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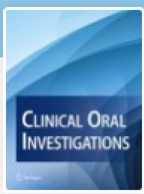

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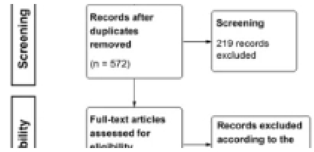

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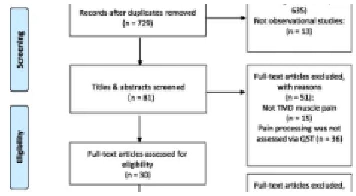

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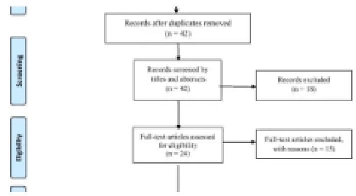

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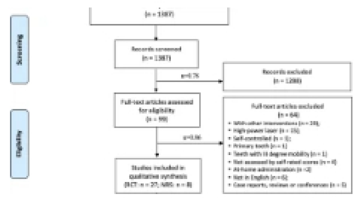

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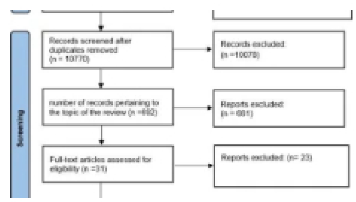

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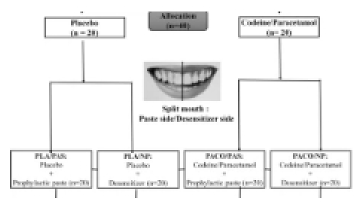

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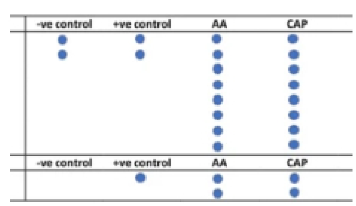

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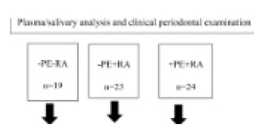

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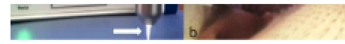

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ORIGINAL ARTICLE

Is third molar development affected by third molar impaction or impaction-related parameters?

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Abstract

Objective To evaluate the effect of third molar impaction and impaction-related parameters on third molar development.

Materials and methods Panoramic radiographs (*N*=3972) from 473 males and 558 females between 3.2 and 23.5 years old were analysed. Three parameters of impaction were examined: hindering contact between third and adjacent second molar, retromolar space availability (only in lower third molars), and angulation between the third and adjacent second molar. From the separate parameters, a definition for impaction was derived. Third molars' development was staged according to a modified Köhler et al. staging technique. A linear model was used to compare within-stage and overall age, as a function of hindering contact, retromolar space, and impaction. Furthermore, a quadratic function was used to study the correlation between age and angulation.

Results Significant differences were found in mean age as a function of hindering contact and retromolar space, depending on third molar location and stage. There was a significant relation between angulation and age, depending on the stage, with all third molars evolving to a more upright position (closer to 0°). Mean ages of subjects with impacted third molars were significantly lower in certain third molar stages, but the differences were clinically small (absolute differences ≤0.65 years). Moreover, after correction for stage differences, no significant differences in age could be demonstrated.

Conclusions The development of impacted and non-impacted third molars can be considered clinically equal in our study population.

Clinical relevance There is no distinction required between impacted and non-impacted third molars for dental age estimation.

Keywords Forensic odontology · Dental age estimation · Third molar · Impaction · Tooth development

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Background

Impacted teeth cannot erupt into their normal functional position [1]. Third molar impaction represents 95% of all teeth impactions [2, 3], with an incidence ranging from 17 to 65%, depending on the examined population [2–6]. A systematic review and meta-analysis reported a worldwide prevalence of third molar impaction equal to 24% (95% confidence interval 19 to 31%) [7]. Moreover, it showed a 58% higher odds of third molar impaction in the mandible than in the maxilla [7]. Furthermore, there is no sex predilection in third molar impaction [2–9].

Although it is not possible to predict third molar impaction, diverse parameters have been described to play a role in it [10–12]. Mostly, those parameters are observed on panoramic radiographs and three of them deserve specific attention. First, contact between the third and second molars was considered as an obstacle for a normal third molar eruption [13, 14]. Second, adequate space between the anterior border of the ramus mandibulae and the distal edge of the adjacent second molar (retromolar space) is required to allow mandibular third molar eruption into the occlusal plane [13, 15–17]. Third, certain angular measurements between the long axes of the third and corresponding second molar were correlated with third molar impaction. Based on the observed angle width, probabilities for third molar eruption were calculated in various conditions [10–12, 18].

There is no consensus about the relation between third molar impaction and development. According to Björk et al., delayed root formation occurred in 3.5% of fully erupted third molars compared to 50% in impacted third molars [15]. However, Friedrich et al. detected irregular root growth in impacted third molars, but no delay or acceleration in tooth development was reported [19]. Because of these contrasting reports and because third molar development is the major dental age predictor in subadults [20, 21], it is important to study the effect of third molar impaction parameters on third molar development. Knowing if impaction or impaction-related parameters affect third molar development will allow establishing adjustment(s) to age estimation outcomes if necessary. Therefore, the aim of the current study was to evaluate how third molar impaction parameters and impaction affect third molar development.

Materials and methods

Study population and staging of development

From 1201 healthy Belgian individuals ranging in age between 3.2 and 23.5 years, 3972 analogue panoramic radiographs were collected. The radiographs were retrospectively selected and anonymized from the patient files of a private orthodontic practice between November 1980 and December 2005. Exclusion criteria were insufficient image quality, developmental abnormalities, and a history of any third molar removal. Longitudinal data were included with a mean number of radiographs per subject of 3.85 (range 1–10). The inclusion criterion was the presence of at least one third molar on the radiograph. All third molars were staged by one observer (RIS) according to a modification of the Köhler et al. staging technique [22]. In particular, one stage was added to the 10-point staging technique: stage 0 for a radiographical onset of the third molar bud until stage 1 (crown half-developed). Furthermore, it was recorded when a third molar was agenetic, which was defined as the absence of a third molar's follicle, while the other third molars were at least in stage 3 or the adjacent second molar was at least in stage 7. All missing third molar scores were excluded from analysis. Informed consent was waived, and ethical clearance was granted by the Research Ethics Committee of KU Leuven.

