Original Article

Validation of the Efficacy of Age Assessment by the Miles Tooth Wear Chart, Using Skulls of Known Age at Death

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Abstract

Background: Age estimation is critical for identification purposes in forensic medicine, with various methods have been proposed for age assessment.
Aims: The present study aims to validate the effectiveness of age assessment by the Miles tooth wear chart, uniquely using skulls of recorded known age at death.
Materials and Methods: Fifty Chinese skulls, of known age recorded at death, ranging from 16 to 62 years, were used. All the skulls were anonymized and outnumbered 1–50, using randomized tables. A 70 mm, ×3 magnification glass with light was used to evaluate tooth wear patterns, and the age was assessed using a newly devised "age calculator" based on the Miles chart.
Statistical Analysis: Bland–Altman plots were used for statistical comparisons.
Results: First and second molars and means of both allowed circa 86% of cases to be allocated within ±5 years of their actual age. Accuracy diminishes when skulls are over 40 years old at death.
Conclusions: The Miles chart can, with caution, be used to arrive at a reasonable estimation of age in this Chinese population.

Key Words: *Age estimation, Chinese skulls, forensic odontology, Miles chart, tooth wear*

Introduction

Age estimation is critical in forensic medicine for identification purposes of deceased victims and missing persons and in the context of felonies and accidents. The difference in tooth eruption times varies according to inherent biological variability, more controlled by genes than by environmental factors,[1] resulting in tooth development showing less variability than other developmental features and also little variability in relation to chronological age. Accordingly, tooth eruption data provide a relatively accurate indication of chronological age and has occasioned various odontological methods to be used to estimate age.

Schour and Massler[2] using data obtained by Logan and Kronfeld[3] compiled two charts showing, schematically, the development of the human dentition. The information in these charts has been extensively used over the years and has proved to be relatively accurate in spite of the medically compromised small sample size which was derived from 25 postmortem specimens of which 19 were under 2 years of age.

More precise and detailed techniques of age estimation have been published.[4-7] Demirjian's method, considered as the gold standard, is based on the calcification of the permanent seven teeth on the left side of the mandible. The calcification of a tooth is divided into eight stages, and each stage has been designated a particular score which is different for boys and girls.[6] Numerous papers report the application of this method in various ethnic populations.[8] It is the most common method for age estimation,[6] and which has been adapted by others,[9,10] though it is not universally accepted as the best method for forensic age estimation purposes.[11,12] These methods involve time-consuming and cost-inefficient techniques subsequent to tooth extraction, the preparation of microscopic sections of teeth, or time-consuming radiographic observation subsequent to obtaining ethical approval. Less laborious, easier to interpret methods for forensic age estimation of large samples have been suggested, based on but potentially as accurate as Demirjian.[13]

Age assessment in older subjects is more exigent.[14] Morphological techniques,[4] or radiology techniques,[15,16] are based on the measurement of regressive changes in teeth including factors such as the loss of periodontal attachment, apposition of cementum at the root apex, amount of apical resorption, and transparency of the tooth root. Once again, their disadvantage lies in the arduous nature of data collection.

Tooth wear patterns have been used for many years as an age estimation scheme, in spite of the acceptance that tooth wear

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patterns are not solely a function of age, being significantly influenced by certain kinds of food, the method of mastication, existence of artificial teeth, gender, geographic location, environmental conditions, and parafunction.[17,18] Most of the schemes, which assess age by tooth wear, first compile a group of young children and adults of "known age" determined from eruption patterns.[19]

Many studies have reported on age assessment by wear scores,[20-22] with the Miles method being used by a sizeable number,[23-27] as well as modifications of his original method.[28,29]

There are sources of error inherent in the Miles system of analysis,[26] but despite this, a high correlation exists between molar wear and adult age at death suggesting that dental wear is a reliable aging technique.[30]

The lack of a suitable known age reference population from which to age past populations is one of the biggest problems in dental wear aging.[31] Several authors[24-26] have cautioned that tooth wear patterns appraised in one population should not be used to assess age in another population or era.[25] The problem of complying with the implication of this statement is that a sufficient number of skulls aged between 6 and 18 years old, aged by eruption dates, is seldom available in any one population collection, and therefore not available to create a "known age" group as recommended by Miles.[19] This has been overcome in the present study which used sixty skulls of known, authenticated recorded age-at-death to validate aging skulls by tooth wear patterns using the Miles chart.

Aim

To validate the efficacy of age assessment by the Miles tooth wear chart, using skulls of known age at death.

