I.O.F.O.S. Recommendations for Quality Assurance: BONE AGE ASSESSMENT IN LIVING INDIVIDUALS

Working Group on Bone Age Assessment in Living Individuals January 2026

IOFOS recommendations reviewed January 2026 with advice from:

Coordinator of the Working Group – Cristiana Palmela Pereira (Portugal)

Working Group Members –Helen Liversidge (England), Sigrid Kvaal (Norway).

Drafting Committee Members – Ashith Acharya (India), Hrvoje Brkic (Croatia), Marin Vodanovic (Croatia), Ricardo Henrique Alves da Silva (Brazil), Stefano Garatti (Italy), Vilma Pinchi (Italy).

International Organization for Forensic Odonto-Stomatology (I.O.F.O.S.) Recommendation Document for Bone Age Assessment in Living Individuals

1. Introduction

Estimating chronological age in living individuals plays a pivotal role in forensic, legal, and humanitarian settings, especially when reliable birth documentation is unavailable or disputed. [1] While dental age assessment has long served as a foundational method, skeletal or bone age assessment offers valuable complementary information, particularly from the hand/wrist bones, clavicular epiphyses, knee and, in some contexts, vertebral maturation. [2-8,10]

Bone age assessment is built on observing predictable ossification and epiphyseal fusion patterns over time, which are influenced by genetic, nutritional, hormonal, and environmental factors. [6-8,11] Classical techniques—such as the Greulich & Pyle atlas and the Tanner-Whitehouse scoring system applied to hand/wrist radiographs—remain central in clinical and forensic practice. [5,6,8,9] Radiographic assessments of the medial clavicular epiphysis (e.g. via CT or high-resolution imaging) are also used for later adolescent ages, since the hand bones may have already matured. [11-18] In certain approaches, vertebral maturation (especially of cervical vertebrae) is evaluated via cephalometric radiographs as a skeletal maturity marker. [19]

Because dentists are trained in interpreting radiographic anatomy and growth of craniofacial structures, they hold a potential role in bone age assessment —provided they are familiar with skeletal imaging, ossification staging, and the anatomical landmarks of the skeletal regions in question. [7,10,20] A dentist with expertise in radiographic evaluation and skeletal biology can integrate dental and skeletal data, thereby enhancing the robustness of age assessment. [2,4,21-28]

This document proposes the IOFOS Recommendations for Bone Age Assessment in Living Persons, preserving the structural framework of the dental age guideline but tailored to skeletal methods (hand/wrist, clavicle, knee, vertebrae). [29,30] It seeks to define minimum methodological standards, ethical safeguards [20], error quantification practices, and interpretative principles, so that bone age assessments in living individuals can be

scientifically defensible, transparent in their limitations, and respectful of individual rights**.** [20,29,31,33]

2. Scope

This document presents the first recommendations of IOFOS for Bone Age Assessment in Living Individuals.[29,30]

3. Background

In many forensic, clinical, and legal contexts, relying solely on dental indicators may not capture the full picture of an individual's maturational status. Integrating dental information with skeletal (bone) data offers a more complete framework for estimating chronological age. [2-4,21,22-26] This is because ossification and epiphyseal fusion in the hand/wrist, clavicle, knee and vertebral bodies follow biologically informed sequences that complement dental maturation trends.[5,6,8,12,16,17,19,34,36-38]

When skeletal development of the hand or wrist is incomplete, this usually indicates a subadult status.[5,6,8] If the hand skeleton is fully mature, an additional evaluation of the medial clavicular epiphysis may be undertaken, as this structure continues to ossify beyond adolescence. [12-18,34,35] The clavicle provides critical information in the transition between late adolescence and early adulthood, complementing dental findings in determining whether a legal age threshold (e.g., 18 years) has been surpassed. [39-49]

In clinical dentistry—particularly in orthodontics—dentists routinely interpret skeletal maturation indicators (e.g. hand/wrist radiographs, cephalometric vertical growth patterns) to guide treatment timing, predict growth spurts, or assess skeletal stage. [5,50-54]

Thus, using such information for bone age assessment in living individuals does not exceed the domain of competence of a trained dentist; rather, it leverages a dimension of expertise already present in dental practice. [39,40,43-45,55-58]

This document proposes to formalize how a dentist, working within a multidisciplinary forensic or medical team, may responsibly incorporate skeletal imaging (such as hand/wrist and clavicle) alongside dental markers to arrive at a combined, justified age assessment without overstepping professional boundaries or ethical constraints. [7,10,20,27,59]

4. Terms and Definitions for Bone Age Assessment

Note: For the purposes of this document, the terms and definitions given in the IOFOS Recommendation's Document for Dental Age Assessment in Living Individuals apply. The following additional terms and definitions are specific to bone age assessment:

4.1 Bone age

Is the age inferred from bone development stages or structural bone changes, used to approximate chronological age.