Impaction parameters

Three third molar impaction parameters were examined. (1) Hindering contact between the third and adjacent second molar (CONTACT) was defined differently for third molars in a status before or after an alveolar eruption. In the former, contact with the third molar's follicle was considered, while in the latter, contact of the third molar crown with any part of the second molar was examined (Fig. 1). When the widest part of the third molar crown had surpassed the widest part of the second molar crown, the contact was considered not hindering. CONTACT was registered as a binary variable (1= hindering contact, 0 = no hindering contact). (2) Retromolar space availability (SPACE) was evaluated according to the method of Olive et al. and consequently only applicable to mandibular third molars [23]. The distance of the retromolar space was compared with the mesio-distal crown width of the corresponding third molar (Fig. 2). When the former was higher than or equal to the latter, 1 was allocated and 0 when smaller. (3) Angulation between the third and the adjacent second molars (ANGLE) was measured as the angle between their long axes (Fig. 3). Angulation was positive for third molars with a mesial inclination and negative for third molars with a distal inclination (Fig. 4).

Impaction

In the studied sample, all fully erupted third molars (upper jaw n=104, lower jaw n=91) had an angulation ranging between −22° and +18° in the upper jaw, and between −17° and +12° in the lower jaw (Table 1). Based on these observations, the assumption was made that third molars with ANGLE values outside these extremes could not fully erupt. Thus, the following third molars were classified as impacted: CONTACT=1

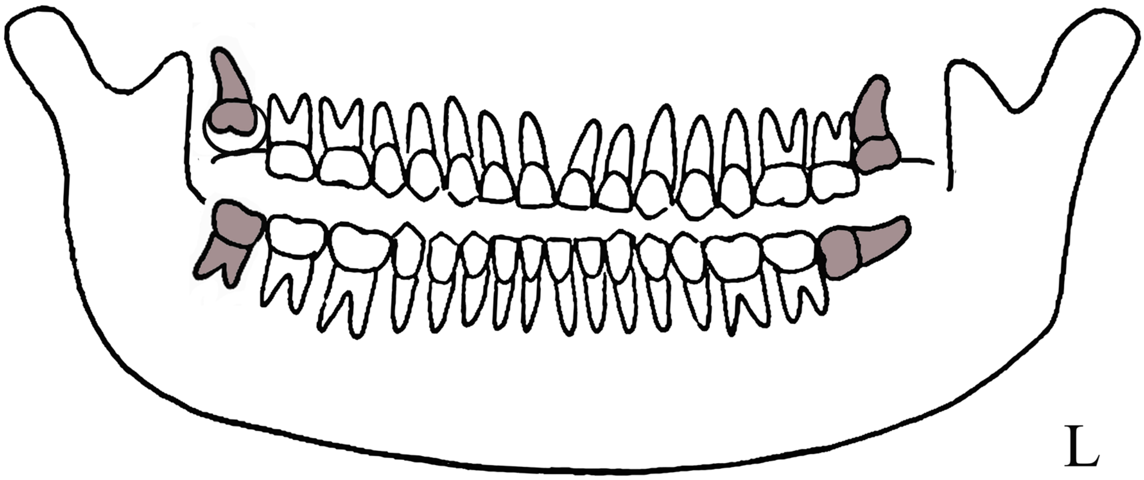

Fig. 1 Schematic illustration of possible contact (CONTACT) situations. In the upper jaw, hindering contact (CONTACT=1) is illustrated before an alveolar eruption. The third molar follicle or part of the third molar is in touch with a part of the second molar and has not surpassed the widest part of the second molar. In the left lower jaw, contact is illustrated after an alveolar eruption. In the right lower jaw, the widest part of the third molar has surpassed the widest part of the second molar. Therefore, it was not considered as a hindering contact (CONTACT=0)

and ANGLE<−22° or ANGLE>+18° for upper third molars, CONTACT=1 and ANGLE<−17° or ANGLE>+12° for lower third molars. The remaining third molars were classified as non-impacted.

Statistical analysis

For each third molar separately, a linear mixed model was used to evaluate the difference in age between impacted and non-impacted teeth. The model contained fixed effects of impaction (yes/no), stage, sex, and the three pairwise first-order interactions. A random intercept was used to take into account the correlation between the longitudinal age measures of the same patient, and the residual variance was allowed to differ between stages (the latter is important since typically, age shows a higher variability for higher Köhler stages). The same type of model was used to compare age as a function of CONTACT, SPACE, and impaction. The difference in age was reported in two ways: (1) the overall difference, corrected for differences in stage, and (2) within-stage differences. For ANGLE, a linear mixed model was used too, with ANGLE, stage, sex, and their interactions as fixed effects. However,

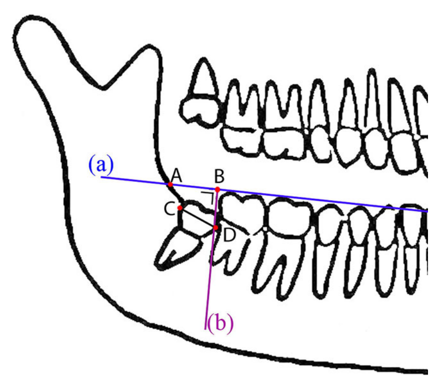

Fig. 2 Schematic illustration of landmarks for retromolar space (SPACE) measurements. The line through the tip of the most superior cusp of the first premolar and the tip of the most superior mesial cusp of the second molar was defined as the occlusal line (a). Next, a line perpendicular to (a) was drawn through the most distal point of the second molar crown (b). The distance between the intersection of (a) and (b), B, and the intersection of (a) and the anterior border of the ramus mandibulae on (a), A, was measured and compared with the maximal mesio-distal third molar distance, C-D. When the distance A-B was equal to or bigger than the distance C-D, 1 was allocated, and 0 when it was smaller