Materials and Methods

Intra- and inter-observer reliability

Patterns and degrees of tooth wear were learned during an initial period of the study using the five descriptions and scores given in Table 1. This learning process was undertaken on mandibles from the Edinburgh University Turner collection which would not be used in the main study. The training was repeated over several weeks until an agreement was reached on tooth wear pattern descriptions.

Intrareliability of an assessor was made to test how reliable assessments were at different time periods. Ten skulls were chosen by an independent colleague (IC) from the Skull Collection, Department of Anatomy, The University of Edinburgh. Chinese skulls to be used in the main study were excluded. Only mandibles were used with all premolars and molars present on one side at least.

These were numbered by IC, and all numbering and any other identification marks on the mandibles were obscured by wrapping the mandible in tin foil so that only the occlusal surfaces of the teeth were visible [Figure 1]. The mandibles were then placed on an examination table ordered from 1 to 10 using randomized tables. Only IC knew the "museum identification number" (MIN) which related to this sequence.

Table 1: Occlusal tooth wear patterns scores

Score	Description of wear
0	No wear
1	Enamel facets. No dentine exposed
2	Dentine exposed on buccal cusps. Area <1 mm
3	Dentine exposed on buccal and lingual cusps. Area <1 mm
4	Dentine exposed. Area <1 mm
5	Dentine exposed. Areas are confluent

Figure 1: Mandible with only occlusal surface of left lower molars visible

The wear patterns on the mandibular first and second molars were recorded using the above descriptions, and each mandible was given a "score". This was designated as Sequence A. After a period of 3 weeks, the same skulls were arranged by the IC in a different sequence, again according to randomized tables, designated as Sequence B. Scores for Sequence A and B were obtained [Table 2].

Interobserver reliability was accomplished similarly. The wear patterns on mandibular first and second molars were scored independently by two assessors, the author plus one other (not the IC). The two sets of scores were then compared. Three weeks later, the same skulls were arranged by the IC in a different sequence (Sequence B), again only the occlusal surfaces being visible. Scores for Sequence B were obtained by two observers and then compared. Scores recorded by the two observers were required to be almost identical for agreement criteria to be met [Table 3].

Confirmation of validity of age estimation by tooth wear patterns using skulls of known age

Seventy-six skulls were obtained from the Turner Collection, Department of Anatomy, University of Edinburgh. The sex and age at death of each skull were known, having been recorded at the time of acquisition.[32] In attestation of this, the collector stated "the age of each was noted at death and the age, sex, and nationality are beyond doubt."

The criteria for inclusion in the present study were that the third molar teeth were fully erupted into the arches and that there had been little or no premortem tooth loss or broken or damaged teeth and both arches were shown to be in occlusion. This resulted in fifty Chinese adult skulls being included in the study, all known to be over 16 years old at death.

All the skulls had been numbered with a MIN, placed at the time of deposition of the skulls in the museum (MIN), and this matched the recorded age-at-death. An IC obscured all identification marks on the skulls by wrapping the mandible in tin foil, so that only the teeth occlusal surfaces were visible [Figure 1]. Using randomized tables, the skulls were then laid out, numbered 1–50. The mandibular teeth were cleaned with nonalcoholic material to ensure clearness of wear faceting. A handheld 70 mm, ×3 magnifying glass, with light (Rolson, Ruscombe, Twyford, Berkshire, United Kingdom) was used to appraise tooth wear patterns.

A newly devised "age calculator" was used, based on the Miles chart, and consists of:

1. A blank record card (RC) [Figure 2], one for each of the 50 teeth consisted of:
   a. A space to record the sequence number, and the eventual estimated age
   b. Two blank schematic teeth [occlusal surfaces] on which the tooth wear patterns could be drawn
   c. On the right side, an aid to show the colors used to illustrate the patterns
   d. Space for the skull number
   e. Space for the actual age.
   (d and e to be filled in at the end of age assessment).
2. A transparent sheet, with a vertical red line, to be placed over the completed RC (in Figure 2, the red line has been aligned with first molar [M1])
3. The Miles chart, to be inserted between the RC and the transparent sheet. This can be moved horizontally until

