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AGE ASSESSMENT BASED ON TRANSLUCENT DENTINE

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Abstract

The purpose of this investigation was to examine the relationship between age and the area of translucent dentine (TA) at root apex, and to compare these findings with those obtained by using the methods of Bang & Ramm[6] and of Johanson.[5] The material consisted of 500 teeth, 50 of each tooth type, molars excluded. For statistical analyses an XT microcomputer and SPSS/PC regression programme were used. The correlation between age and ATD varied from 0,83 to 0,57 for different types of teeth. In stepwide multiple regression analyses ATD was preferred to other types of measurement of the translucency. The factors $(ATD)^2$ and sex contributed significantly to the regression for some types of teeth. Regression analyses using several factors according to Johanson's method resulted in a stronger correlation for most teeth, while the method of Bang & Ramm resulted in a weaker correlation except in the case of mandibular first premolars.

Introduction

Several investigations[1–7] have demonstrated the advantage of age assessment based on dental findings. Gustafson[1] in 1950 introduced the first method for age assessment by evaluating the degree of attrition, periodontal destruction, secondary dentine apposition, cementum apposition, apical root resorption and translucency. Since then, several similar methods[2–7] have been presented which to a varying extent have improved the accuracy of age estimates.

It has been observed that the extent of the apical zone of translucent dentine, the amount of secondary dentine and the thickness of apical cementum are more strongly correlated with age than are the other three factors.[2–5] Apical translucent dentine showed the strongest correlation in several investigations.[4–6]

Dalitz[7] was the first to employ multiple regression analyses in developing his method for age assessment. This type of analysis was also used by Johanson[5] when he improved Gustafson's method, using a more finely graded scoring scale and a larger sample of teeth.

Miles[4] estimated the length of the translucent area from the apex and arrived at one formula for age estimation for all teeth. Bang & Ramm[6] also measured the length of the translucent zone and their formulae were specific for each tooth.

A biomedical image-processing method for age assessment has recently been suggested.[8] This method is based on unsectioned teeth where the three-dimensional amount of translucent dentine is estimated, but the method requires rather complicated and expensive equipment. As far as we know, no studies of correlation between age and the volume of translucent dentine have been carried out using this method.

The size of the translucent zone has been considered to depend on tooth size.[1,2,5] Other investigators have found the translucent zone to be merely a function of age, uninfluenced by the size of the root.[4,6]

The aims of the present investigation were:

— to examine the relationship between age and the area of the apical translucent zone,
— to examine the influence of tooth age, size and sex on the extent of this zone,
— to compute formulae for age estimation based on translucency,
— to decide which teeth may be best suited for age estimation and
— to compare the findings with two previously recommended methods for age estimation, namely those of Johanson[5] and of Bang & Ramm.[6]

Material

The material consisted of 500 teeth, comprising 50 teeth from each type of tooth in both jaws, molars excluded. Only one of the two contralateral teeth from the same individual could be used, and the right tooth was chosen. The teeth originated from a Caucasian population, either extracted in dental practice or removed at autopsy. The reason for removal was recorded as well as the individual's age and the sex. Using the tables of Anderson *et al.*[9] the tooth age was calculated. Descriptive data are given in Table 1.

Table 1: Descriptive data for the material

Tooth	*Male/Female ratio*	*x Age*	*x Tooth Age*	*Age Range*
11/21	0,46	48,0	38,1	21-80
12/22	0,52	47,0	36,5	21-79
13/23	0,66	45,9	32,6	21-80
14/24	0,72	40,9	27,5	16-94
15/25	0,64	43,8	30,6	17-77
41/31	0,50	47,5	39,0	21-83
42/32	0,50	50,3	40,8	21-80
43/33	0,60	50,4	37,6	20-96
44/34	0,50	44,4	31,9	18-77
45/35	0,62	47,1	35,6	18-94

n = 50 for all types of teeth

Methods

The teeth were cut according to the half-tooth technique.[10] The sectioned surface of each tooth was then photographed and the colour slides transferred to paper, scale 1:50. Using a planigraph*, the following areas were measured in square millimetres:

1. Total area of the sectioned tooth surface, excluding enamel (TA).
2. Total root area (TRA), i.e. the area of the dentine apically to a straight line between the vestibular and the lingual enamel/cementum junction.
3. Area of translucent dentine (ATD) (Fig. 1).

The area of the pulp was included in each measurement as shown in Fig. 1.

