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Proposal for a grading system to determine the clinical status and sequence of permanent teeth eruption: A pilot study

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ABSTRACT

Objectives: The objective of the study was to propose and test a new grading system to quantify the clinical eruption of teeth into the oral cavity. In addition, the study also aimed to apply the grading system to a sample population to determine the chronology and sequence of permanent tooth eruptions, comparing the results with an existing standard table.

Methods: A cross-sectional study was designed, and 1220 children aged 5–18 years were selected from five schools in Chennai. The clinical status of permanent tooth eruption was graded using the newly proposed system. The sequence and chronology of permanent tooth eruptions were determined using Probit analysis and compared with those established by Logan and Kronfeld. The difference in stages of eruption between the sexes was analyzed using the ANOVA test.

Results: The study sample included 515 boys and 705 girls. A total of 23,218 permanent maxillary and mandibular teeth were examined and graded. Of the 11,085 maxillary teeth, 367 were classified as grade 1, 660 as grade 2, and 10,058 as grade 3. Similarly, of the 12,133 mandibular teeth, 497 were grade 1, 793 were grade 2, and 10,843 were grade 3. The eruption of the maxillary canines, second molars, and mandibular second premolars was observed to have occurred earlier than in the traditional table of tooth eruption. The most significant differences in the stages of eruption between the sexes were observed in the 9–12 age group.

Conclusions: The newly proposed grading system was found to be simple, objective, less confusing, and more robust, compared with the existing systems in determining the clinical status of tooth eruptions. The ages of eruption of maxillary canines, second molars, and mandibular second premolars were earlier.

1. Introduction

Tooth eruption is an orderly, sequential, and age-specific biological process by which a developing tooth emerges through the jaw and overlying mucosa to enter the oral cavity and contact the tooth of the opposing arch.[1] Although external factors exert minimal influence over primary teeth, marked variations in the eruption time and sequence of permanent teeth exist among different world populations.[2] General factors (genetic background, sex, ethnic origin, socioeconomic class, nutrition, growth, and hormonal variation) and local factors (cysts, malformations, trauma, and extraction of primary antecedents) influence the eruption age.[3] The timing and sequence of tooth eruption provide an important foundation for understanding the biology and culture of different generations. Knowledge of the timing of tooth eruption is clinically significant for general and dental health planning for children.[4]

A permanent tooth may take 2–4 years to move through the alveolar bone and into occlusion.[5] The most rapid progress occurs just after breaking through the oral mucosa when its root is approximately two-thirds developed.[5] Clinical examination helps analyze tooth

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eruption, whereas radiographic and histological evidence aids in understanding tooth formation and development. However, there is no exact method to clinically determine the developmental stage of permanent teeth.[6] For clinical and research purposes, a tooth is considered to erupt when one of its cusps or incisal edges penetrates the oral mucosa.[7] The World Health Organization (WHO) criteria state that a tooth is considered to have erupted if the tip of the WHO probe touches any part of its enamel.[8] These criteria provide very little information regarding the timing of the later eruption stages. Carvalho,[9] Pahkala,[10] and Eskeli[11] classified eruptions into different grades based on their clinical visibility. All grading systems proposed wide ranges between grades of eruption, whereas Carvalho and Pahkala graded eruptions only for the posterior teeth. However, discrepancies in the grading were observed because the continuous eruption process was divided into discrete phases. Overall, the possible limitations in the existing grading systems include the potential subjective bias, complexity in scoring, and the ability to address only specific (anterior/posterior) teeth.

The need for accurate chronological division of the tooth-eruption process to help dentists in clinical practice has motivated researchers to observe tooth development from the pre-functional eruptive phase to the antagonist tooth-contact phase. A structured adaptable system that addresses both the anterior and posterior teeth, reduces subjectivity, and serves as a quality improvement tool for clinical and research purposes is an essential need. Therefore, this study aimed to facilitate a precise, systematic grading system that addresses the limitations of existing systems. We also aimed to apply this new grading system to a sample population to assess the chronology and sequence of permanent tooth eruptions, comparing the findings with those found in a standard reference table.

2. Methods

2.1. Ethical approval and informed consent

Ethical approval for this cross-sectional study was obtained from the Institutional Ethics Committee **(REF: IEC-NI/19/FEB/68/02)**. Before scheduling the examination day, permission was obtained from the heads of selected schools Active parental consent was obtained through the school principals via the parent-communication channel. Parents notified the schools if they did not wish their child to be enrolled in the study. The children were informed briefly about the procedure involved and examinations were carried out after their verbal assent.