4.2 Bone age range (interval) assessment

Processes using bone information and relating it to chronological age.

4.3 Bone age assessment technique

Method used for bone age assessment.

5. Procedures and Steps

Note:

1- Please consult the IOFOS Recommendations for Dental Age Assessment for Living Individuals for procedures and steps already specified there; this document adds the bone estimation components not covered in the dental guidance.

2- The use of bone age markers, imaging procedures, and bone assessment methods must comply with the legal and regulatory frameworks of the jurisdiction in question, as requirements for ionizing radiation or imaging in living individuals differ between countries.

The choice of bone assessment methods (for instances such as hand/wrist, knee and clavicle) must be grounded in the dental findings: the developmental status of the dentition guides which bone regions and imaging modalities are most informative in the given case. For the hand/wrist, the Greulich & Pyle atlas approach remains a classical method to compare radiographs of carpal and phalangeal ossification with standard reference plates. [4] For the clavicle, a staging system of medial clavicular epiphyseal fusion can be applied, in CT or high-resolution imaging, to interpret ossification progression corresponding to age thresholds. [15,16] In both domains, the relevant reference studies must be carefully selected — those that document chronological ages associated with each ossification stage, in populations comparable to the subject — to calibrate the bone age assessment meaningfully in relation to the dental age results.

The use of alternative methods or bones must be supported by appropriate reference studies, establishing valid correlations between ossification or morphological markers and chronological age in the relevant population.

6. Conclusions

In forensic bone age assessment, the expert's report should integrate the findings from skeletal development (e.g., hand, wrist, and clavicle, etc) with dental markers to provide a scientifically justified estimate of chronological age. The assessment must define both the most probable age and/or a minimum age, in accordance with the forensic purpose and national legal or regulatory context.

As in dental age assessment, the minimum-age concept may be considered in some jurisdictions and case contexts; however, its use remains debated. Where applied, it ensures that the reported age does not overestimate the true biological age, thereby safeguarding the individual from being incorrectly classified as an adult. Reference studies appropriate to sex, population, and imaging modality (such as, radiograph, CT, MRI) must be used to justify stage assignment and age inference.

Finally, the interpretation of bone age must always be contextual and integrative, combining skeletal and dental markers. Where there is evidence or a reasonable basis to suspect such effects, variations attributable to population background, socioeconomic factors, or medical conditions shall be considered and documented in the interpretation. The final forensic opinion should provide a transparent statement of uncertainty, explicitly indicating whether the evidence supports or refutes that the individual has surpassed the relevant legal age threshold.

7. Summary

Forensic age assessment is frequently requested by judicial or administrative bodies when an individual's actual age is unknown or disputed. Traditionally, dental age assessment has provided fundamental indicators, but skeletal maturation offers additional, complementary insights—especially through analysis of bone development such as in the hand/wrist, clavicle and knee.

This document presents the first IOFOS Recommendations for Bone Age Assessment in Living Individuals, intended to be used alongside the existing dental age assessment recommendations.

The proposed framework includes methodology for selecting imaging modalities, staging bone maturity, integrating reference studies, documenting uncertainties, and combining skeletal and dental indicators into a coherent final age assessment. Legal, ethical, and radiological constraints must be respected per jurisdiction, and all novel methods must be justified by validated reference studies.

The goal of these recommendations is to ensure bone age assessments in living persons are transparent, scientifically defensible, and compatible with individual rights and legal rigor.

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8. References

1. Kvaal SI, Haugen M. Comparisons between skeletal and dental age assessment in unaccompanied asylum seeking children. *J Forensic Odontostomatol.* 2017;35(2):115–123.
2. Kvaal SI, Kolltveit KM, Solheim T, Thomsen IO. Age estimation of adults from dental radiographs. Forensic Sci Int. 1995;74(3):175–185.
3. Schmeling A, Grundmann C, Fuhrmann A, Kaatsch HJ, Knell B, Ramsthaler F, et al. Criteria for age estimation in living individuals. *Int J Legal Med.* 2008;122(6):457–460.
4. Schmeling A, Dettmeyer R, Rudolf E, Vieth V, Geserick G. Forensic age estimation. In: Schmidt S, ed. *Forensic Medicine: From Old Problems to New Challenges.* Hoboken (NJ): Wiley; 2016. p. 44–50.
5. Greulich WW, Pyle SI. *Radiographic atlas of skeletal development of the hand and wrist.* 2nd ed. Stanford (CA): Stanford University Press; 1959. p. 110–123.
6. Tisè M, Mazzarini L, Fabrizzi G, Ferrante L, Giorgetti R, Tagliabracci A. Applicability of Greulich and Pyle method for age assessment in forensic practice on an Italian sample. *Int J Legal Med.* 2011;125(3):411–416.

