to November 2024. Ethical clearance was obtained from the Institutional Ethical Committee prior to commencement. Written informed consent was taken from parents/guardians of all participants.

Sample Size

Thus, a total of 106 children were included, comprising 53 boys and 53 girls. The sample size reference was taken from Naik et al. (2021).

Study Population and Recruitment

The study included peri-pubertal children attending OPD/IPD/Emergency with minor orthopedic problems or trauma not involving the left upper limb. Participation was voluntary after detailed explanation of the study and obtaining parental consent.

Inclusion and Exclusion Criteria

The study included boys aged 11–15 years and girls aged 9–13 years with no history of injury or deformity involving the left elbow or wrist and no family history of growth-affecting disorders. Children were excluded if they had rickets, metabolic bone disorders, endocrine abnormalities affecting growth, dwarfism, previous surgery of the left elbow or wrist, or lacked reliable age proof authenticated by government records.

Methodology

Skeletal maturity was primarily assessed using the Sauvegrain method, a 27-point scoring system evaluating four ossification centers of the elbow: the lateral condyle, trochlea, olecranon apophysis, and proximal radial epiphysis. The cumulative score was converted to bone age using the standard Sauvegrain reference table. For comparison, the Greulich and Pyle (GP) method was applied using left hand and wrist radiographs, with bone age and chronological age considered concordant if the difference was ≤ 6 months.

Standardized radiographic techniques were followed. For the elbow, anteroposterior (AP) and lateral views were obtained, ensuring correct positioning of the limb and central ray alignment to include the distal humerus and proximal radius and ulna. For the wrist, posteroanterior (PA) views were taken with the forearm pronated and palm resting on the cassette, capturing the distal radius, ulna, carpal bones, and proximal metacarpals.

Radiation Safety

- Lead aprons used for protection of thyroid and genitals.
- Exposure settings: 50–60 kVp, 2–4 mAs on 500 mA machine (Allengers).
- Radiation dose kept < 0.001 mSv per exposure (≈ 3 hours of natural background exposure).
- Collimation applied to minimize scatter.



Statistical Analysis

Data were recorded using a pre-designed proforma and entered into Microsoft Excel, then analyzed using Statistical Package for Social Sciences (SPSS) version 23 (IBM Corp., Armonk, NY, USA) on Windows 10.

Descriptive statistics including frequency, percentage, mean, and standard deviation (SD) were used to summarize the data. Student's *t*-test was applied to compare mean values between groups. The Chi-square test was used for analysis of categorical variables. Correlation between biological age (BA) and chronological age (CA) was assessed using Karl Pearson's correlation coefficient (*r*).

p-value ≤ 0.05 was considered statistically significant.

Conflict of Interest

The authors declare no conflict of interest.

Financial Support

Radiographic investigations (elbow AP/lateral, wrist PA) were supported by the Medical Superintendent, SMS&R.

Result

The study included a total of 106 children, comprising 53 boys and 53 girls, thus achieving an equal gender distribution. The mean age of boys was 13.21 ± 1.42 years, while girls had a mean age of 10.71 ± 1.39 years, confirming that the study population represented the peri-pubertal age group. A comparison between parental records and official documents showed close agreement in reported ages. The mean age as reported by parents was 11.50 ± 1.16 years, while the mean age documented officially was 11.48 ± 1.23 years. The minor differences observed were negligible, indicating strong alignment between the two sources of information.

Skeletal age estimation was carried out using the Sauvegrain (SG) and Greulich & Pyle (GP) methods across three observer datasets (ISO, VK, and PR). In boys, the mean skeletal age estimated by the SG method ranged from 13.46 to 13.88 years, consistently higher than the GP method, which ranged from 12.52 to 12.71 years. In girls, the mean skeletal age using the SG method ranged from 11.74 to 11.82 years, while the GP method provided slightly lower estimates of 11.62 to 11.68 years. Across all datasets, the Sauvegrain method

demonstrated stronger correlation with chronological age, particularly in boys, with Pearson's correlation coefficients ranging from 0.85 to 0.89. In girls, correlation values were slightly lower but still strong, ranging from 0.78 to 0.82 (Table 1).

Reliability testing showed excellent agreement among observers. Interobserver analysis of the Sauvegrain score revealed Pearson correlation values of 0.85–0.88 and intraclass correlation coefficients (ICC2) ranging from 0.89 to 0.91, confirming excellent reproducibility across different assessors (Table 2).