2.2. Subject selection and study setting

The target population was selected based on their regional locations within the city (North/Central/South zones), their age group(5–18 years), and their gender(males/females) by a multistage random sampling method. Five schools in Chennai were selected randomly from the three zones (North-1, Central-3, South-1) based on convenience. Males and females from each age group were selected by a simple random sampling method. Based on the average age of eruption of the first permanent tooth (approximately 6 years) and the last permanent tooth (approximately 17 years); the age range limits were set as 5–18 years to accommodate any eruption-based variations.

2.3. Sample size

The sample size was calculated based on a study by Lakshmappa et al.[12] Based on a 95 % confidence interval, a relative precision value varying between 10 and 20 %, and the least prevalence of eruption (i.e., 2 %) among different ages, the total sample size for this pilot study was calculated to be 1220. To meet the sample size requirements, boys and girls were selected from each age group in equal proportions. Children were categorized into Groups I (5–8 years), II (9–12 years), and III (13–18 years) based on convenience.

2.4. Inclusion/exclusion criteria

Children aged 5–18 years studying in any Chennai-based school were included. Children with recognized syndromes, systemic illnesses, a history of premature extraction of primary teeth or trauma to primary teeth, and those undergoing orthodontic treatment were excluded.

2.5. Grading system

We proposed a new simple method for classifying tooth eruption, based on a clinical assessment-dependent visual approach (Fig. 1). According to the new grading system for clinical tooth eruption (based on tooth division into thirds), teeth eruption in the oral cavity can be recorded as follows.

- ➢ Grade 0: Not visible in the oral cavity
- ➢ Grade 1: Up to the incisal (anterior)/occlusal (posterior) third of the tooth surface is exposed (<3 mm).
- ➢ Grade 2: Up to middle third of the tooth surface is exposed (3–6 mm)
- ➢ Grade 3: Up to the cervical third of the tooth surface is exposed (>6 mm)

2.6. Calibration

The system was calibrated to ensure accuracy, reliability, and compliance with the standards. Ten pairs of maxillary and mandibular mixed-age (9–12 years) dental stone casts, approved by a subject expert, were used for calibration. Each model pair was assigned an identification number to ensure that the examiners were blind to the calibration process. To evaluate intra-examiner consistency, 20 dental stone casts were recorded twice using the proposed grading system for tooth eruption with an interval of 14 days. A kappa value of 0.891 was obtained, signifying a near-perfect agreement.

2.7. Demographic data collection

Approximately 245 children from Classes I to XII were randomly selected from each school. Specially designed data sheets were assigned to each child; three trained dentists recorded basic demographic details, such as name, age, date of birth, and sex. The ages of children were recorded as the age at their last birthday[8] and confirmed using school records.

2.8. Clinical oral examination

Routine dental examinations were performed by a single examiner using adequate natural illumination, a mouth mirror, and a Marquis color-coded probe to determine the tooth eruption status. The Marquis color-coded probe is a first-generation probe with a straight or curved design and a slim tip. Calibrations were performed with 3-mm sections. The probe tip was placed parallel to the long axis of the tooth, and it measured from the gingival sulcus to the highest point of the crown. A new eruption-grading system was adopted for the study population. Each tooth was systematically scored based on eruption grade; the score was recorded by trained dentists in the datasheet of the individual.

2.9. Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences (version 25 for Windows). The eruption status was categorized as “unerupted” for grade 0 and “erupted” for grades 1, 2, and 3. Based on this, a probit regression analysis was used to determine the mean age at eruption for each tooth. The probit regression graphs were plotted by taking age along the X axis and the probability values along the Y axis. The probabilities of eruption values for each age for each tooth were computed. The age which corresponds to 0.5 probabilities was taken as