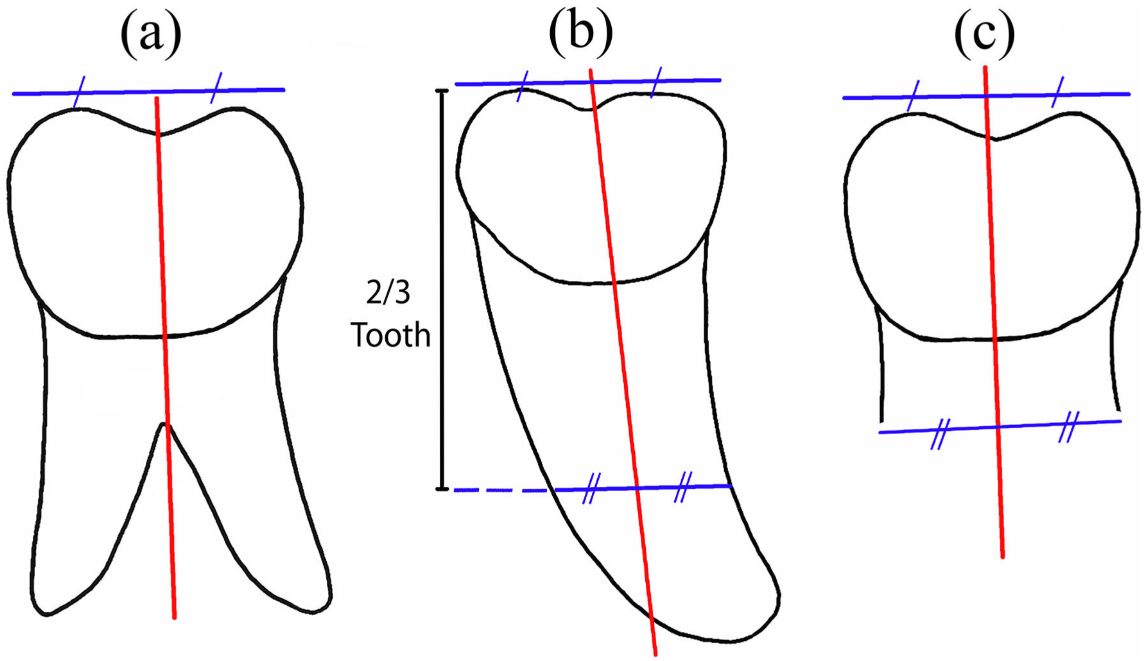

Fig. 3 Schematic illustration of second and third molar long axis determination, allowing to evaluate the angulation (ANGLE) between them. The long axis (red lines) was constructed differently according to the observed tooth morphology or developmental status. In fully developed roots with a bifurcation (**a**), the long axis connected the midpoint of the occlusal surface of the crown and the midpoint of the root bifurcation. In fully developed roots without a bifurcation (**b**), the long axis connected the midpoint of the occlusal surface of the crown and the midpoint of the tooth at two-thirds of its root length. In developing teeth (**c**), the long axis connected the midpoints of the occlusal surface of the crown and the most developed part of the tooth

since ANGLE is a continuous variable, a quadratic function was needed to allow a non-linear relation with age. *P*-values were considered significant if smaller than 0.05. However, for the stage-specific results, a Bonferroni-Holm correction for

Fig. 4 Schematic illustration of positive and negative angulation between third molar and corresponding second molars (ANGLE). At the patient's right side, positive angulation ( ) is illustrated, and at the left side negative angulation (-)

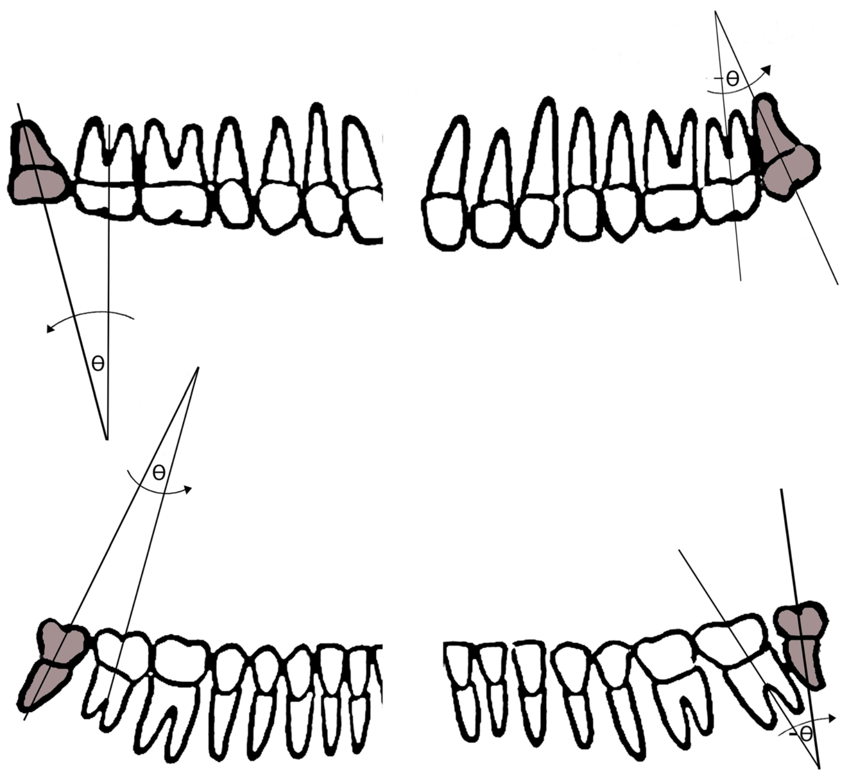

Table 1 Observed angulations between the third and corresponding second molars (ANGLE) of fully erupted third molars

ANGLE (°)	Number of third molars
Upper jaw	
−22	2
−21	1
−20	2
−19	2
−16	2
−15	7
−14	3
−13	13
−12	11
−11	7
−10	11
−9	3
−8	3
−7	3
−4	1
−3	1
0	20
3	1
4	2
5	1
6	1
10	1
11	1
12	1
13	1
17	1
18	2
Lower jaw	
−17	2
−16	1
−15	4
−14	3
−13	2
−12	1
−11	2
−10	1
−9	1
−8	1
−7	4
−5	1
−4	1
−3	2
−2	1
0	6
2	1
3	1
4	1
5	4
6	4
7	6
8	4
9	7
10	18
11	6
12	6

multiple testing was applied per variable-tooth combination. All analyses were performed using SAS software for Windows version 9.4.