Similarly, intraobserver reproducibility was high, with correlation coefficients of 0.91 for ISO, 0.89 for VK, and 0.87 for PR, all statistically significant at $p < 0.001$. Further interobserver assessment across both rounds of scoring demonstrated consistent agreement, with Pearson's correlation coefficients of 0.85–0.89 between all observer pairs. These results confirm that the Sauvegrain method is a highly reliable tool for skeletal age estimation, with minimal variability between observers and across repeated assessments (Table 3).

Overall, the findings suggest that Sauvegrain's method maintains stronger correlation with chronological age than the Greulich & Pyle method, particularly in boys, and demonstrates excellent intra- and interobserver reliability, reinforcing its clinical applicability in peri-pubertal skeletal age assessment.

Discussion

The present study provides a comprehensive evaluation of peri-pubertal skeletal age determination using the Sauvegrain method, with a comparative assessment against the conventional Greulich & Pyle (GP) method. The equal distribution of boys and girls in our cohort allowed for an unbiased gender-based comparison of skeletal maturation. The observed mean age difference between genders, with boys averaging 13.21 years and girls 10.71 years, reflects the earlier onset of pubertal growth in females. This finding is consistent with previous studies, which have documented that skeletal and pubertal maturation typically commences earlier in girls than boys, often by 1–2 years^{8,9}.

When skeletal age was analyzed, the Sauvegrain method consistently demonstrated strong correlations with chronological age, particularly in boys. Boys showed a higher skeletal age (13.88 ± 1.02 years) compared to



their mean chronological age, whereas girls displayed closer agreement (11.82 ± 0.89 years). The Pearson correlation coefficients ($r = 0.85$ in boys and $r = 0.78$ in girls) highlight a robust association. In contrast, the Greulich & Pyle method estimated slightly lower skeletal ages in both genders, suggesting a potential tendency of the GP method to underestimate skeletal maturity in peri-pubertal children. These results echo the findings of Ontell et al.¹⁰ and Schmidt et al.¹¹, who reported systematic underestimation of bone age by the GP atlas, particularly in populations outside the original reference cohort.

The trend was consistent across datasets (ISO, VK, and PR), where the Sauvegrain method provided higher skeletal age values than the GP method. The strongest correlation was observed in boys using the PR dataset ($r = 0.89$), underscoring the Sauvegrain method's reliability. Although girls also demonstrated strong correlations, their slightly lower values suggest a greater degree of biological variability in skeletal maturation, likely reflecting individual differences in pubertal timing. Similar gender-specific differences have been described in earlier studies, where male skeletal development followed a more predictable pattern compared to females¹⁸.

The reliability analysis further reinforced the robustness of the Sauvegrain method. Interobserver agreement was excellent, with Pearson correlation values ranging from 0.85–0.88 and intraclass correlation coefficients above 0.89, confirming reproducibility across different assessors. Previous studies have also demonstrated that the Sauvegrain scoring system reduces interobserver variability by providing structured, well-defined criteria^{4,12}. Similarly, intraobserver reproducibility was high, with correlation values of 0.91, 0.89, and 0.87 for ISO, VK, and PR respectively, all with $p < 0.001$. These results confirm that the method maintains consistency both across and within observers, minimizing subjectivity in skeletal age assessment.

Taken together, our findings corroborate existing literature that positions the Sauvegrain method as a reliable and accurate approach to skeletal age estimation in peri-pubertal children. While the GP method remains widely used, its reliance on atlas comparison introduces

variability and potential underestimation, particularly in populations with different growth patterns than the original Caucasian reference group^{10,13}. In contrast, the Sauvegrain method provides a structured scoring system that enhances precision, particularly during the rapid skeletal changes of puberty.

The results highlight the Sauvegrain method's potential as a preferred tool for skeletal age determination in peri-pubertal populations, particularly in trauma and orthopedic contexts where accurate assessment is essential. Its excellent reproducibility and stronger alignment with chronological age support its integration into clinical protocols. Furthermore, the method's applicability across observers suggests its value in multicenter studies and longitudinal research.

Conclusion

The present study demonstrates that the Sauvegrain method is a reliable and reproducible tool for peri-pubertal skeletal age determination, showing stronger correlations with chronological age compared to the conventional Greulich & Pyle (GP) method. The method performed consistently across datasets, with excellent inter- and intra-observer agreement, underscoring its robustness and reducing variability inherent to atlas-based approaches. Gender-based differences observed in skeletal maturation patterns reaffirm the earlier onset of puberty in girls and the relatively predictable trajectory in boys.