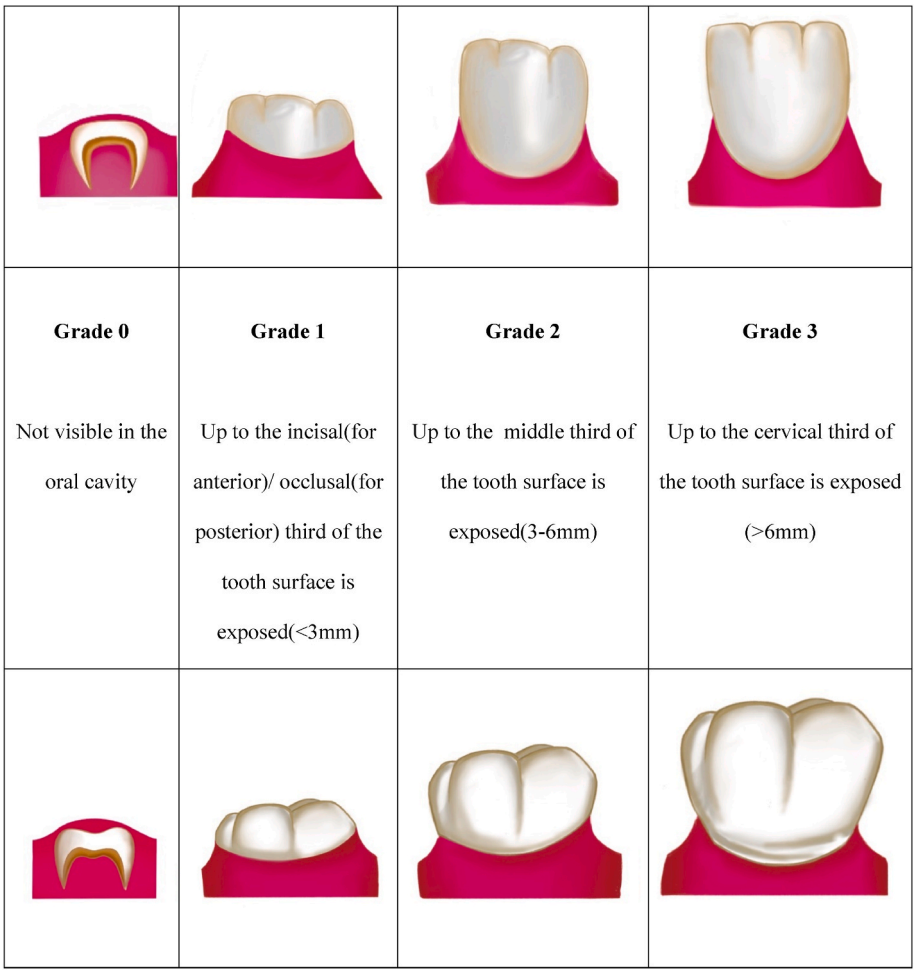

Fig. 1. Diagrammatic representation of the proposed grading system.

the mean age of eruption for that particular tooth under each category. Hence, the cut-off age was calculated based on the probit model.

The grading system was used to determine and confirm the sequence of permanent tooth eruptions. Analysis of variance (ANOVA) was used to compare the developmental stages of dentition between girls and boys in Groups I, II, and III.

3. Results

The study sample included 1220 children comprising 515 boys and 705 girls aged 5–18 years. The mean age of the participants was 11.5 years (standard deviation ± 4.03). Using the new grading system, the clinical status of tooth eruption was scored for the representative population. Table 1 outlines the sample distribution based on eruption grades. A total of 23,218 permanent maxillary (n = 11,085; grade 1: 367, grade 2: 660, and grade 3: 10,058) and mandibular (n = 12,133; grade 1: 497, grade 2: 793, grade 3: 10,843) teeth were examined and graded.

The difference in the mean age at eruption of permanent teeth based on clinical eruption was compared using ANOVA (Supplementary Table 1). The analysis showed that the difference in eruption ages of the teeth between the sexes based on eruption grades was significant in the following cases: in Group I for the eruption of maxillary and mandibular central and lateral incisors, first molars, and mandibular right canine; in Group II for the second molars, first and second premolars, and canines; and in Group III for all the second molars and the maxillary left second premolar. Differences between sexes were most clearly observed in the intermediate-age group (Supplementary Table 2).

The mean age at teeth eruption in this study was computed using probit analysis (Supplementary Figs. 1–32) and compared with that in the standard table of Logan and Kronfeld[13](Table 2).In the present study, the eruption of the maxillary canines was at an earlier age of 10.2 years, compared with that in the standard table (standard range: 11–12 years). The maxillary second molars erupted at approximately 11.1 years (standard range: 12–13 years). The mandibular second premolars were found to erupt as early as 10.7 years (standard range: 11–12 years). The mean age at eruption for the remaining teeth was comparable with those in the standard table. However, the p-value could not be computed because the standard deviations were not provided in the traditional table.

Table 3 summarizes the advantages of this grading method over other comparable methods.

4. Discussion

In this study, the clinical status of tooth eruption was recorded in a sample population of 1220 children using a newly proposed grading system. This system was preferred over existing methods due to its simplicity, improved accuracy, and reduced subjectivity during assessment. Calibration of this system using inter- and intra-reliability assessments yielded a near-perfect agreement. We also derived the chronology and sequence of permanent tooth eruptions based on this system and compared it to the standard reference table of Logan and Kronfeld.[13]

Tooth eruption age is significant for diagnosis, orthodontic treatment planning, and preventive dental procedures. To study dental plaque and

Table 1
Distribution of eruption grading in permanent maxillary and mandibular teeth in a sample population aged 5–17 years.