Results

Study population

Agenesis of all third molars was present in 141 subjects. The number of third molars in stages 8 and 9 was relatively low, especially within the group with signs of impaction. Since the stage is a categorical variable in the analyses, these few cases would have a large impact on the result for the main effect of impaction. Therefore, subjects were not included in the third molar specific analyses, when this third molar was in stages 8 or 9. Twenty-nine subjects were excluded because all their third molars were in stages 8 or 9. Moreover, subjects with all third molars fully developed (stage 10) were also excluded from the analyses (N=27), since the mean age within the stage is heavily biased by the age range of the study population. Thus, the final study population used for analyses consisted of 1031 subjects (473 males, 558 females) with the same age range as the initial sample (Fig. 5).

Impaction parameters

In the majority of the linear models, the interaction between the considered parameter and sex was not significant. Therefore, no sex-specific results were reported. Figure 6 illustrates the effect of the impaction parameters on the mean age for tooth 38. Depending on sex and third molar location, the percentage of third molars (on all teeth from all subjects) with hindering contact ranged between 72% and 80%. Corrected for differences in stage, the differences in mean age between subjects with third molars having CONTACT or not was small (≤ 0.28 years) and only significant for tooth 38 and 48 (Table 2). In Table 3, the mean age as a function of CONTACT was reported for each developmental stage separately. In most stages, third molars with hindering contact had a younger age compared to third molars without hindering contact, regardless of third molar location. However, in none of the third molars, did the effect of CONTACT depend on stage (all interactions between CONTACT and stage were not significant).

Corrected for differences in stage, there was a small significant difference in mean age as a function of SPACE for tooth 38 (0.25 years) and 48 (0.42 years) (Table 4). The differences depended significantly on stage, which was mostly due to stage 5 (Table 5). Stage-specific age differences were clinically small (≤0.65 years). Stage 0 was not included in this part of the analysis, because in all subjects, the mesio-distal width of the tooth bud in stage 0 was bigger than the retromolar space (SPACE=0). Overall, third molars with sufficient retromolar

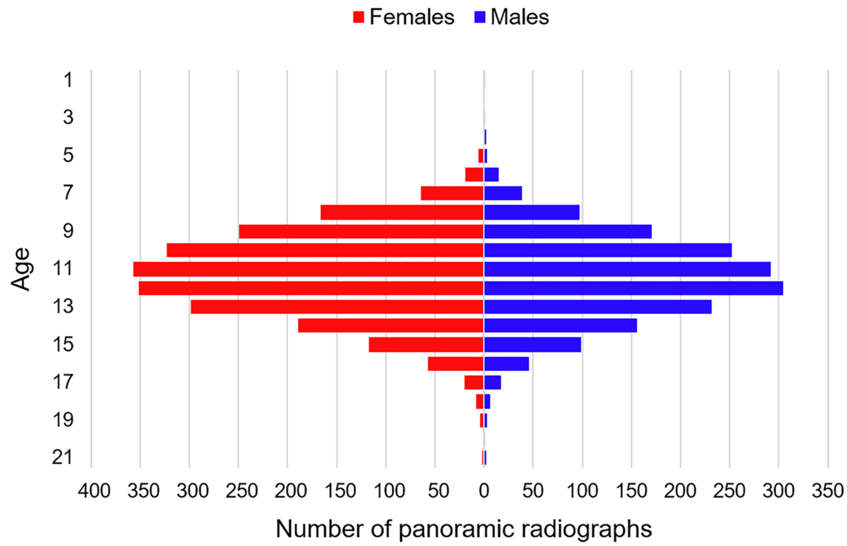

Fig. 5 The number of included subjects per age category of one year (e.g. age 14 corresponds with ages 14.00 to 14.99).

space tended to have a younger age than third molars without sufficient space.

The majority of ANGLE measurements in the upper jaw were in the range between −40° and 10°, and there was a positive relation with age, which was significant for tooth 18. In the lower jaw, the relation with age was significantly negative, and the majority of ANGLE measurements were in the range between 10 and 50°. Both relations reflect the tendency of observing angulation values closer to zero with higher ages (Table 6). For tooth 18 and 28, the relation between ANGLE and age depended significantly on stage (p<0.0001). Mean values for age as a function of ANGLE and stage were given in Table 6.

Impaction

The distribution of impacted and non-impacted third molars was presented in Table 7. Corrected for the differences in stage, the mean age of impacted third molars was lower than in non-impacted third molars. Furthermore, Table 8 shows statistically significant differences in mean age per stage between impacted and non-impacted third molars in stages 4 and 5 (tooth 18), stage 5 (tooth 28), stages 1 and 3 (tooth 38), and stage 1 (tooth 48). Within stages, the difference in mean age between impacted and non-impacted third molars was small (≤0.37 years). Moreover, for upper third molars, the difference was not constant among stages. Within stage, the mean age of the impacted third molars was lower than that of the non-impacted third molars in 91% of the possible settings (4 third molars, 8 analysed stages; Table 9).

Discussion and conclusion

In earlier studies, diverse parameters were examined during third molar development and considered as indicators for third molar impaction. However, the reported probabilities of causing the third molar impaction varied and not one study reported a parameter guaranteeing third molar impaction at dental maturity. Hattab et al. stated that 11% of clinically diagnosed mesial/horizontal impacted third molars changed position and erupted to the occlusal plane [13]. In a second study, the same author detected that almost half (42%) of the third molars

Table 2 Differences in mean age between third molars with and without hindering contact (CONTACT). These results were corrected for differences in stage. Numbers 18, 28, 38, and 48 represent FDI tooth location numbering. Data between parentheses represent the lower and upper bounds of 95% confidence intervals

Tooth	No contact (CONTACT=0)		Contact (CONTACT=1)		Difference in mean age	p-value
	N	Mean age (year)	N	Mean age (year)		
18	470	13.25 (13.10; 13.39)	3122	13.14 (13.03; 13.26)	0.11	0.052
28	501	13.21 (13.06; 13.35)	3136	13.16 (13.05; 13.27)	0.05	0.419
38	221	13.55 (13.31; 13.79)	1086	13.27 (13.10; 13.43)	0.28	0.008
48	473	13.57 (13.43; 13.71)	2240	13.42 (13.30; 13.54)	0.15	0.031