7. Solheim T. Quality assurance in forensic odontology. *Forensic Sci Int.* 2018;285:53–57.
8. Dahlberg PS, Mosdøl A, Ding KY, Bleka Ø, Rolseth V, Straumann GH, et al. Samsvar mellom kronologisk alder og skjelettalder basert på Greulich og Pyle-atlaset for aldersestimering: en systematisk oversikt. Oslo: Folkehelseinstituttet; 2017.
9. Pinchi V, De Luca F, Ricciardi F, Focardi M, Piredda V, Mazzeo E, Norelli GA. Skeletal age estimation for forensic purposes: A comparison of GP, TW2 and TW3 methods on an Italian sample. *Forensic Sci Int.* 2014;238:83–90. doi:10.1016/j.forsciint.2014.02.030.
10. Rösing FW, Graw M, Marré B, Ritz-Timme S, Rothschild MA, Rötzscher K, et al. Recommendations for the forensic diagnosis of sex and age from skeletons. *Homo.* 2007;58(1):75–89. doi:10.1016/j.jchb.2005.07.002.
11. Schmeling A, Reisinger W, Loreck D, Vendura K, Markus W, Geserick G. Effects of ethnicity on skeletal maturation: consequences for forensic age estimations. *Int J Legal Med.* 2000;113(5):253–258.
12. Kellinghaus M, Schulz R, Vieth V, Schmidt S, Schmeling A. Enhanced possibilities to make statements on the ossification status of the medial clavicular epiphysis using an amplified staging scheme in evaluating thin-slice CT scans. *Int J Legal Med.* 2010;124(4):321–325.
13. Rudolf E, Kramer J, Schmidt S, Vieth V, Winkler I, Schmeling A, et al. Intraindividual incongruences of medially ossifying clavicles in borderline adults as seen from thin-slice CT studies of 2595 male persons. *Int J Legal Med.* 2018;132(3):629–636.
14. Rudolf E, Kramer J, Winkler I, Schmeling A. Technical note: utilization of 3D-rendering for CT evaluation of extremitas sternalis claviculae within medical age assessment practice. *Int J Legal Med.* 2019;133(3):931–934.
15. Rudolf E, Kramer J, Schmidt S, Vieth V, Winkler I, Schmeling A, et al. Anatomic shape variants of extremitas sternalis claviculae as collected from sternoclavicular thin-slice CT studies of 2820 male borderline-adults. *Int J Legal Med.* 2019;133(6):1517–1528.
16. Schulz R, Zwiesigk P, Schiborr M, Schmidt S, Schmeling A. Ultrasound studies on the time course of clavicular ossification. *Int J Legal Med.* 2008;122(2):163–167.
17. Pfeiffer H, Schmidt S, Schmeling A. The value of substages and thin slices for the assessment of the medial clavicular epiphysis: a prospective multi-center CT study.

Int J Legal Med. 2014;128(1):163–169.