Maxillary Right Arch														
Central incisor (n = 1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	85	77	49	18	5	3	8	20	12	2	1	0	0	280
Grade 1	0	0	2	2	1	0	0	0	0	0	0	0	0	5
Grade 2	0	4	16	18	0	0	0	0	0	0	0	0	0	38
Grade 3	3	3	31	60	93	105	107	98	88	96	94	79	40	897
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Lateral incisor (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	82	79	56	16	7	9	20	12	2	1	0	0	372
Grade1	0	1	1	8	2	2	0	0	0	0	0	0	0	14
Grade 2	0	1	11	19	13	6	1	0	1	0	0	0	0	52
Grade3	0	0	7	15	68	93	105	98	87	96	94	79	40	782
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Canine (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade0	88	84	97	95	85	63	32	29	14	2	1	0	0	590
Grade1	0	0	0	3	4	17	13	3	1	0	0	0	0	41
Grade2	0	0	0	0	5	10	15	10	1	1	1	0	0	43
Grade3	0	0	1	0	5	18	55	76	84	95	93	79	40	546
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
First premolar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade0	88	84	97	94	76	49	18	24	12	2	1	0	0	545
Grade1	0	0	0	1	4	9	9	8	0	0	0	0	0	31
Grade2	0	0	0		6	7	17	9	1	1		0	0	41
Grade3	0	0	1	3	13	43	71	77	87	95	94	79	40	603
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Second premolar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade0	88	84	97	98	89	72	60	29	11	3	1	0	0	632
Grade1	0	0	0	0	2	5	11	9	2	0	0	0	0	29
Grade2	0	0	0	0	2	2	14	15	7	0	0	0	0	40
Grade3	0	0	1	0	6	29	30	65	80	95	94	79	40	519
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
First molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade0	71	43	13	2	1	0	8	19	12	2	1	0	0	172
Grade1	2	5	1	1	0	0	0	0	0	0	0	0	0	9
Grade2	3	4	3		0	0	0	1	1	0	0	0	0	12
Grade3	12	32	81	95	98	108	107	98	87	96	94	79	40	1027
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Second molar(n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade0	88	84	97	98	91	71	73	28	3	4	1	0	0	638
Grade1	0	0	0	0	0	3	14	12	6	0	0	0	0	35
Grade2	0	0	0	0	1	2	13	35	31	9	11	2		104
Grade3	0	0	1	0	7	32	15	43	60	85	83	77	40	443
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Third molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade0	88	84	98	98	99	108	115	116	99	97	95	78	37	1212
Grade1	0	0	0	0	0	0	0	1	0	1		1	2	5
Grade2	0	0	0	0	0	0	0	0	1	0	0	0	1	2
Grade3	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Maxillary Left Arch														
Central incisor(n = 1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
0	86	75	49	17	1	3	4	20	12	2	1	0	0	270
1	0	2	4	4	1	1	0	0	0	0	0	0	0	12
2	0	4	14	18	0	1	0	0	0	0	0	0	0	37
3	2	3	31	59	97	103	111	98	88	96	94	79	40	901
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Lateral incisor (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
0	88	82	81	60	13	8	5	20	12	2	1	0	0	372
1	0	2	3	6	5	1	0	0	0	0	0	0	0	17
2	0	0	8	16	10	7	0	0	1	0	0	0	0	42
3	0	0	6	16	71	92	110	98	86	96	94	79	40	788
Total	88	84	98	98	99	108	115	118	99	98	95	79	40	1219
Canine (n=1220)														

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Table 1 (*continued*)