Table 3 Stage and third molar location-specific differences in mean age between third molars with and without hindering contact (CONTACT) (visualized in Fig. 6 for tooth 38). Numbers 18, 28, 38, and 48 represent FDI tooth location numbering. Data between parentheses represent the lower and upper bounds of 95% confidence intervals. *Significant after Bonferroni-Holm correction

Tooth	Stage	No contact (CONTACT=0)		Contact (CONTACT=1)		Difference in mean age (year)	*p*-value
		N	Mean age (year)	*N*	Mean age (year)		
18	0	16	9.68 (9.37; 9.99)	135	9.68 (9.54; 9.82)	0	0.990
	1	26	10.52 (10.27; 10.76)	198	10.48 (10.36; 10.61)	0.04	0.772
	2	26	11.57 (11.31; 11.84)	348	11.37 (11.25; 11.49)	0.20	0.102
	3	16	12.36 (12.07; 12.65)	301	12.13 (12.01; 12.25)	0.23	0.109
	4	55	13.15 (12.93; 13.37)	591	12.95 (12.83; 13.07)	0.20	0.059
	5	150	14.93 (14.72; 15.13)	1157	14.63 (14.51; 14.75)	0.30	0.002*
	6	53	16.34 (16.08; 16.60)	209	16.35 (16.20; 16.51)	−0.01	0.917
	7	38	17.42 (17.10; 17.75)	115	17.55 (17.34; 17.77)	−0.13	0.479
28	0	19	9.90 (9.58; 10.21)	136	9.73 (9.58; 9.88)	0.17	0.299
	1	23	10.50 (10.26; 10.74)	203	10.56 (10.44; 10.69)	−0.06	0.564
	2	36	11.40 (11.17; 11.63)	344	11.39 (11.27; 11.51)	0.01	0.925
	3	22	12.21 (11.94; 12.47)	246	12.10 (11.98; 12.23)	0.11	0.419
	4	60	13.15 (12.93; 13.37)	625	12.96 (12.84; 13.08)	0.19	0.068
	5	167	14.70 (14.50; 14.89)	1190	14.62 (14.50; 14.74)	0.08	0.411
	6	51	16.39 (16.12; 16.67)	220	16.39 (16.23; 16.55)	0	0.993
	7	41	17.41 (17.09; 17.73)	110	17.54 (17.33; 17.76)	−0.13	0.463
38	0	6	10.05 (9.35; 10.75)	75	9.64 (9.38; 9.89)	0.41	0.253
	1	19	11.10 (10.64; 11.56)	92	10.49 (10.27; 10.72)	0.61	0.011
	2	20	11.91 (11.47; 12.34)	76	11.71 (11.48; 11.95)	0.20	0.376
	3	8	12.78 (12.20; 13.35)	63	12.19 (11.97; 12.42)	0.59	0.047
	4	32	13.32 (12.98; 13.66)	225	13.15 (12.96; 13.33)	0.17	0.303
	5	47	15.07 (14.76; 15.38)	394	14.79 (14.61; 14.96)	0.28	0.060
	6	19	16.50 (16.11; 16.89)	91	16.37 (16.15; 16.58)	0.27	0.512
	7	20	17.68 (17.16; 18.19)	45	17.79 (17.42; 18.15)	−0.11	0.710
48	0	31	10.09 (9.76; 10.43)	240	9.78 (9.63; 9.93)	0.31	0.031
	1	34	11.02 (10.72; 11.32)	153	10.74 (10.58; 10.90)	0.28	0.061
	2	43	11.76 (11.52; 12.00)	175	11.77 (11.62; 11.92)	−0.01	0.071
	3	31	12.73 (12.40; 13.06)	143	12.51 (12.36; 12.66)	0.22	0.926
	4	66	13.51 (13.27; 13.75)	436	13.39 (13.26; 13.53)	0.12	0.197
	5	117	15.00 (14.78; 15.23)	828	15.01 (14.88; 15.14)	−0.01	0.331
	6	33	16.68 (16.38; 16.97)	136	16.59 (16.42; 16.76)	0.09	0.939
	7	28	17.79 (17.40; 18.17)	73	17.66 (17.40; 17.92)	0.13	0.584

initially diagnosed as un-erupted or partially erupted, erupted to full occlusion in a 4-year period due to changes in the third molar position [24]. Similarly, based on a 12-year follow-up study, Venta et al. concluded that during maturation, third molars showed considerable changes in position until the chronological age of 32 years [17]. Haavikko et al. found that the probability of a third molar to erupt was one in three if its angle with the adjacent second molar was between 20 and 30° [10]. Björk et al. reported that the formation of the retromolar space altered during the vertical and sagittal condylar growth

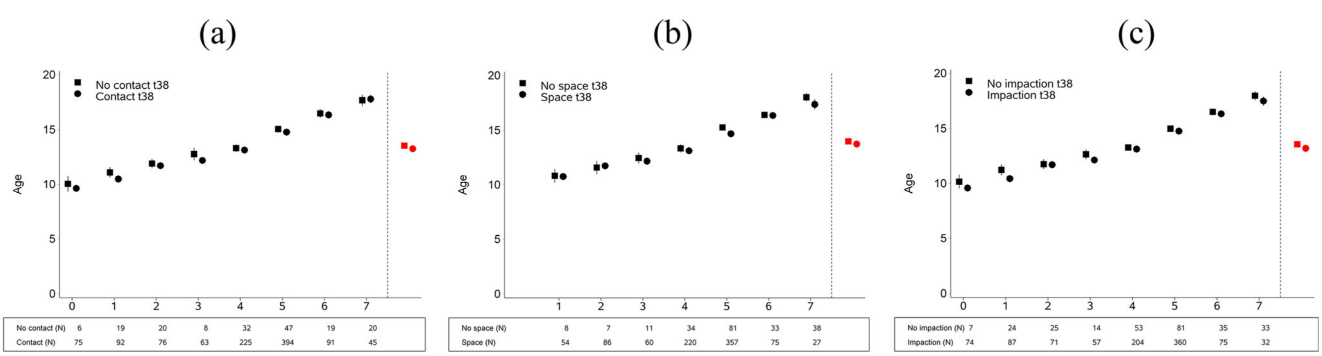

Fig. 6 Mean age and its 95% confidence interval, per stage for tooth 38 with and without the studied characteristics. The mean age, corrected for differences in stage, is shown in red on the right of each graph. *N* represents the number of third molars. Age is expressed in years. **a** Hindering contact. **b** Retromolar space availability. **c** Impaction