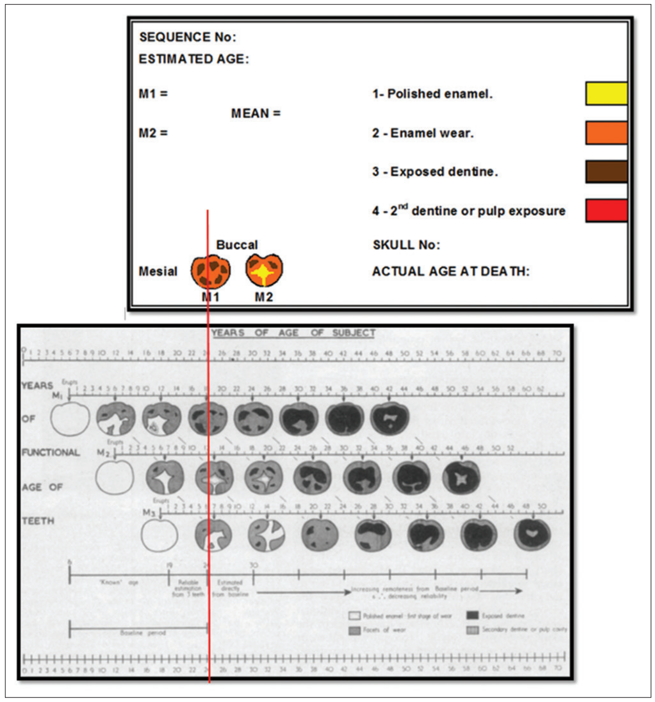

Figure 2: Calculator (Miles chart) with record card

Table 2: Intra-observer scoring of occlusal tooth wear patterns

Skull number	*M1 Sequence A	*M1 Sequence B	**M2 Sequence A	**M2 Sequence B
1	3	3	2	2
2	5	5	4	4
3	3	3	2	2
4	3	4	3	3
5	2	2	2	2
6	4	4	3	3
7	5	5	5	5
8	3	4	2	3
9	2	2	2	2
10	5	5	4	4

*M1: First molar, **M2: Second molar

Table 3: Inter-observer scoring of occlusal tooth wear patterns

Skull number	*M1 Sequence A	*M1 Sequence B	**M2 Sequence A	**M2 Sequence B
1	5	5	5	4
2	3	3	2	2
3	5	5	5	5
4	2	3	2	2
5	3	3	2	2
6	3	3	2	2
7	5	5	4	4
8	3	3	2	2
9	4	3	3	4
10	4	4	3	3

*M1: First molar, **M2: Second molar

the recorded wear pattern on the RC corresponds with a similar pattern on the Miles chart.

Using the record card

The wear patterns of the first molar (M1) and second molar (M2) for each tooth are registered on the RC in the blank schematic teeth. The transparent sheet is overlaid and the Miles chart inserted between the two. The chart is moved until the recorded pattern [M1] on the RC, corresponds with a similar pattern on the Miles chart. In doubtful cases of tooth wear patterns, the age is always assessed upwards. This process is repeated for M2. The functional age of M1 and M2 is then translated to age-at-death in years, and also, the mean (M1 + M2) age at death was calculated, and the RC completed.

Only after all the 50 records were complete was the MIN and actual age logged on the RC by the IC. Then the estimated age according to M1, M2 and the mean estimated age, were compared with the actual age.

Statistical analyses

"Weighted Kappa," quantifying intrarater agreements, was calculated for both M1 and M2 scores, using the GraphPad QuickCalcs (website: http://www.graphpad.com/quickcalcs/kappa1.cfm).

A Bland–Altman plot approach[33] was performed using GraphPad Prism version 6.01 for Windows (GraphPad Software, La Jolla, California USA). The same software was used to compare these statistics. This was recommended by a professional statistician.

Results

Table 4 gives the results of the intra- and inter-observer reliability for both the first molar tooth (M1) and the second molar tooth (M2) together with weighted kappa score showing the strength of agreement.

The intra- and inter-observer reliability testing indicated that tooth wear assessment at different time periods and between the various assessors was precise to the extent that it could be used in age assessment methods.

The agreement between the estimated age of the first molar (M1), second molar (M2), and the average of M1 and M2 and the actual age of the Chinese skulls were analyzed using Bland–Altman Plots as follows:

Actual age versus estimated age (M1)

Figure 3 shows that there is a good agreement between the estimated and actual age. Approximately 86% of estimated ages lay between ±5 years. The estimation and the accuracy of ages are less and underestimated in skulls aged 45 years or older.

Actual age versus average age (M1 and M2)

Figure 4 shows that there is a good agreement between the estimated and actual age. Approximately 88% of estimated ages lay between ±5 years. Once again, estimation and the accuracy of ages is less and underestimated in skulls aged 45 years or older.

