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# Minor migrants' age estimation: Comparison of two dental methods

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ABSTRACT

In case of minor migrants, absence of valid identification documents that clearly define age is a critical issue, because without these data the child cannot enjoy the rights provided by the Convention on the Rights of the Child. Differentiation between minors and adults is fundamental when age is disputed in human identification, asylum seeking, criminal liability, and child abuse fields. Few indications are available about qualitative/statistical agreement of different age estimation methods. Ages of 301 individuals were estimated through two dental methods in order to: determine quantitative and statistical agreements in legal age definition; identify practical recommendations. The study pointed out discrepancy between the two methods in 7/301 cases. From a statistical point of view, this finding corresponded to an almost perfect agreement. Thus, authors suggested that the two methods can be alternately used for legal age assessment, but operators should use both methods when the estimated age is 18.5 years.



## 1. Introduction

The Convention on the Rights of the Child (1989) states that "States Parties undertake to respect the right of the child to preserve his or her identity, including nationality, name and family relations as recognized by law without unlawful interference. Where a child is illegally deprived of some or all of the elements of his or her identity, States Parties shall provide appropriate assistance and protection, with a view to re-establishing rapidly his or her identity" [1]. In case of minor migrants, absence of valid identification documents that clearly define age is a critical issue, because without these data the child cannot enjoy the rights provided by the Convention. In this scenario, child best interest matches with careful assessment of his/her age.

Several age estimation methods have been proposed [2–5]. They usually rely on the correlation between bone/dental maturation and chronological age [6–13]. In 2010 AlQahtani and colleagues described an atlas (The London Atlas of Human Tooth Development and Eruption) of tooth development in order to estimate age between 28 weeks intrauterine and 23 years [14]. Besides, this method was applied to several population samples, in order to evaluate its accuracy in people of different geographical areas [15–17]. Cameriere and colleagues described an innovative method (third molar maturity index − $I_{3M}$) that allows to distinguish adults ($I_{3M} < 0.08$) from minors ($I_{3M} \geq 0.08$) [18]. $I_{3M}$ is calculated "as the sum of the widths of the inner margins of the two open apices than divided by tooth length" [19].

From a practical point of view, in the most part of European and non-European countries legal age is reached when an individual turns 18 years old [20,21]. In case of subjects who do not have proper documents, differentiation between minors (<18 years old) and adults (≥18 years old) is fundamental when age is disputed in human identification, asylum seeking, criminal liability, and child abuse fields. In the literature, there are several studies that evaluate accuracy and intra-observer/inter-observer agreement of each of the two abovementioned methods [15,17]. Nevertheless, comparative analyzes of results obtained through these methods are not available. In particular, there are no indications that allow: 1) to determine quantitative and statistical agreements between the AlQahtani atlas and the Cameriere method in legal age definition; 2) to identify recommendations that operators should take into account when they use these methods in order to minimize errors.

In the light of the above, the authors propose a comparison between the results of the London Atlas and the third molar

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maturity index method on an unknown age population, in order to define quantitative and statistical agreements, and to identify practical recommendations when it comes to determine legal age using the aforementioned methods.

## 2. Materials and methods

The study included 301 orthopantomography (OPG) images corresponding to 301 individuals without valid identify documents; actual chronological ages of the study sample were unknown. These individuals had been consecutively evaluated from November 2014 to April 2018 by the operators of the "A.O.U. Città della Salute e della Scienza di Torino" (Italy) hospital, in order to produce identification/age estimation assessments. Individuals' nationality, sex, and OPG images were obtained from electronic medical records (Trakcare® platform). Medical record review excluded recurrence of systemic diseases or developmental problems in the study population. A numerical code was assigned to each image in order to anonymize them. In addition, these numerical codes were reported into two different Excel® files. Left and right mandibular third molars were respectively defined as 38 and 48, according to classification by Federation Dentaire Internationale [22]. In the first session, a forensic odontologist (experienced in age estimation; with ten year experience in age assessment through the two aforementioned methods) analyzed 38s and 48s of the 301 OPG images throughout the MPDicom Viewer® software. For each molar, the abovementioned operator/observer assigned a dental age (in the form of binary categorical variables: < 18 years old if $I_{3M} \geq 0.08$; ≥18 years old if $I_{3M} < 0.08$), using the third molar index method described by Cameriere and colleagues [18]. Then, the observer collected ages in one of the aforementioned Excel® file in association with the correspondent numerical code.