Table 4 Differences in mean age between lower third molars with and without retromolar space availability (SPACE). These results were corrected for differences in stage. Numbers 38 and 48 represent FDI tooth location numbering. Data between parentheses represent the lower and upper bounds of 95% confidence intervals

Tooth	No space (SPACE=0)		Space (SPACE=1)		Difference in mean age (year)	*p*-value
	N	Mean age (year)	*N*	Mean age (year)		
38	261	14.00 (13.75; 14.25)	911	13.75 (13.58; 13.93)	0.25	0.036
48	397	14.26 (14.07; 14.45)	1976	13.84 (13.72; 13.97)	0.42	<.001

of the mandible between the ages of 12 and 20 years [15]. In a 7- to 10-year observational study, Richardson et al. detected that the presence of sufficient retromolar space in the early stages of third molar development was not a certainty for that third molar to erupt [25].

Because of the different reported parameter changes in third molar development and the uncertainties in impaction prediction, in the current study, a combination of parameters was considered to classify developing impacted and non-impacted third molars. The range of ANGLE in all fully erupted third molars in the study sample was considered as impaction thresholds for all developing third molars with a hindering contact (Table 1). SPACE was not included in the established standard for impacted third molars because of its high dependence on the growth of the surrounding bony structures [15]. Similar to our findings, other authors did not report sex differences in the prevalence of third molar impaction [2–6, 8, 9].

Most third molars in the current study had CONTACT with the adjacent second molar. This was in agreement with Jung et al. They reported that most third molars are in contact with the crown and/or the root of the adjacent second molar, regardless of their eruption level [14]. In addition, the current study revealed that the differences of mean age between subjects with and without CONTACT were clinically small (≤ 0.61 years) and in most stages subjects with CONTACT had a younger age compared to subjects without. Consequently, the presence of a hindering contact has a low impact on third molar development and does not seem to slow down their development.

The mean age of subjects with lower third molars with sufficient retromolar space was significantly younger than those without. However, the maximal observed difference was clinically small (0.25 years for 38, and 0.42 year for 48), which implies that the lack of SPACE did not substantially slow down third molar development. Conversely, Marchiori et al. detected a delay of one developmental stage (using 6 modified Demirjian et al. stages) in lower third molars without SPACE, compared to third molars with SPACE. Note that the results of the Marchiori et al. study cannot fairly

Table 5 Stage-specific differences in mean age between lower third molars (38/48) with and without retromolar space availability (SPACE). Numbers 38 and 48 represent FDI tooth location numbering. Data between parentheses represent the lower and upper bounds of 95% confidence intervals. *Significant after Bonferroni-Holm correction

Tooth	Stage	No space (SPACE=0)		Space (SPACE=1)		Difference in mean age (year)	*p*-value
		N	Mean age(year)	*N*	Mean age (year)		
38	1	54	10.84 (10.22; 11.45)	8	10.77 (10.49; 11.04)	0.07	0.825
	2	86	11.59 (10.98; 12.21)	7	11.75 (11.50; 12.00)	−0.16	0.628
	3	60	12.47 (11.97; 12.96)	11	12.18 (11.93; 12.43)	0.29	0.278
	4	220	13.35 (12.98; 13.72)	34	13.13 (12.94; 13.32)	0.22	0.233
	5	357	15.28 (15.01; 15.55)	81	14.69 (14.51; 14.87)	0.59	<.001*
	6	75	16.43 (16.13; 16.72)	33	16.37 (16.14; 16.60)	−0.03	0.734
	7	27	18.02 (17.64; 18.40)	38	17.37 (16.92; 17.83)	0.65	0.022
48	1	102	11.18 (10.69; 11.67)	12	10.82 (10.64; 11.00)	0.36	0.163
	2	194	12.01 (11.61; 12.40)	14	11.63 (11.48; 11.78)	0.38	0.058
	3	160	12.90 (12.53; 13.28)	12	12.37 (12.22; 12.52)	0.53	0.005*
	4	446	13.77 (13.51; 14.03)	54	13.26 (13.13; 13.40)	0.51	<.001*
	5	815	15.32 (15.10; 15.55)	127	14.85 (14.72; 14.99)	0.47	<.001*
	6	123	16.80 (16.55; 17.06)	45	16.45 (16.28; 16.63)	0.35	0.010*
	7	50	17.82 (17.52; 18.12)	50	17.51 (17.21; 17.81)	0.31	0.123

Table 6 Stage and third molar location-specific predicted mean age for a selection of angulation (ANGLE) values. The selected values are restricted to the range encountered in the study population per location. Note that the third molars tend to reach a more vertical position (closer to ANGLE = 0) with increasing age. Numbers 18, 28, 38, and 48 represent FDI tooth location numbering