Maxillary Left Arch														
Central incisor(n = 1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
0	88	84	97	95	85	60	32	26	13	2	2	0	0	584
1	0	0	0	3	5	19	8	2	2	0	0	0	0	39
2	0	0	0	0	7	11	19	10	1	1	1	0	0	50
3	0	0	1	0	2	18	56	80	84	95	92	79	40	547
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
First premolar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
0	88	84	97	96	79	51	22	25	12	2	1	0	0	557
1	0	0	0	0	4	6	9	9	0	0	0	0	0	28
2	0	0	0	1	3	7	21	7	1	1	0	0	0	41
3	0	0	1	1	13	43	63	77	87	95	94	79	40	593
Total	88	84	98	98	99	107	115	118	100	98	95	79	40	1219
Second premolar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
0	88	84	97	98	88	72	63	32	11	3	1	0	0	637
1	0	0	0	0	3	4	11	11	0	0	0	0	0	29
2	0	0	0	0	2	2	15	8	9	0	0	0	0	36
3	0	0	1	0	6	30	26	67	80	95	94	79	40	518
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
First molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
0	70	49	12	1	1	1	11	20	12	2	1	2	0	182
1	3	3	4	1	0	0	0	0	0	0	0	0	0	11
2	2	3	4	0	0	0	1	1	1	0	0	0	0	12
3	13	29	78	96	98	107	103	97	87	96	94	77	40	1015
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Second molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
0	88	84	97	98	91	72	77	30	3	3	1	0	0	644
1	0	0	0	0	0	2	9	11	6	1	0	0	0	29
2	0	0	0	0	1	2	11	31	30	10	10	2	0	97
3	0	0	1	0	7	32	18	46	61	84	84	77	40	450
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Third molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
0	88	84	98	97	99	108	114	115	99	98	95	78	37	1210
1	0	0	0	0	0	0	0	1	1	0	0	1	1	4
2	0	0	0	0	0	0	0	1	0	0	0	0	2	3
3	0	0	0	1	0	0	1	1	0	0	0	0		3
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Mandibular left arch														
Central incisor (n = 1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	72	51	17	2	0	2	5	21	12	2	1	0	0	185
Grade 1	6	5	8	0	0	0	0	0	0	0	0	0	0	19
Grade 2	4	8	12	2	0	0	0	0	0	0	0	0	0	26
Grade 3	6	20	61	94	99	106	110	97	88	96	94	79	40	990
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Lateral incisor (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	77	50	19	1	2	5	21	12	2	1	0	0	278
Grade 1	0	2	11	4	1	0	0	0	0	0	0	0	0	18
Grade 2	0	4	13	17	7	1	1	0	0	0	0	0	0	43
Grade 3	0	1	24	58	90	105	109	97	88	96	94	79	40	881
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Canine (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	84	96	83	66	25	12	22	12	2	1	0	0	491
Grade 1	0	0	1	5	10	25	11	3	0	0	0	0	0	55
Grade 2	0	0	0	6	8	17	12	3	0	0	0	0	0	46
Grade 3	0	0	1	4	15	41	80	90	88	96	94	79	40	628
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
First premolar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	84	97	97	87	64	26	21	12	2	1	0	0	579
Grade 1	0	0	0	0	1	10	12	8	0	0	0	0	0	31
Grade 2	0	0	0	0	3	6	17	9	2	0	0	0	0	37
Grade 3	0	0	1	1	8	28	60	80	86	96	94	79	40	573
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Second premolar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total

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Table 1 (*continued*)

Mandibular left arch														
Central incisor (n = 1220)														
Grade 0	88	84	96	98	88	71	60	31	11	2	1	0	0	630
Grade 1	0	0	0	0	2	4	16	8	1	0	0	0	0	31
Grade 2	0	0	1	0	2	3	10	12	9	0	0	0	0	37
Grade 3	0	0	1	0	7	30	29	67	79	96	94	79	40	522
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
First molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	66	41	10	1	1	0	10	21	12	2	1	0	0	165
Grade 1	6	3	4	1	0	0	0	0	0	0	0	0	0	14
Grade 2	4	7	6	0	0	0	0	2	1	0	0	0	0	20
Grade 3	12	33	78	96	98	108	105	95	87	96	94	79	40	1021
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Second molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	84	97	98	90	69	76	29	4	1	1	0	0	637
Grade 1	0	0	0	0	1	3	11	17	5	0	0	0	0	37
Grade 2	0	0	0	0	2	1	14	36	35	14	15	2	1	120
Grade 3	0	0	1	0	6	35	14	36	56	83	79	77	39	426
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Third molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	84	98	98	99	108	115	116	98	96	93	77	38	1208
Grade 1	0	0	0	0	0	0	0	1	0	2	2	1	1	7
Grade 2	0	0	0	0	0	0	0	1	1	0	0	0	1	3
Grade 3	0	0	0	0	0	0	0	0	1	0	0	1	0	2
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Central incisor(n = 1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	72	48	17	2	3	1	2	21	12	2	1	0	0	181
Grade 1	7	7	7	0	0	0	0	0	0	0	0	0	0	21
Grade 2	3	8	12	2	0	0	0	0	0	0	0	0	0	25
Grade 3	6	21	62	94	96	107	113	97	88	96	94	79	40	993
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Lateral incisor (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	87	84	96	82	64	27	9	22	12	2	1	0	0	486
Grade 1	0	0	1	6	10	25	9	2	0	0	0	0	0	53
Grade 2	0	0	0	6	8	18	11	6	0	0	0	0	0	49
Grade 3	1	0	1	4	17	38	86	88	88	96	94	79	40	632
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Canine (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	87	84	96	82	64	27	9	22	12	2	1	0	0	486
Grade 1	0	0	1	6	10	25	9	2	0	0	0	0	0	53
Grade 2	0	0	0	6	8	18	11	6	0	0	0	0	0	49
Grade 3	1	0	1	4	17	38	86	88	88	96	94	79	40	632
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
First premolar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	84	97	98	88	65	28	21	12	2	1	0	0	584
Grade 1	0	0	0	0	0	13	10	7	0	0	0	0	0	30
Grade 2	0	0	0	0	5	7	19	11	2	0	0	0	0	44
Grade 3	0	0	1	0	6	23	58	79	86	96	94	79	40	562
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Second premolar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	84	97	97	89	70	61	30	11	2	1	0	0	630
Grade 1	0	0	0	0	1	6	17	12	1	0	0	0	0	37
Grade 2	0	0	0	0	3	1	11	12	8	0	0	0	0	35
Grade 3	0	0	1	1	6	31	26	64	80	96	94	79	40	518
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
First molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	64	37	12	1	1	1	6	21	12	2	1	0	0	158
Grade 1	6	6	1	1	0	0	0	0	0	0	0	0	0	14
Grade 2	3	5	6	0	0	0	0	3	1	0	0	0	0	18
Grade 3	15	36	79	96	98	107	109	94	87	96	94	79	40	1030
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Second molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	84	97	98	90	68	81	28	4	3	1	0	0	642
Grade 1	0	0	0	0	1	5	10	19	7	1	0	0	0	43
Grade 2	0	0	0	0	2	1	13	34	35	12	15	2	1	115