In the second session (performed one week later the first one), the same forensic odontologist analyzed 38s and 48s of the same 301 OPG images throughout the MPDicom Viewer® software. In this session, the operator/observer had not access to the results of the first Excel® file. For each molar, the observer assigned an estimated age, using the atlas described by AlQahtani and colleagues [14]. Then, the operator collected ages in the second Excel® file in association with the correspondent numerical code.

After these sessions, a second operator merged the two Excel® files in a third one in which numerical codes, nationality, sex, and estimated ages were matched. Assessed ages obtained using the AlQahtani atlas were transformed in binary categorical variables (<18 or ≥ 18 years old), in order to allow quantitative and statistical comparisons.

At first, quantitative comparison of the estimated ages was carried out. Then, statistical agreement in legal age assessment of the methods was separately calculated for 38s and 48s through the IBM SPSS Statistics 20 software. In particular, the Cohen's kappa coefficient (K) was used to evaluate statistical agreement of binary qualitative categories (<18 or ≥ 18 years old) [23]. Even if K is commonly performed to test observations of a single dataset between two observers, according to the scientific literature its use for the same rater evaluating the same data at two time points is considered as acceptable [24]. However, this use has limitations because it does not take into account the magnitude of differences (especially for ordinal data) [24].

## 3. Results

All results are summarized in Table 1. Among the 301 individuals, 44 were female and 257 were male (Table 1). They mostly came from the African continent; in particular from Nigeria (52/301), Guinea (39/301), Senegal (32/301), Mali (22/301), Gambia (20/301), Ivory Coast (18/301), and Morocco (16/301). In both sessions: 38 and 48 were simultaneously absent in 10/301 individuals; 38 was absent in 16/301 subjects; 48 was absent in 14/301 cases. Quantitative analysis yielded the following results:

- for 38s, the Cameriere method defined 216 ages as ≥ 18 years and 59 as < 18 years;
- for 38s, the AlQahtani atlas defined 223 ages as ≥ 18 years and 52 as < 18 years;
- for 48s, the Cameriere method defined 212 ages as ≥ 18 years and 65 as < 18 years;
- for 48s, the AlQahtani atlas defined 219 ages as ≥ 18 years and 58 as < 18 years.

In 7 cases, there was discrepancy in legal age assessment of both molars, because the Cameriere method identified ages as < 18 years, while the AlQahtani atlas as correspondent to 18.5 years (≥18 years old).

In one case, the operator/observer reported different maturation stages for 38 and 48, defining (through both methods) 38 as correspondent to ≥ 18 years and 48 as correspondent to < 18 years in both sessions.

Statistical analysis of the agreement (K) of the aforementioned methods yielded the following results:

- K = 0.921 for left mandibular third molar (38);
- K = 0.927 for right mandibular third molar (48).

## 4. Discussion

The results of the present manuscript pointed out that quantitative agreement in the identification of legal age was correspondent to 97.59%. Indeed, lower third molars of the same 7 individuals were identified as correspondent to ≥18 years through the AlQahtani method and as < 18 years through the Cameriere one. This study does not allow to define the reasons of the discrepancy. However, it is important to highlight that in all 7 cases the operator/observer assessed through the London Atlas both 38 and 48 as correspondent to 18.5 years. Therefore, it is possible to suggest that the two methods are more likely to differ when the AlQahtani atlas defines a chronological age that is just above 18 years old. However, it is important to note that in the other 9 cases in which the same atlas identified a chronological age of 18.5 years, there was concordance with the third molar index method. These results demonstrate that the abovementioned discrepancy does not seem to be a constant finding.