Table 4: Intra- and inter-observer reliability

	Intra-observer reliability		Inter-observer reliability	
	*M1	**M2	*M1	**M2
Number of observed agreements	8=80.0%	9=90.0%	8=80.0%	8=80.0%
Number of agreements expected by chance	2.6=26.0%	3.1=31.0%	3.5=35.0%	3.2=32.0%
Weighted Kappa score	0.851	0.909	0.804	0.836
The strength of agreement	Very good		Very good	

*M1: First molar, **M2: Second molar

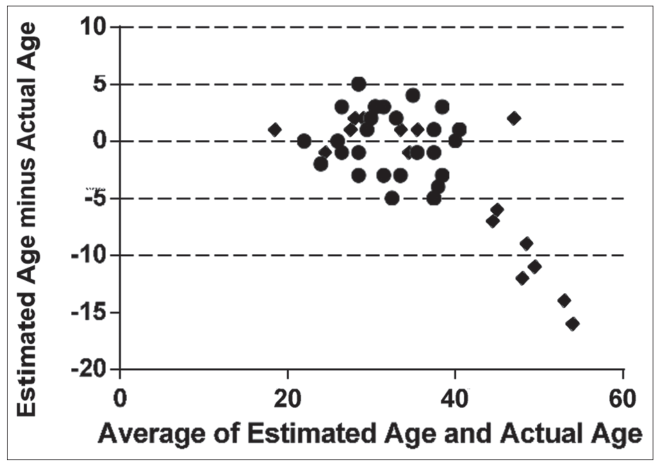

Figure 3: Bland–Altman plot of actual age and age estimated from M1 (in years)

Summary of results

Using the Miles chart, M1, M2, and means of M1 + M2 all allow circa 86% of cases to be allocated within ±5 years of their actual age. Accuracy diminishes when skulls are over 40 years of age at death.

Discussion

A literature review showed that no other study has been published which used skulls of authenticated recorded age-at-death to validate the Miles chart. The Chinese skulls used in the present study had been collected by Gordon Harrower, Professor of Anatomy, National University of Singapore. The sample consisted of 62 Chinese skulls, only two of the Chinese skulls were females, and these were excluded, leaving 60 male skulls. Sexual dimorphism could not be addressed in the study because of this issue. The Chinese skulls were recorded as being Hokkien–Hylam Chinese, were all from one site, and represented burials of the late 19th and the early 20th centuries.[32]

The present study is an attempt to evaluate the use of the Miles chart as a preliminary screening age assessment device. Its limitations, as such, will be thoroughly discussed. However, it is of importance to understand the difference in connotation between the Miles method of age assessment by tooth wear and the use of the Miles chart as a device for assessing age by tooth wear.

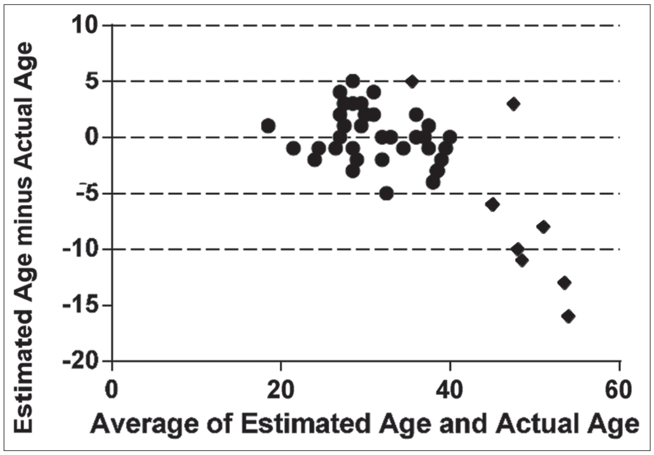

Figure 4: Bland–Altman plot of actual age and calculated as average age estimated from M1 and M2 (in years)

The Miles method of age assessment relies on obtaining a "known age" group of subjects ranging from 6 years to 18 or 19 years as assessed by tooth eruption. The functional life of the first molar (M1) from the time of eruption at about 6 years, to the end of its 1st 12 years in function, is recorded and compared with tooth wear in the second molar (M2) after 6 years in function, i.e., at 18 years of age. In this way, the data from the "known age" group is projected forward for another 6 years to extend the period of what could be regarded as reasonably confident estimation, up to the age of 24 years. This provided a basis on which M1 wear, up to 18 years, could be compared to 12 years of M2 wear and up to 6 years of the third molar (M3) wear and as the baseline group on which the ages of other specimens could be assessed.