(*continued on next page*)

Table 1 (*continued*)

Central incisor(n = 1220)														
Grade 3	0	0	1	0	6	34	11	37	54	82	79	77	39	420
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220
Third molar (n=1220)														
Age (in years)	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Grade 0	88	84	98	98	99	107	115	117	99	98	94	75	37	1209
Grade 1	0	0	0	0	0	0	0	0	1	0	0	2	2	5
Grade 2	0	0	0	0	0	0	0	1	0	0	0	1	1	3
Grade 3	0	0	0	0	0	1	0	0	0	0	1	1	0	3
Total	88	84	98	98	99	108	115	118	100	98	95	79	40	1220

Mandibular right arch.
Grade 0: Not visible in the oral cavity.
Grade 1: Up to the incisal (anterior)/occlusal (posterior) third of the tooth surface is exposed (<3 mm).
Grade 2: Up to middle third of the tooth surface is exposed (3–6 mm).
Grade 3: Up to the cervical third of the tooth surface is exposed (>6 mm).

caries on occlusal surfaces of first permanent molars with their eruption stage, Carvalho et al.[9] used the following criteria to record the eruption status of each molar: (0) unerupted; (1) the occlusal surface partially erupted; (2) the occlusal surface fully erupted, but more than half of the facial surface covered with gingival tissue; (3) the occlusal surface erupted, and less than half of the facial surface was covered with gingival tissue; and (4) full occlusion. However, there are no specific criteria for recording anterior teeth eruption in this system. Additionally, terms such as "partially erupted" could lead to subjective conflicts because a tooth that is one-third or two-thirds erupted can both be regarded as partly erupted. Subsequently, the proposed alternative grading system addresses the criteria for both anterior and posterior teeth. A systematic approach that follows the natural path of the eruption process can potentially overcome subjective errors.

Pahkala et al.[10] classified the clinical eruption of each tooth into four grades: grade 0 = not visible in the oral cavity; grade 1 = at least one cusp visible; grade 2 = the whole occlusal surface/mesiodistal width of the tooth visible; and grade 3 = in occlusion or at the occlusal level if the antagonistic tooth is not fully erupted. A possible limitation of this system is the wide range between eruption stages. Grading a posterior tooth with two or three erupted cusps as grade 1 would understate its clinical position, whereas regarding it as grade 2 would overstate it. Assessment of eruption status can also become difficult because of the restrictions of grading criteria for specific teeth. Conversely, with its methodological approach and generalizability, the current grading method addresses these limitations.