ANGLE (°)	Stage	Predicted mean age (year)								Stage	Predicted mean age (year)							
		18		28		38		48			18		28		38		48	
		M	F	M	F	M	F	M	F		M	F	M	F	M	F	M	F
−40	0	9.66	9.73	9.73	9.81	-	-	-	-	4	12.89	12.82	12.91	12.92	-	-	-	-
−20		9.59	9.68	9.70	9.65	-	-	-	-		12.95	12.91	13.02	12.91	-	-	-	-
0		9.78	9.66	9.85	9.74	-	-	-	-		13.21	12.96	13.11	12.93	-	-	-	-
10		9.96	9.66	10.00	9.87	10.15	10.18	10.06	9.83		13.41	12.98	13.14	12.95	13.46	13.46	13.69	13.58
20		-	-	-	-	9.99	9.97	9.89	9.70		-	-	-	-	13.40	13.36	13.54	13.47
30		-	-	-	-	9.81	9.79	9.84	9.66		-	-	-	-	13.22	13.18	13.40	13.34
50		-	-	-	-	9.39	9.49	10.11	9.84		-	-	-	-	12.48	12.56	13.18	13.02
−40	1	10.55	10.59	10.56	10.55	-	-	-	-	5	14.38	14.44	14.23	14.35	-	-	-	-
−20		10.38	10.45	10.63	10.49	-	-	-	-		14.50	14.58	14.55	14.55	-	-	-	-
0		10.50	10.37	10.65	10.44	-	-	-	-		14.86	14.74	14.83	14.76	-	-	-	-
10		10.67	10.35	10.64	10.42	11.08	10.96	11.12	11.01		15.13	14.82	14.95	14.87	14.91	15.02	15.12	15.14
20		-	-	-	-	10.86	10.70	10.90	10.83		-	-	-	-	14.89	14.97	15.05	15.11
30		-	-	-	-	10.66	10.50	10.78	10.72		-	-	-	-	14.76	14.84	14.93	15.00
50		-	-	-	-	10.35	10.31	10.81	10.66		-	-	-	-	14.13	14.32	14.53	14.51
−40	2	11.45	11.32	11.44	11.30	-	-	-	-	6	16.24	16.55	16.07	16.48	-	-	-	-
−20		11.41	11.31	11.51	11.25	-	-	-	-		16.20	16.53	16.15	16.43	-	-	-	-
0		11.52	11.21	11.54	11.21	-	-	-	-		16.27	16.40	16.29	16.51	-	-	-	-
10		11.63	11.13	11.54	11.20	12.18	12.09	12.09	11.93		16.35	16.29	16.38	16.59	16.43	16.54	16.51	16.80
20		-	-	-	-	12.12	12.00	11.96	11.85		-	-	-	-	16.39	16.46	16.49	16.82
30		-	-	-	-	11.95	11.83	11.85	11.74		-	-	-	-	16.28	16.35	16.40	16.74
50		-	-	-	-	11.27	11.27	11.65	11.46		-	-	-	-	15.85	16.04	16.05	16.30
−40	3	12.13	12.00	12.02	12.00	-	-	-	-	7	15.81	15.91	17.00	17.25	-	-	-	-
−20		12.18	12.07	12.20	12.05	-	-	-	-		17.01	17.13	17.36	17.48	-	-	-	-
0		12.38	12.07	12.26	12.05	-	-	-	-		17.67	17.59	17.51	17.57	-	-	-	-
10		12.55	12.05	12.25	12.02	12.56	12.69	12.78	12.57		17.80	17.53	17.52	17.57	17.82	17.59	17.87	17.70
20		-	-	-	-	12.44	12.53	12.71	12.54		-	-	-	-	17.56	17.28	17.72	17.59
30		-	-	-	-	12.23	12.32	12.63	12.46		-	-	-	-	17.78	17.50	17.61	17.49
50		-	-	-	-	11.55	11.75	12.41	12.15		-	-	-	-	19.65	19.49	17.53	17.31

be compared with current study results, since their subjects were in the age range between 17 and 24 years [26]. Thus, in contrast to the current study, only late third molar development was considered. Moreover, their definition of SPACE

Table 7 Distribution of impacted and non-impacted third molars, sex, and third molar location-specific. Numbers 18, 28, 38, and 48 represent FDI tooth location numbering

Tooth	Male Non-impacted	Impacted	Female Non-impacted	Impacted	Total
18	982 (65%)	530 (35%)	1279 (65%)	703 (35%)	3494
28	1040 (68%)	493 (32%)	1332 (67%)	671 (33%)	3536
38	227 (21%)	871 (79%)	399 (26%)	1126 (74%)	2623
48	210 (19%)	901 (81%)	432 (27%)	1156 (73%)	2699
Total	2459	2795	3442	3656	12352

Table 8 Difference in mean age between impacted and non-impacted third molars. These results were corrected for differences in stage. Numbers 18, 28, 38, and 48 represent FDI tooth location numbering. Data between parentheses represent the lower and upper bounds of 95% confidence intervals

Tooth	Non-impacted		Impacted		Difference in mean age(year)	*p*-value
	N	Mean age(year)	*N*	Mean age(year)		
18	2366	13.03 (12.86; 13.19)	1226	13.17 (13.06; 13.29)	−0.14	0.035
28	2469	13.09 (12.95; 13.23)	1168	13.18 (13.07; 13.30)	−0.09	0.082
38	337	13.21 (13.04; 13.37)	970	13.58 (13.36; 13.79)	−0.37	<.001
48	707	13.42 (13.30; 13.54)	2004	13.57 (13.43; 13.71)	−0.15	0.009

Table 9 Difference in mean age in a stage between impacted and non-impacted third molars. Numbers 18, 28, 38, and 48 represent FDI tooth location numbering. Data between parentheses represent the lower and upper bounds of 95% confidence intervals. *Significant after Bonferroni-Holm correction

	Stage	Non-impacted		Impacted		Difference in mean age (year)	*p*-value
Tooth		*N*	Mean age (year)	*N*	Mean age (year)		
18	0	89	9.73 (9.57;9.89)	62	9.60 (9.42;9.78)	0.13	0.169
	1	132	10.43 (10.30;10.57)	92	10.53 (10.39;10.68)	−0.10	0.129
	2	196	11.39 (11.25;11.53)	178	11.34 (11.20;11.48)	0.05	0.428
	3	158	12.17 (12.04;12.31)	159	12.09 (11.96;12.23)	0.08	0.194
	4	351	13.03 (12.90;13.16)	295	12.89 (12.75;13.02)	0.14	0.012
	5	910	14.75 (14.62;14.87)	397	14.48 (14.33;14.63)	0.27	<.001*
	6	232	16.33 (16.18;16.48)	30	16.55 (16.22;16.89)	−0.22	0.197
	7	148	17.55 (17.36;17.74)	5	16.73 (15.81;17.65)	0.82	0.085
28	0	87	9.73 (9.56; 9.90)	68	9.76 (9.57; 9.94)	−0.03	0.759
	1	135	10.56 (10.42; 10.70)	91	10.55 (10.39; 10.70)	0.01	0.887
	2	234	11.40 (11.27; 11.53)	146	11.35 (11.20; 11.50)	0.05	0.444
	3	154	12.15 (12.01; 12.29)	114	12.06 (11.91; 12.21)	0.09	0.201
	4	398	12.99 (12.86; 13.12)	287	12.96 (12.82; 13.09)	0.03	0.628
	5	958	14.73 (14.61; 14.86)	399	14.38 (14.23; 14.53)	0.35	<.001*
	6	229	16.41 (16.25; 16.57)	42	16.27 (15.94; 16.61)	0.14	0.432
	7	139	17.51 (17.31; 17.71)	12	17.41 (16.81; 18.00)	0.10	0.733
38	0	7	10.17 (9.54; 10.80)	74	9.59 (9.33; 9.85)	0.58	0.086
	1	24	11.24 (10.75; 11.74)	87	10.45 (10.22; 10.67)	0.79	0.002*
	2	25	11.76 (11.31; 12.21)	71	11.71 (11.47; 11.95)	0.05	0.838
	3	14	12.66 (12.22; 13.09)	57	12.14 (11.91; 12.37)	0.52	0.023
	4	53	13.28 (12.99; 13.57)	204	13.14 (12.95; 13.33)	0.14	0.325
	5	81	15.00 (14.74; 15.26)	360	14.78 (14.60; 14.95)	0.22	0.067
	6	35	16.52 (16.21; 16.84)	75	16.35 (16.12; 16.57)	0.17	0.298
	7	33	17.97 (17.57; 18.37)	32	17.48 (17.08; 17.89)	0.49	0.066
48	0	34	10.07 (9.77; 10.38)	237	9.78 (9.62; 9.93)	0.29	0.053
	1	39	11.03 (10.75; 11.30)	148	10.72 (10.56; 10.88)	0.31	0.033
	2	45	11.78 (11.54; 12.01)	173	11.76 (11.62; 11.91)	0.02	0.907
	3	43	12.67 (12.41; 12.93)	131	12.50 (12.35; 12.65)	0.47	0.206
	4	116	13.53 (13.33; 13.72)	386	13.37 (13.24; 13.50)	0.16	0.090
	5	207	15.04 (14.85; 15.22)	736	15.00 (14.87; 15.13)	0.04	0.660
	6	57	16.71 (16.47; 16.94)	112	16.57 (16.39; 16.74)	0.14	0.268
	7	45	17.74 (17.42; 18.06)	56	17.67 (17.38; 17.96)	0.07	0.746