18. Rudolf E, Kramer J, Winkler I, Schumacher G, Löschner J, Schmeling A. *Morphologies of medial clavicular ossification.* Luxembourg: Publications Office of the European Union; 2020.
19. Vieth V, Schulz R, Heindel W, Pfeiffer H, Buerke B, Schmeling A, et al. Forensic age assessment by 3.0T MRI of the knee: proposal of a new MRI classification of ossification stages. *Eur Radiol.* 2018;28(8):3255–3262.
20. Thevissen PW, Kvaal SI, Dierickx K, Willems G. Ethics in age estimation of unaccompanied minors. *Int J Legal Med.* 2012;126(1):22–24.
21. Pereira CP, Augusto D, Santos A, Nushi V, Rodrigues A, Santos R. Dental age assessment and dental scoring systems: combined different statistical methods. *Int J Legal Med.* 2024;138:1533–1557. doi:10.1007/s00414-024-03216-0.
22. Pereira CP, Santos R, Nushi V, Lameiro MV, Antunes P, Carvalho R, Major T, AlQahtani SJ. Dental age assessment: scoring systems and models from the past until the present—how is it presented in the court? *Int J Legal Med.* 2023;137:1497–1504. doi:10.1007/s00414-023-03011-3.
23. Augusto D, Pereira CP, Rodrigues A, Cameriere R, Salvado F, Santos R. Dental age assessment by I2M and I3M: Portuguese legal age thresholds of 12 and 14 year olds. *Acta Stomatol Croat.* 2021;55(1):45–55. doi:10.15644/asc55/1/6.
24. Pereira CP, Lameiro MV, Rodrigues A, Salvado F, Santos R. Bone age and dental age to assess criminal responsibility: Part I. *Int J Legal Med.* 2025;139(4):1691–1705. doi:10.1007/s00414-025-03451-z.
25. Palmela Pereira C, Antunes P, Rodrigues A, et al. Bone age and dental age to assess criminal responsibility: Part II. *Int J Legal Med.* 2025;139:1707–1719. doi:10.1007/s00414-025-03454-w.
26. Pinchi V, De Luca F, Focardi M, Pradella F, Vitale G, Ricciardi F, Norelli GA. Combining dental and skeletal evidence in age classification: pilot study in a sample of Italian sub-adults. *Legal Medicine.* 2016;20:75–79. doi:10.1016/j.legalmed.2016.04.009.
27. Pradella F, Pinchi V, Focardi M, Grifoni R, Palandri M, Norelli GA. The age estimation practice related to illegal unaccompanied minors immigration in Italy. *J Forensic Odontostomatol.* 2017;35(2):147–156.
28. Thevissen PW, Kaur J, Willems G. Human age estimation combining third molar and skeletal development. *Int J Legal Med.* 2012;126(2):285–292. doi:10.1007/s00414-

011-0639-5.

29. International Organization for Forensic Odonto-Stomatology (IOFOS). *Recommendations for quality assurance in dental age assessment.* Leuven: IOFOS; 2018.
30. International Organization for Forensic Odonto-Stomatology (IOFOS). *Recommendations for dental age assessment.* Leuven: IOFOS; 2008.
31. Schmeling A. Die aktuelle medizinethische Debatte über forensische Altersdiagnostik bei unbegleiteten minderjährigen Flüchtlingen. In: Informationsverbund Asyl und Migration (asyl.net). 2018.
32. Kellinghaus M, Schulz R, Vieth V, Schmidt S, Schmeling A. Forensic age estimation in living subjects based on the ossification status of the medial clavicular epiphysis as revealed by thin-slice multidetector computed tomography. *Int J Legal Med.* 2010;124(2):149–154.
33. Sironi E, Pinchi V, Taroni F. Probabilistic age classification with Bayesian networks: A study on the ossification status of the medial clavicular epiphysis. *Forensic Sci Int.* 2016;258:81–87. doi:10.1016/j.forsciint.2015.11.010.
34. Liversidge HM. Timing of human mandibular third molar formation. *Ann Hum Biol.* 2008;35(3):294–321. doi:10.1080/03014460801971445.
35. AlQahtani SJ, Hector MP, Liversidge HM. Brief communication: The London atlas of human tooth development and eruption. *Am J Phys Anthropol.* 2010;142(3):481–490. doi:10.1002/ajpa.21258.
36. Acharya AB. Age estimation in Indians using Demirjian's 8-teeth method. *J Forensic Sci.* 2011;56(1):124–127. doi:10.1111/j.1556-4029.2010.01566.x.
37. Mincer HH, Harris EF, Berryman HE. The A.B.F.O. study of third molar development and its use as an estimator of chronological age. *J Forensic Sci.* 1993;38(2):379–390.
38. Olze A, van Niekerk P, Taniguchi M, Maeda H, Schmeling A. Forensic age estimation in living subjects: the ethnic factor in wisdom tooth mineralization. *Int J Legal Med.* 2004;118(3):170–173.
39. Olze A, Schmeling A, Rieger K, Kalb G, Geserick G. Untersuchungen zum zeitlichen Verlauf der Mineralisation bei einer deutschen Population. *Rechtsmedizin.* 2003;13(1):5–10.
40. Olze A, Solheim T, Schulz R, Kupfer M, Pfeiffer H, Schmeling A. Assessment of the radiographic visibility of the periodontal ligament in the lower third molars for the

purpose of forensic age estimation in living individuals. *Int J Legal Med.* 2010;124(5):445–448.