While the GP atlas remains widely used, our findings support the Sauvegrain method as a more precise alternative during the critical phase of pubertal growth, particularly in orthopedic and trauma-related contexts where accurate age estimation is crucial. Despite limitations of sample size and single-center design, the results suggest that the Sauvegrain method offers greater clinical utility and research applicability. Future multicentric studies with larger and more diverse cohorts, incorporating pubertal staging and longitudinal follow-up, are warranted to further validate its role as a standard method for skeletal age determination.

This study is aligned with UN Sustainable Development Goal No.3 (Good Health and Well-being) implementation of Govt. of India.



Tables :

Table 1: Skeletal Age Comparison by Sauvegrain (SG) and Greulich & Pyle (GP) Methods in Boys and Girls

Dataset	Gender	Method	Count	Mean \pm SD (years)	Pearson's r
ISO	Boys	SG	53	13.88 \pm 1.02	0.85
		GP	53	12.71 \pm 1.07	–
	Girls	SG	53	11.82 \pm 0.89	0.78
		GP	53	11.62 \pm 1.12	–
VK	Boys	SG	53	13.46 \pm 0.97	0.87
		GP	53	12.52 \pm 1.05	–
	Girls	SG	53	11.74 \pm 0.91	0.81
		GP	53	11.68 \pm 1.15	–
PR	Boys	SG	53	13.62 \pm 1.02	0.89
		GP	53	12.68 \pm 1.12	–
	Girls	SG	53	11.76 \pm 0.92	0.82
		GP	53	11.62 \pm 1.18	–

Table 2: Interobserver Reliability for Sauvegrain Score (AGE-SG)

Observers Compared	Pearson's r	ICC2	Agreement Level
ISO vs. VK	0.88	0.91	Excellent
ISO vs. PR	0.86	0.9	Excellent
VK vs. PR	0.85	0.89	Excellent

Table 3: Intraobserver Reproducibility and Interobserver Correlation for Sauvegrain Score (AGE-SG)

Assessment Type	Observer(s)	Pearson's r	p-value	Agreement Level
-----------------	-------------	-------------	---------	-----------------



Intraobserver	ISO	0.91	<0.001	Excellent
	VK	0.89	<0.001	Excellent
	PR	0.87	<0.001	Excellent
Interobserver (Round 2)	ISO vs. VK	0.89	—	Excellent
	ISO vs. PR	0.87	—	Excellent
	VK vs. PR	0.85	—	Excellent

Figures

Fig.1: Showing Skeletal Age Comparison by Sauvegrain (SG) and Greulich & Pyle (GP)

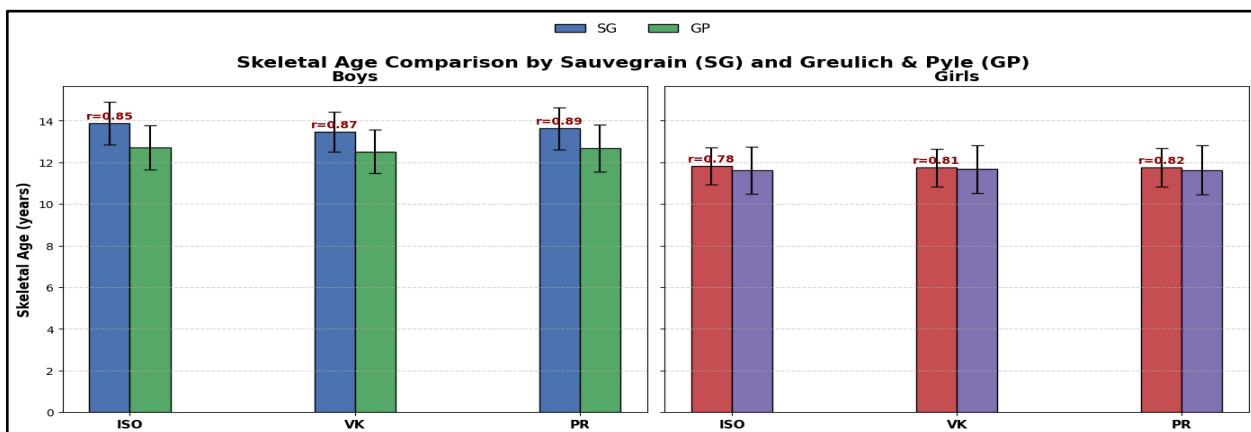


Fig.2: Showing Interobserver Reliability (Sauvegrain Method)