From a statistical point of view, identification of binary categorical variables can differ or agree as a result of chance. For this reason, Cohen Kappa coefficient (K) evaluated agreement between the two methods by eliminating the so-called per chance agreement/disagreement [23]. The results of Kappa statistics yielded a value of >0.8. Therefore, this result suggested that the London Atlas and the Cameriere method are characterized by an almost perfect agreement (K > 0.8) [22,24,25]. Indeed, according to Ranganathan and colleagues (2017) and Vierra and Garrett (2005) a value of K from 0.81 to 0.99 is defined as almost perfect agreement [24,25]; thus, the two methods are statistically comparable.

From a practical point of view, the abovementioned considerations are meaningful. Indeed, the almost perfect agreement allows to state that the AlQahtani method and the Cameriere third molar maturity index can be alternately used for legal age assessment [24,25]. Nevertheless, quantitative data suggest a careful approach when the London Atlas identifies a chronological age of 18.5 years.

**Table 1**
Caption: Summary of the results (in years).

| Case number | Sex | Nationality | Cameriere 38 | AlQahtani 38 | Cameriere 48 | AlQahtani 48 |
|---|---|---|---|---|---|---|
| 1 | Female | Mali | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 2 | Male | Nigeria | Absent | Absent | <18 | <18 (16.5) |
| 3 | Male | Bangladesh | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 4 | Male | Pakistan | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 5 | Male | Mali | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 6 | Male | Mali | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 7 | Male | Gambia | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 8 | Male | Nigeria | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 9 | Male | Gambia | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 10 | Male | Gambia | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 11 | Male | Nigeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 12 | Male | Ivory Coast | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 13 | Male | Bangladesh | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 14 | Male | Nigeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 15 | Male | Nigeria | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 16 | Male | Nigeria | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 17 | Female | Nigeria | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 18 | Female | Nigeria | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 19 | Female | Nigeria | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 20 | Male | Cameroon | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 21 | Male | Senegal | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 22 | Female | Eritrea | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 23 | Male | Ethiopia | ≥18 | ≥18 (18.5) | ≥18 | ≥18 (18.5) |
| 24 | Male | Cameroon | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 25 | Male | Sudan | ≥18 | ≥18 (18.5) | ≥18 | ≥18 (18.5) |
| 26 | Male | Somalia | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 27 | Female | Nigeria | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 28 | Male | syria | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 29 | Female | Eritrea | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 30 | Female | Eritrea | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 31 | Female | Nigeria | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 32 | Female | Nigeria | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 33 | Female | Nigeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 34 | Female | Nigeria | ≥18 | ≥18 (18.5) | ≥18 | ≥18 (18.5) |
| 35 | Male | Ghana | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 36 | Male | Eritrea | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 37 | Male | Eritrea | <18 | <18 (15.5) | <18 | <18 (16.5) |
| 38 | Male | Sudan | ≥18 | ≥18 (22.5) | Absent | Absent |
| 39 | Male | Eritrea | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 40 | Male | Somalia | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 41 | Male | Somalia | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 42 | Female | Nigeria | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 43 | Female | Nigeria | ≥18 | ≥18 (18.5) | ≥18 | ≥18 (18.5) |
| 44 | Female | Nigeria | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 45 | Female | Nigeria | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 46 | Male | Morocco | Absent | Absent | Absent | Absent |
| 47 | Male | Morocco | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 48 | Male | Morocco | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 49 | Male | Pakistan | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 50 | Male | Gambia | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 51 | Male | Nigeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 52 | Male | Pakistan | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 53 | Male | Algeria | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 54 | Male | Mali | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 55 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 56 | Female | Nigeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 57 | Male | Gabon | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 58 | Male | Guinea | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 59 | Male | Ivory Coast | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 60 | Female | Nigeria | <18 | ≥18 (18.5) | <18 | ≥18 (18.5) |
| 61 | Male | Morocco | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 62 | Female | Nigeria | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 63 | Female | Nigeria | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 64 | Female | Nigeria | ≥18 | ≥18 (18.5) | ≥18 | ≥18 (18.5) |
| 65 | Male | Iraq | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 66 | Male | Gambia | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 67 | Female | Nigeria | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 68 | Male | Ghana | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 69 | Male | Morocco | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 70 | Male | Ivory Coast | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 71 | Female | Nigeria | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 72 | Male | Egypt | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 73 | Female | Nigeria | <18 | <18 (15.5) | <18 | <18 (15.5) |