Using this method, Miles produced an age assessment chart based on tooth wear patterns. The limitations in the generality of the Miles chart was not lost on the author who stated that tooth wear patterns appraised in one population should not be used to assess age in another population or era, an opinion concurred by others.[24-26]

Brothwell[25] reported that the rates of wear in earlier British populations did not appear to have changed much from Neolithic to Medieval times, and the Miles chart should be roughly correct for all these periods, an implication of this being that tooth eruption times (vide supra) did not significantly change during these periods. In support of the constancy in the age of eruption of permanent teeth, Helm and Prydsö[34] showed that the age at eruption of permanent teeth was similar, as was the rate of attrition of the first and second molars, in medieval Danish skulls compared with contemporary Danish children. Furthermore, it is interesting to note that, despite the small sample used by Schour and Massler[2] compared to the broad cross-section sample of Blenkin and Taylor,[35] the atlas style charts, pertaining to the age of eruption of permanent teeth, produced by both these authors, and others, are very similar. The conclusion to be drawn from these reports is that establishing a "known age" group of subjects evaluated by tooth eruption is not a major shortcoming.

Data from the present study showed that the use of wear patterns on M1, M2, and means of M1 + M2 allows circa 86% of cases to be allocated within ±5 years of their actual age. Bearing in mind the ethnic, geographical, and temporal diversity of the Miles' Anglo-Saxon sample and the 19th Chinese sample, a tentative hypothesis that a non-refined food type is the primary cause of tooth wear. This statement should be considered in the understanding that tooth wear patterns have been shown to vary in type and degree, in any one population, between populations. Sexual dimorphism is also reported.[36,37] That a good relationship existed between tooth attrition patterns and the type of food given is highlighted in a report on five groups of hunter-gatherers and five groups of agriculturalists.[38] Hunter-gatherers, whose food was rough, showed worn, almost flat, molar surfaces. In populations, whose food was based on wheat or corn, wear patterns changed, and the worn molar surfaces tended to be more oblique.

Contrary to this and in support of the use of the Miles chart within different populations and eras, Lovejoy[39] reported that tooth wear patterns from the Libben American Indian population were similar to that provided by Murphy[22] for Australian Aborigines.

Notwithstanding the diversity of the Miles sample and the Chinese skulls, the results compare favorably with other recent age-at-death assessment studies. Using dental panoramic tomograms of living patients of both sexes with documented ages, 18–77 years and data treated by regression analysis, the error was ±2.55 years.[40] Using dental stone casts, the estimation of an individual's age was within ±3 years in 42.4% of males and 49.4% of females, within ±5 years in 61.8% of males and 63.3% of females,[41] and within ±5 years of actual ages in 63.5% of males, and 64.0% of females,[42] and within ±5 years of actual age in 70% of males and 68.3% females, and within ±3 years of actual age in 50% of males and 50.1% of females.[18]

The Bland–Altman plot[43] was used to analyze the data to see how close the estimated ages corresponded to the actual ages. It is an easy way to evaluate a bias between the mean differences and to determine an agreement interval, within which fall 95% of the differences in the second method, compared to the first one. This statistical method was devised because the use of correlation was considered inadequate and misleading.[33] The Bland–Altman plot has the further advantage in that the spread of this relationship can be visually identified and can be seen mostly to lie within ±5 years or a ±10 years span.

It is seen that about 86% of estimated ages corresponded with actual age, within ±5 years, and about 92% within 10 years. The charts also illustrate how the estimated ages are underestimated after about 40 years of age. A study by Millard and Gowland[31] used statistical probability methods to assess age by wear. Contrary to the present findings, their method produced older ages than traditional methods, especially in the older age groups. This may be due to ethnic or genetic variations, or eating habits, as they pointed out that their results in this respect were especially noted in individuals showing large differences in tooth wear patterns.

It can be concluded that age estimation using tooth wear patterns is considered to be fairly accurate in young individuals up to 40 years old, but the accuracy decreases with age, because of difficulty in assessing levels of tooth wear in older people. This is consistent with many previous studies.[23,27,34]

Although these are favorable results, it is not proposed that the Miles chart can be used without appreciation being given to the population in question. It is not recommended as a replacement for other well-established age assessment methods, but rather as a non-time-consuming, user-friendly initial screening method appropriate for the evaluation of large case numbers.

Forensic odontologists should not limit assessments to one particular technique. Different, more accurate techniques and repetitive measurements should be employed in most cases.

Conclusions

The Miles chart can be used to arrive at a reasonable estimation of age in this Chinese population. The chart should not be used without considering the demographics of the population in question. With this in mind, the Miles chart, based on tooth wear, can be used as an initial method of age assessment, allowing for easier and more rapid data collection with no loss of overall accuracy.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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