was based on cone-beam computed tomography measurements, as opposed to panoramic radiographs in the current study.

A negative relation between age and ANGLE was observed in the lower third molars due to their predominant mesial inclination. The opposite was observed in the upper third molars, which mostly had a distal inclination. Similarly, Hattab et al. observed a trend of third molars evolving from a more tilted to a more upright position (ANGLE=0°) during their development, and an increasing chance to erupt [24]. This was in agreement with the current results, which revealed ANGLE values closer to 0° with increased age, in the upper and lower jaw.

Within stages, most of the subjects with (an) impacted third molar(s) had a younger mean age than those with (a) non-impacted third molar(s), implicating a slightly advanced or similar third molar development. Conversely, Björk et al. reported a relation between impaction and retarded maturation of the mandibular third molars. Their findings were based on similar results detected in a cohort study of individuals examined at the age of 12 and 20 years old, and in a sample of individuals in the age range between 19 and 30 years old. When compared with the current study outcomes, these contrasting results might be due to the Björk et al study mainly considering late third molar development. By contrast, the apical closure stages (late third molar stages 8, 9, and 10) were not considered in the current study. Also, the initial third molar stage 0.5 was included and was even detected in a subject at the extreme age of 3.2 years. Moreover, Björk et al. highlighted in detail that indeed the age of the examined persons and thus their tooth developmental status, together with how impaction is defined and the dental condition as a whole, are principal issues to be taken into account when third molar impaction-related parameters and impaction are studied and compared [15].

In other studies, only specific periods of third molar development and consequently, only the related stages were examined [10, 13, 14, 16]. Moreover, different staging techniques were applied, while fair comparisons between studies can only be established when equal staging techniques were applied and when corresponding stages were considered.

The current results need to be interpreted with caution because specific dental treatment affects the impaction of third molars. In particular, orthodontic treatment whether or not combined with tooth extraction has an effect on third molar impaction parameters and the third molar impaction status [27–31]. Because the analyzed sample was collected in an orthodontic practice including panoramic radiographs of patients at intake and during treatment, the study results cannot be generalized for forensic age estimation practice. Furthermore, analyses were restricted to third molars in a stage lower than or equal to 7, meaning that the final third molar maturation stages (8, 9, 10) were not studied. In those stages, the root length is fully developed, and the apical root end grows from parallel walls to a closed apex. However, it can be expected that these developmental changes have a low impact on the third molar position and thus on its impaction-related parameters or impaction status.

Taking these limitations into account, the study revealed no clinically relevant differences in mean age per stage between subjects with or without CONTACT, SPACE, or impacted third molars. Moreover, impacted third molars mainly had younger ages than non-impacted third molars. This suggests that impacted third molars have equal or in fact, a slightly advanced tooth development compared to non-impacted third molars. The consequence for forensic age estimation practice is that no adjustments of age estimation methods based on third molar(s) development are necessary when the age prediction is based on (a) developing impacted third molar(s).

In conclusion, hindering contact (CONTACT) and retromolar space availability (SPACE) had no clinically relevant influence on third molar development in our study population. In the upper and lower jaw, angulation values (ANGLE) were approaching an upright position (0°) with increased age. Although there were significant differences in mean age between subjects with impacted and non-impacted third molars, all within-stage differences were clinically small. At each third molar location and in each stage, most of the subjects with impacted third molar had a younger age than those without. Although some study limitations need to be taken into account, there was no evidence that a distinction should be made between impacted and non-impacted developing third molars for age estimation.

Author contribution Conception and design of the study was performed by Rosalina Intan Saputri, Jannick De Tobel, and Patrick Thevissen. Data acquisition was performed by Rosalina Intan Saputri, Martine Van Vlierberghe, and Patrick Thevissen. Data analysis and interpretation were performed by Rosalina Intan Saputri, Jannick De Tobel, Steffen Fieuws, and Patrick Thevissen. The first draft of the manuscript was written by Rosalina Intan Saputri and Jannick De Tobel. The manuscript was revised by Rosalina Intan Saputri, Jannick De Tobel, Myrthel Vranckx, Anna Ockerman, Martine Van Vlierberghe, Steffen Fieuws, and Patrick Thevissen. All authors read and approved the final manuscript.

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Declarations

Ethical approval The study was conducted in full accordance with the World Medical Association Declaration of Helsinki and approved by the KU Leuven ethics committee (Date: 14 November 2017).

Informed consent For this type of study, formal consent is not required.

Conflict of interest The authors declare no competing interests.

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