(*continued on next page*)

**Table 1** (*continued*)

| Case number | Sex | Nationality | Cameriere 38 | AlQahtani 38 | Cameriere 48 | AlQahtani 48 |
|---|---|---|---|---|---|---|
| 74 | Male | Somalia | ≥18 | ≥18 (18.5) | ≥18 | ≥18 (18.5) |
| 75 | Male | Nigeria | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 76 | Female | Ivory Coast | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 77 | Male | Mali | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 78 | Male | Gambia | <18 | ≥18 (18.5) | <18 | ≥18 (18.5) |
| 79 | Male | Bangladesh | Absent | Absent | Absent | Absent |
| 80 | Male | Bangladesh | ≥18 | ≥18 (20.5) | Absent | Absent |
| 81 | Male | Ghana | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 82 | Male | Mali | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 83 | Male | Gabon | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 84 | Male | Togo | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 85 | Male | Ivory Coast | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 86 | Male | Bangladesh | Absent | Absent | ≥18 | ≥18 (22.5) |
| 87 | Male | Bangladesh | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 88 | Female | Nigeria | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 89 | Male | Senegal | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 90 | Male | Ghana | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 91 | Male | Nigeria | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 92 | Male | Senegal | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 93 | Male | Guinea | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 94 | Male | Guinea | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 95 | Male | Morocco | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 96 | Male | Nigeria | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 97 | Male | Egypt | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 98 | Male | Benin | Absent | Absent | <18 | <18 (15.5) |
| 99 | Female | Nigeria | <18 | ≥18 (18.5) | <18 | ≥18 (18.5) |
| 100 | Female | Nigeria | <18 | ≥18 (18.5) | <18 | ≥18 (18.5) |
| 101 | Male | Nigeria | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 102 | Male | Burkina Faso | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 103 | Female | Nigeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 104 | Female | Nigeria | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 105 | Male | Somalia | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 106 | Male | Bangladesh | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 107 | Female | Nigeria | <18 | ≥18 (18.5) | <18 | ≥18 (18.5) |
| 108 | Male | Bangladesh | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 109 | Male | Somalia | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 110 | Male | Ivory Coast | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 111 | Male | Gambia | Absent | Absent | ≥18 | ≥18 (21.5) |
| 112 | Male | Algeria | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 113 | Male | Morocco | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 114 | Male | Egypt | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 115 | Male | Guinea | ≥18 | ≥18 (23.4) | ≥18 | ≥18 (23.5) |
| 116 | Male | Mali | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 117 | Male | Mali | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 118 | Male | Mali | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 119 | Male | Gabon | ≥18 | ≥18 (22.5) | Absent | Absent |
| 120 | Male | Ivory Coast | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 121 | Male | Ivory Coast | ≥18 | ≥18 (20.4) | ≥18 | ≥18 (20.5) |
| 122 | Male | Pakistan | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 123 | Male | Senegal | ≥18 | ≥18 (23.5) | Absent | Absent |
| 124 | Male | Senegal | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 125 | Female | Nigeria | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 126 | Male | Nigeria | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 127 | Male | Bangladesh | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 128 | Male | Myanmar | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 129 | Male | Afgahnistan | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 130 | Male | Afgahnistan | Absent | Absent | Absent | Absent |
| 131 | Male | Guinea | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 132 | Male | Senegal | ≥18 | ≥18 (23.5) | Absent | Absent |
| 133 | Male | Mali | ≥18 | ≥18 (18.5) | ≥18 | ≥18 (18.5) |
| 134 | Male | Guinea | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 135 | Male | Guinea | ≥18 | ≥18 (18.5) | ≥18 | ≥18 (18.5) |
| 136 | Male | Nigeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 137 | Male | Algeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 138 | Male | Guinea | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 139 | Male | Senegal | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 140 | Male | Senegal | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 141 | Male | Morocco | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 142 | Male | Mali | ≥18 | ≥18 (20.5) | Absent | Absent |
| 143 | Male | Pakistan | Absent | Absent | <18 | <18 (17.5) |
| 144 | Male | Gambia | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 145 | Male | Guinea | ≥18 | ≥18 (22.5) | Absent | Absent |
| 146 | Male | Gambia | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 147 | Male | Gabon | Absent | Absent | Absent | Absent |
| 148 | Female | Nigeria | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |

**Table 1** (*continued*)

| Case number | Sex | Nationality | Cameriere 38 | AlQahtani 38 | Cameriere 48 | AlQahtani 48 |
|---|---|---|---|---|---|---|
| 149 | Female | Romania | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 150 | Female | Nigeria | <18 | ≥18 (18.5) | <18 | ≥18 (18.5) |
| 151 | Male | Pakistan | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 152 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 153 | Male | Senegal | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 154 | Male | Senegal | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 155 | Male | Senegal | ≥18 | ≥18 (20.5) | Absent | Absent |
| 156 | Male | Gambia | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 157 | Male | Guinea | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 158 | Male | Senegal | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 159 | Male | Gambia | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 160 | Male | Bangladesh | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 161 | Male | Senegal | Absent | Absent | ≥18 | ≥18 (22.5) |
| 162 | Male | Roamania | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 163 | Male | Ivory Coast | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 164 | Male | Tunisia | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 165 | Male | Guinea | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 166 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 167 | Male | Guinea | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 168 | Male | Morocco | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 169 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 170 | Male | Gabon | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 171 | Male | Guinea | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 172 | Male | Gambia | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 173 | Male | Mali | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 174 | Female | Nigeria | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 175 | Male | Nigeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 176 | Male | Morocco | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 177 | Male | Guinea | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 178 | Male | Guinea | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 179 | Male | Cameroon | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 180 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 181 | Male | Guinea | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 182 | Male | Cameroon | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 183 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 184 | Female | Serbia | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 185 | Male | Senegal | Absent | Absent | Absent | Absent |
| 186 | Male | Gambia | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 187 | Male | Nigeria | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 188 | Male | Nigeria | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 189 | Male | Guinea | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 190 | Male | Senegal | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 191 | Male | Guinea | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 192 | Male | Guinea | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 193 | Male | Guinea | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 194 | Male | Mali | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 195 | Male | Ivory Coast | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 196 | Male | Mali | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 197 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 198 | Male | Guinea | Absent | Absent | ≥18 | ≥18 (22.5) |
| 199 | Male | Guinea | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 200 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 201 | Male | Nigeria | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 202 | Male | Ivory Coast | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 203 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 204 | Female | Nigeria | <18 | ≥18 (18.5) | <18 | ≥18 (18.5) |
| 205 | Male | Libya | Absent | Absent | ≥18 | ≥18 (22.5) |
| 206 | Male | Sudan | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 207 | Male | Ivory Coast | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 208 | Male | Eritrea | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 209 | Male | Egypt | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 210 | Male | Senegal | ≥18 | ≥18 (21.5) | Absent | Absent |
| 211 | Male | Senegal | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 212 | Male | Tunisia | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 213 | Male | Zambia | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 214 | Male | Gambia | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 215 | Male | Gambia | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 216 | Male | Gambia | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 217 | Male | Guinea Bassau | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 218 | Male | Gambia | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 219 | Male | Senegal | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 220 | Male | Senegal | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 221 | Male | Gabon | ≥18 | ≥18 (22.5) | Absent | Absent |
| 222 | Male | Libya | Absent | Absent | Absent | Absent |

(*continued on next page*)