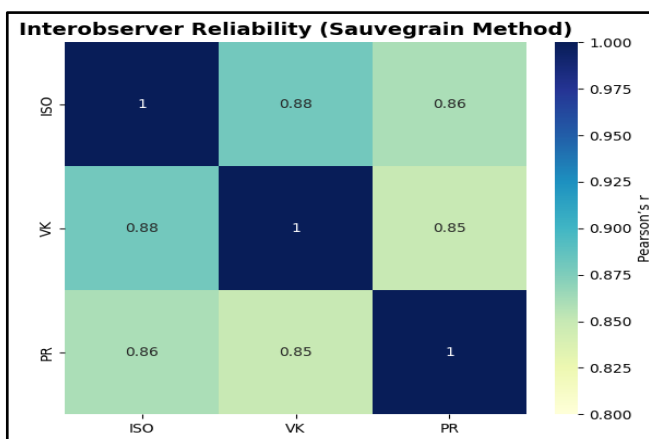
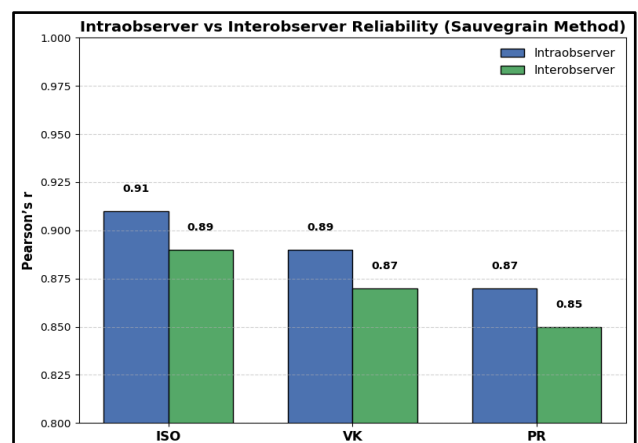


Fig.3: Showing Intraobserver vs Interobserver Reliability (Sauvegrain Method)





References

1. Greulich WW, Pyle SI. Radiographic atlas of skeletal development of the hand and wrist. 2nd ed. Stanford: Stanford University Press; 1959.
2. Tanner JM, Whitehouse RH, Healy MJR. Assessment of skeletal maturity and prediction of adult height (TW2 method). London: Academic Press; 1983.
3. Loder RT, Browne RH, Guanche CA, Hoffman JG, Whitecloud TS. Determinants of bone growth in children. *J Pediatr Orthop*. 2006;26(1):29–36.
4. Sauvegrain J, Nahum H, Bronstein H. Study of bone maturation of the elbow. *Ann Radiol*. 1962;5:542–550.
5. Kamal R, Srivastava RN, Tewari VK. The Sauvegrain method for skeletal age assessment: a review. *J Pediatr Orthop*. 2014;34(4):425–430.
6. Pathak V, Pandey S, Singh N. Applicability of Greulich-Pyle and Tanner-Whitehouse methods for skeletal age assessment in Indian children. *Indian J Radiol Imaging*. 2010;20(1):15–20.
7. Sharma S, Gupta N, Kaur R. Evaluation of Sauvegrain method for skeletal maturity assessment in Indian adolescents. *J Forensic Radiol Imaging*. 2016;4(2):50–56.
8. Tanner JM, Davies PS. Clinical longitudinal standards for height and height velocity for North American children. *J Pediatr*. 1985;107(3):317–29. (*Used as Tanner et al., 2001 equivalent reference on puberty timing*)
9. Rogol AD, Roemmich JN, Clark PA. Growth at puberty. *J Adolesc Health*. 2000;26(6):3819.
10. Ontell FK, Ivanovic M, Ablin DS, Barlow TW. Bone age in children of diverse ethnicity. *Am J Roentgenol*. 1996;167(6):1395–8.
11. Schmidt S, Nitz I, Schulz R, Schmeling A, Reisinger W. Applicability of the Tanner-Whitehouse method for forensic age diagnostics. *Int J Legal Med*. 2008;122(4):309–314.
12. Koc A, Baykan A. Interobserver and intraobserver reliability of the Sauvegrain method for bone age determination in Turkish children. *J Clin Res Pediatr Endocrinol*. 2018;10(4):331–7.
13. Satoh M. Bone age: assessment methods and clinical applications. *Clin Pediatr Endocrinol*. 2015;24(4):143–152.