41. Olze A, Solheim T, Schulz R, Kupfer M, Schmeling A. Evaluation of the radiographic visibility of the root pulp in the lower third molars for the purpose of forensic age estimation in living individuals. *Int J Legal Med.* 2010;124(2):183–186.
42. Olze A, Bilang D, Schmidt D, Geserick G. Validation of common classification systems for assessing the mineralization of third molars. *Int J Legal Med.* 2005;119(1):22–26.
43. Pereira CP, Rodrigues A, Augusto D, Santos A, Salvado F, Santos R, Cameriere R. Forensic age estimation using new models of mathematical regression formula constructed with molar indexes: dental age assessment. *J Stomatol.* 2021;74(2):95–100. doi:10.5114/jos.2021.106540.
44. Pereira CP, Rodrigues A, Santos A, Salvado F, Santos R, Cameriere R. Cut-off for the legal ages in the Portuguese population by Third Maturity Index: measures of accuracy. *Arch Oral Biol.* 2021;125:105089. doi:10.1016/j.archoralbio.2021.105089.
45. Olze A, van Niekerk P, Schulz R, Ribbecke S, Schmeling A. The influence of impaction on the rate of third molar mineralisation in male black Africans. *Int J Legal Med.* 2012;126(6):869–874.
46. Thevissen PW, Fieuws S, Willems G. Human third molars development: comparison of 9 country specific populations. *Forensic Sci Int.* 2010;201(1–3):102–105. doi:10.1016/j.forsciint.2010.04.054.
47. Olze A, Pynn B, Kraul V, Schulz R, Heinecke A, Pfeiffer H, Schmeling A. Dental age estimation based on third molar eruption in First Nations people of Canada. *J Forensic Odontostomatol.* 2010;28(1):32–38.
48. Haavikko K. *The formation and the alveolar and clinical eruption of the permanent teeth: an orthopantomographic study.* Helsinki: University of Helsinki; 1970.
49. Wilmott SE, Hector MP, Liversidge HM. Accuracy of estimating age from eruption levels of mandibular teeth. *Forensic Sci Int.* 2019;295:187–194.
50. Kahl B, Schwarze CW. Aktualisierung der Dentitionstabelle von I. Schour und M. Massler von 1941. *Fortschr Kieferorthop.* 1988;49(5):432–443.
51. Galić I, Vodanović M, Cameriere R, Nakaš E, Galić E, Selimović E, Brkić H. Accuracy of Cameriere, Haavikko, and Willems radiographic methods on age estimation on Bosnian-Herzegovian children age groups 6–13. *Int J Legal Med.* 2011;125(2):315–321. doi:10.1007/s00414-010-0515-8.

52. Pinchi V, Norelli GA, Pradella F, Vitale G, Rugo D, Nieri M. Comparison of the applicability of four odontological methods for age estimation of the 14 years legal threshold in a sample of Italian adolescents. *J Forensic Odontostomatol.* 2012;30(2):17–25.
53. Moorrees CFA, Fanning EA, Hunt EE. Age variation of formation stages for ten permanent teeth. *J Dent Res.* 1963;42(6):1490–1502.
54. Gleiser I, Hunt EE Jr. The permanent mandibular first molar: its calcification, eruption and decay. *J Dent Res.* 1955;34(2):253–266.
55. Pires AC, Vargas de Sousa Santos RF, Pereira CP. Dental age assessment by the pulp/tooth area proportion in cone beam computed tomography: is medico-legal application for age estimation reliable? *J Forensic Odontostomatol.* 2021;39(2):2–14.
56. Palmela Pereira C. Dental age assessment methods in children and adolescents. In: Chowdhry A, Kapoor P, editors. *Dental Age Assessment.* Cham: Springer; 2026. doi:10.1007/978-3-032-08788-1_6.
57. Kvaal SI, Solheim T. A non-destructive dental method for age estimation. *J Forensic Odontostomatol.* 1994;12(1):6–11.
58. Pereira CP, Russell LM, de Pádua Fernandes M, Alves da Silva RH, de Sousa Santos RFV. Dental age estimation based on development dental atlas assessment in a child/adolescent population with systemic diseases. *Acta Stomatol Croat.* 2019;53(4):307–317. doi:10.15644/asc53/4/1.
59. Schmeling A, Reisinger W, Wormanns D, et al. Strahlenexposition bei Röntgenuntersuchungen zur forensischen Altersschätzung Lebender. *Rechtsmedizin.* 2000;10:135–137. doi:10.1007/s001940000060.