**Table 1** (*continued*)

| Case number | Sex | Nationality | Cameriere 38 | AlQahtani 38 | Cameriere 48 | AlQahtani 48 |
|---|---|---|---|---|---|---|
| 223 | Female | Morocco | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 224 | Male | Senegal | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 225 | Male | Guinea Bissau | ≥18 | ≥18 (20.5) | Absent | Absent |
| 226 | Male | Mali | Absent | Absent | <18 | <18 (17.5) |
| 227 | Female | Nigeria | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 228 | Male | Senegal | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 229 | Male | Gambia | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 230 | Male | Morocco | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 231 | Female | Nigeria | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 232 | Male | Bangladesh | Absent | Absent | <18 | <18 (17.5) |
| 233 | Male | Mali | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 234 | Male | Senegal | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 235 | Male | Benin | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 236 | Male | Senegal | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 237 | Male | Nigeria | Absent | Absent | Absent | Absent |
| 238 | Male | Nigeria | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 239 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 240 | Male | Ivory Coast | ≥18 | ≥18 (23.5) | Absent | Absent |
| 241 | Male | Senegal | <18 | <18 (14.5) | Absent | Absent |
| 242 | Male | Morocco | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 243 | Male | Eritrea | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 244 | Male | Eritrea | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 245 | Male | Egypt | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 246 | Male | Ivory Coast | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 247 | Male | Guinea Bissau | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 248 | Male | Bangladesh | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 249 | Male | Senegal | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 250 | Male | Gabon | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 251 | Male | Mali | Absent | Absent | ≥18 | ≥18 (21.5) |
| 252 | Male | Senegal | Absent | Absent | ≥18 | ≥18 (22.5) |
| 253 | Male | Mali | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 254 | Male | Ivory Coast | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 255 | Male | Guinea | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 256 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 257 | Male | Mali | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 258 | Male | Ivory Coast | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 259 | Male | Afgahnistan | <18 | <18 (15.5) | <18 | <18 (15.5) |
| 260 | Male | Sudan | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 261 | Male | Bosnia-Erzegovina | <18 | <18 (14.5) | <18 | <18 (14.5) |
| 262 | Male | Mali | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 263 | Male | Morocco | Absent | Absent | ≥18 | ≥18 (22.5) |
| 264 | Male | Gambia | Absent | Absent | Absent | Absent |
| 265 | Male | Tunisia | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 266 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 267 | Male | Senegal | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 268 | Male | Senegal | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 269 | Male | Gabon | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 270 | Female | Tunisia | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 271 | Female | Mali | <18 | <18 (16.5) | <18 | <18 (16.5) |
| 272 | Male | Senegal | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 273 | Male | Morocco | Absent | Absent | <18 | <18 (17.5) |
| 274 | Male | Senegal | Absent | Absent | ≥18 | ≥18 (18.5) |
| 275 | Male | Senegal | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 276 | Male | Romania | Absent | Absent | Absent | Absent |
| 277 | Male | Mali | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 278 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 279 | Male | Guinea | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 280 | Male | Tunisia | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 281 | Male | Tunisia | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 282 | Male | Tunisia | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 283 | Male | Chad | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 284 | Male | Tunisia | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 285 | Male | Guinea | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 286 | Male | Tunisia | Absent | Absent | Absent | Absent |
| 287 | Male | Algeria | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 288 | Male | Tunisia | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 289 | Male | Mauritania | ≥18 | ≥18 (22.5) | Absent | Absent |
| 290 | Male | Cameroon | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 291 | Male | Guinea | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 292 | Male | Tunisia | ≥18 | ≥18 (19.5) | ≥18 | ≥18 (19.5) |
| 293 | Male | Morocco | ≥18 | ≥18 (21.5) | ≥18 | ≥18 (21.5) |
| 294 | Female | Hungary | <18 | <18 (14.5) | <18 | <18 (14.5) |
| 295 | Male | Senegal | Absent | Absent | ≥18 | ≥18 (21.5) |
| 296 | Male | Ivory Coast | ≥18 | ≥18 (20.5) | ≥18 | ≥18 (20.5) |
| 297 | Male | Tunisia | ≥18 | ≥18 (18.5) | <18 | <18 (17.5) |