Eskeli et al.[11] examined the trends in the timing of permanent tooth eruption and determined the clinical eruption phases as follows: grade 0: the tooth is not visible in the oral cavity; grade 1, at least one cusp/part of the incisal edge is visible in the oral cavity; grade 2, the entire occlusal surface/mesiodistal width of the incisal edge of the tooth is visible; and grade 3, the tooth is in occlusion or at the occlusal level if the antagonistic tooth is not fully erupted. Although this grading system addresses the anterior and posterior teeth, the wide scope between grades 1 and 2 may lead to subjective biases, similar to other classifications. The common limitations observed in the grading systems proposed by Carvalho, Pahkala, and Eskeli can be overcome by utilizing a new less subjective method that uses clinical examination and quantification to determine the appropriate eruption grading. Bengston's stages of tooth eruption,[14] modified by AlQahtani[15] and simplified by Liversidge and Molleson,[16] were not mentioned because these methods are based on alveolar eruption assessed using radiographic methods.

The chronology of permanent tooth eruption is a major factor in developing permanent teeth and establishing correct occlusion. The proposed grading system reported that the mean age at eruption was lesser for the maxillary canines, second molars, and mandibular second premolars compared with the Logan and Kronfeld table. Eruption was found to occur earlier in girls than in boys. This difference has been noted in similar studies[12,17] and has been attributed to the early physical development and maturation of girls. The eruption sequence of the maxillary teeth reported in this study was as follows: first molar, central incisor, lateral incisor, first premolar, canine, second premolar, and second molar (Fig. 2). This was in conjunction with other studies in which canines erupted between the two premolars.[18,19] This sequence was confirmed by Hussin et al.,[20] in concordance with those reported by Bucur et al.[21] and Luca.[22] However, the sequence reported by Logan and Kronfeld in 1933 was first molar, central incisor, lateral incisor, first premolar, second premolar, canine, and second molar. Feraru et al.[23] reported similar results in a study, where upper canines erupted after the premolars. The sequence of mandibular tooth eruption, in agreement with that by Logan and Kronfeld, was as follows: first molar, central incisor, lateral incisor, canine, first premolar, second premolar, and second molar (Fig. 2). However, Tisserand–Perrier[24] found that the second premolar erupted before the first premolar and canine. The differences could have occurred because of factors such as the environment, type of food, dental caries, lifestyle, general health, and genetic variations.[2]

Previous studies on tooth eruption were based on binomial values (i.e., erupted or non-erupted). Although the mean age at the eruptions was determined, the eruption sequence could not be predicted. Few systems with graded eruptions have considered the cusp/cusp-tip visibility as a criterion. This could lead to ambiguity in clinical decision-making and effective public health program implementation. The proposed grading system is more precise and less confusing, compared with other grading systems; it is easy to learn, reliable, clinically user-friendly, and is recommended for dental researchers to determine the chronology and sequence of permanent teeth eruption. This supplementary information on eruption status can help dental practitioners make treatment decisions, including orthodontic band placement, management of open apex and young permanent teeth in endodontics, and dental sealant application in pedodontics, and also provide support for effective public health program planning and implementation. The eruption status and sequence are more precise in the newly proposed grading system, contributing to improved accuracy for academic and research purposes.

Despite these advantages, the study assessed eruption by clinical examination only, and without the use of radiographs. Hence unerupted, extracted, avulsed, and congenitally missing teeth could have been overlooked. Another limitation of this system was that it did not consider the antagonist teeth or occlusal contact. As a result, the occlusal status of the tooth may be undetermined. Since this method was tested on a South Indian population, the generalizability of this method needs to be further studied. However, the rationale behind this method (division of tooth eruption into thirds based on crown length dimensions) can be applied to primary and permanent teeth. The global application of this grading system to different populations can also be contemplated. The variations in crown dimensions due to race, environmental factors, and secular trends are potential factors to be considered while determining the cut-off values for this grading system. For eg, as per the

Table 2
Mean age of eruption (in years) vs Logan & Kronfeld (1933) table.

	Tooth type	Mean age of eruption + SD (Present study)	Mean age of eruption (Logan & Kronfeld 1933)
Maxillary teeth	Right third molar	–	–
	Right second molar	11.1 ± 3.9	12–13
	Right first molar	5.8 ± 4.4	6–7
	Right second premolar	10.7 ± 3.5	10–12
	Right first premolar	9.9 ± 3.1	10–12
	Right canine	10.2 ± 3.6	11–12
	Right lateral incisor	8.1 ± 3.3	8–9
	Right central incisor	7.1 ± 3.4	7–8
	Left central incisor	7.0 ± 3.27	7–8
	Left lateral incisor	8.1 ± 3.23	8–9
	Left canine	10.2 ± 3.66	11–12
	Left first premolar	10.0 ± 3.14	10–12
	Left second premolar	10.8 ± 3.56	10–12
	Left first molar	5.9 ± 4.7	6–7
	Left second molar	11.0 ± 3.99	12–13
	Left third molar	–	–
Mandibular teeth	Left central incisor	6.0 ± 4.64	6–7
	Left lateral incisor	7.2 ± 3.37	7–8
	Left canine	9.4 ± 3.46	9–10
	Left first premolar	10.2 ± 2.7	10–12
	Left second premolar	10.7 ± 3.62	11–12
	Left first molar	5.6 ± 5.57	6–7
	Left second molar	11.1 ± 4.02	11–13
	Left third molar	–	–
	Right central incisor	6.0 ± 4.98	6–7
	Right lateral incisor	7.2 ± 3.53	7–8
	Right canine	9.3 ± 3.43	9–10
	Right first premolar	10.3 ± 2.72	10–12
	Right second premolar	10.7 ± 3.51	11–12
	Right first molar	5.5 ± 5.36	6–7
	Right second molar	11.1 ± 3.95	11–13
	Right third molar	–	–