**Table 1** (*continued*)

| Case number | Sex | Nationality | Cameriere 38 | AlQahtani 38 | Cameriere 48 | AlQahtani 48 |
|---|---|---|---|---|---|---|
| 298 | Male | Afgahnistan | <18 | <18 (17.5) | <18 | <18 (17.5) |
| 299 | Male | Algeria | ≥18 | ≥18 (22.5) | ≥18 | ≥18 (22.5) |
| 300 | Male | Ivory Coast | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |
| 301 | Male | Gambia | ≥18 | ≥18 (23.5) | ≥18 | ≥18 (23.5) |

In these cases, the latter method should be used in association with the Cameriere one, in order to minimize the risk to define a minor as adult. The present manuscript does not allow to understand which of the two methods correctly defines legal age in the aforementioned 7 cases, because actual chronological ages of the study sample were unknown. However, it is important to note that in 2017 the Council of European Union (Child Right Division) recommended "Authorities to interpret inconclusive results in the applicant's favour, *in dubio pro refugio* or *in dubio pro minore*" [26]. Thus, in such cases the use of both methods allows a proper implementation of the following fundamental principle: the so called benefit of the doubt.

The absence of both 38 and 48 in the same individual was registered in 10/301 cases (3.32%). The latter result shows that age estimation methods that rely on mandibular third molars can be widely useable for age assessment. In addition, the present study shows a high concordance in legal age definition, comparing results obtained evaluating 38 and 48 of the same person. Indeed, except for one individual, in all cases right and left mandibular third molars were characterized by the same developmental stage. Only in one case the operator/observer defined (through both methods) the left mandibular third molar as correspondent to $\geq$ 18 years and the right one as correspondent to < 18 years. These findings are meaningful because they highlight that both methods are applicable to age estimation of people who have only one of mandibular third molars.

Limitations of the present study rely on the lack of actual chronological ages of the study sample; for this reason, bias and inaccuracy could not be calculated [27]. In particular, sensitivity/specificity and positive/negative predictive values of K could not be obtained, because according to the scientific literature neither AlQahtani atlas nor Cameriere third molar index can be identified as "gold-standard" method [26,27]. However, these limitations are consistent with study design that was aimed to apply two dental ageing methods onto migrants without valid identify documents in a real forensic casework.

Further limitations rely on the study population. Indeed, it is well known that age estimation methods are strictly dependent on the underlying structure of datasets used to construct them. Therefore, results of their application in different study populations can be biased because of intrinsic differences between study samples. It is important to note that the London Atlas of Human Tooth Development and Eruption by AlQahtani and colleagues is based on a sample of half Caucasian and half Bangladeshi individuals [14]; whereas the Cameriere index was obtained by way of the study of an entirely Caucasian population [18]. In the present paper, the latter methods were used to analyze a population composed by a significant number of North African and sub-Saharan Africans. It is important to highlight this discrepancy because it can negatively influence study results. In the scientific literature, there are several manuscripts in which authors validate age estimation methods on populations of different geographical areas. For example, the third molar index was used to determine minor/major age of South African samples [28,29], stating that "$I_{3M}$ is a valuable method to distinguish subjects who are around legal adult age in South Africa" [28]. However, even if an increasing number of population studies have been reported [28,29], the scientific literature is far behind the validation of age estimation methods for several populations of different geographical areas. For these reasons, the above-mentioned considerations should be taken into account in order to better understand study results, and to promote the implementation of further researches in this field.

## 5. Conclusions

The study demonstrates that AlQahtani and Cameriere methods are characterized by a high statistical agreement. For this reason, they can be alternately used for legal age assessment. In case of the London Atlas identifies a chronological age of 18.5 years, operators should use both methods in order to minimize the risk to define a minor as adult.

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## Declaration of competing interest

The authors have not conflict of interest to disclose.

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