proposed system, Grade 1 refers to tooth eruption up to the incisal (anterior)/occlusal (posterior) third of the exposed tooth surface (<3 mm), however, if the average crown length dimension is 10 mm in a particular population, the cut-off can be adjusted to 3.3 mm. The applicability of this system to a larger sample size is currently in progress and will be reported later.

5. Conclusion

The newly proposed system was found to be more useful and robust than the existing systems for determining the clinical status of tooth eruptions. The chronology and sequence derived using this grading, when compared with the Logan and Kronfeld table, showed earlier eruption ages for the maxillary canines, second molars, and mandibular second premolars.

Table 3
Comparison of different eruption grading methods based on criteria.

Criteria	Carvalho grading (1989)	Pahkala grading (1991)	Eskeli grading (2016)	Proposed grading (2024)
Basis for the grading system	Based on the observed stage of eruption of their first permanent molars	Not mentioned	Not mentioned	Based on the division of tooth eruption into thirds as per crown length dimensions
Type of approach in grading	Visual only	Visual only	Visual only	Visual approach + clinical assessment
Susceptibility to bias	Prone to subjective bias	Prone to subjective bias	Prone to subjective bias	Objective measurement reduces subjective bias
Distinction to grade anterior/ posterior teeth	Criteria more relevant to posterior teeth	Criteria more relevant to posterior teeth	Criteria address both anterior and posterior teeth	Criteria address both anterior and posterior teeth
Information on status of occlusion	Provides information when the tooth is in complete occlusion	Provides information on occlusion/ occlusal level if the antagonistic tooth is not fully erupted	Provides information on occlusion/ occlusal level if the antagonistic tooth is not fully erupted	Does not provide information on the occlusal status of the tooth

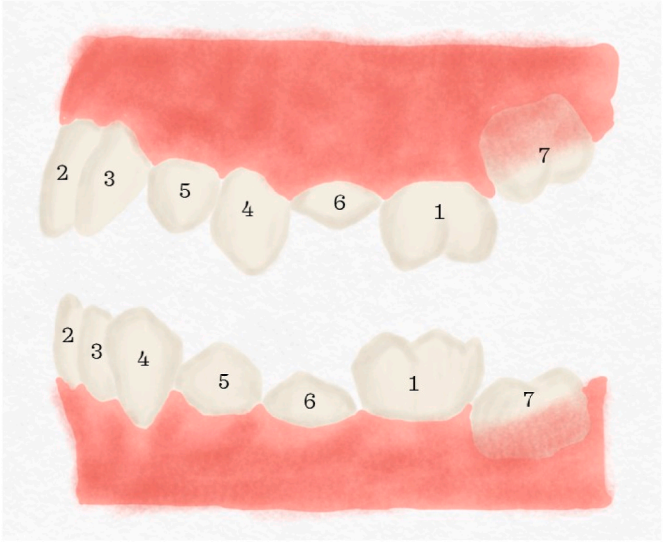

Fig. 2. Sequence of eruption noted in the current study.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Ethics statement

The ethical approval for this cross-sectional study **(REF: IEC-NI/19/FEB/68/02)** was obtained from the Institutional Ethics Committee, Sri Ramachandra Institute of Higher Education and Research, Chennai, India.

Author contributions statement

Vandana S: Conceptualization, methodology, software, validation, investigation, resources, data curation, writing – original draft, writing-review and editing, visualization, project administration. Muthu MS: Conceptualization, methodology, validation, investigation, writing-review and editing, supervision, project administration Kandaswamy D: Conceptualization, validation, data curation, writing-review and editing, supervision, project administration. Aswath Narayanan MB: Conceptualization, validation, writing-review and editing, supervision, project administration.

Declaration of competing interest

The author(s) declare(s) that there is no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jobcr.2024.07.005.

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