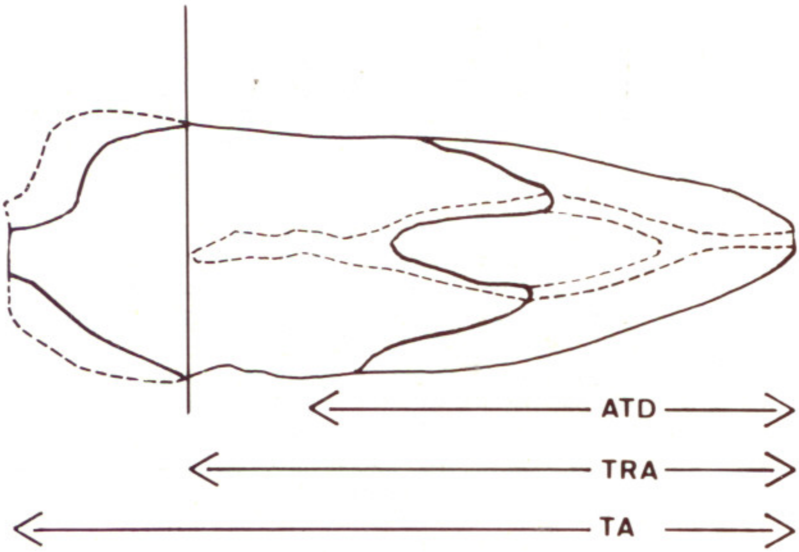

Fig. 1. Illustration of the planigraphic measurements on the cut tooth surface.

Estimates of attrition, secondary dentine, periodontal changes, cementum apposition, root resorption and apical translucent zone were also scored as described by Johanson,[5] and the length of the translucent zone was recorded in mm according to Bang & Ramm's description.[6] All data were entered into a Tandon** microcomputer and an SPSS/PC multiple regression programme was used for statistical analyses.[11]

Statistical Analyses

The sizes of the translucent zone (ATD), root area (TRA) and tooth surface (TA), measured planigraphically, were used as independent variables, as were the sex and the squared values of ATD. A stepwise multiple regression procedure was run for each type of tooth, using first individual age and then tooth age as dependent variables. Inclusion level was $p < 0{,}05$. The procedure also included calculation of Pearson's

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correlation coefficient. This coefficient expresses the relationship between two or more variables. If the coefficient is ± 1,00 there is a linear relationship between the variables. If on the other hand the coefficient is 0,00 no such relation exists.

For each type of tooth the statistical analyses comprised multiple regression analyses of our data of the variables according to the methods of Johanson[5] and Bang & Ramm.[6] For each method a stepwise multiple regression procedure was run.

Results

It can be seen in Table 2 that estimated age, as calculated by the regression formulae, was strongly correlated with chronologic age from birth. The formulae for maxillary canines had the strongest correlation coefficient, while the formulae for mandibular laterals had the weakest correlation coefficient. The formulae for the maxillary centrals and laterals, and the mandibular second premolars all had a correlation coefficient above 0,80.

The squared values of ATD with a negative sign contributed significantly to the regression for maxillary centrals and canines, and for mandibular centrals, laterals, canines and second premolars.

The use of tooth age instead of individual's age did not improve the correlation between age assessment and translucency. Consequently, only the results regarding individual's age from birth will be used in the following presentation and discussion.

Table 2: Multiple regression analyses with Pearson's correlation coefficients and standard deviation

Tooth	*Formula for age evaluation: Age =*	*Corr. coeff.*	*SD*
11/21	$= 37,27 + 2,71\ ATD - 0,03\ ATD^2 - 0,21\ TA$	0,82	9,0
12/22	$= 31,14 + 1,30\ ATD - 8,28\ Sex$	0,84	9,2
13/23	$= 19,19 + 1,46\ ATD - 0,01\ ATD^2$	0,86	8,7
14/24	$= 21,90 + 0,69\ ATD$	0,75	13,1
15/25	$= 22,89 + 0,90\ ATD$	0,70	12,1
41/31	$= 23,96 + 2,06\ ATD - 0,02\ ATD^2 - 9,74\ Sex$	0,76	10,9
42/32	$= 25,44 + 1,68\ ATD - 0,02\ ATD^2$	0,64	12,9
43/33	$= 23,51 + 1,60\ ATD - 0,02\ ATD^2$	0,78	12,0
44/34	$= 27,85 + 1,04\ ATD$	0,68	12,0
45/35	$= 21,60 + 1,59\ ATD - 0,01\ ATD^2$	0,81	11,4

ATD = planigraphic measurement of translucent zone.
TA = total area in square millimetres of the sectioned tooth surface, excluding the enamel.
Sex: male = 1, female = 0.
Corr. coeff. = Pearson's correlation coefficient for the regression formula.
SD = standard deviation of the calculated age.

The measurements of TA and TRA were not included in the regression except for maxillary central incisors, where TA was included. The sex was included for maxillary laterals and mandibular centrals, and the sign was negative for this factor.

It can also be observed from Table 2 that there were differences in multiple regression equations for different types of teeth. Correlation coefficients show that the most reliable tooth types for age estimation may be the maxillary centrals, laterals and canines, and the mandibular second premolars, while the mandibular laterals and first premolars may be the least reliable.

Table 3: Comparison of Pearson's correlation coefficients between estimated and real age for three methods of age estimation based on multiple regression

Tooth	*Measurements of ATD*	*Method of Johanson*	*Method of Bang & Ramm*
11/21	0,82	0,84	0,70
12/22	0,84	0,84	0,66
13/23	0,86	0,77	0,73
14/24	0,75	0,86	0,73
15/25	0,70	0,84	0,70
41/31	0,76	0,79	0,64
42/32	0,64	0,76	0,58
43/33	0,78	0,81	0,75
44/34	0,68	0,73	0,69
45/35	0,81	0,86	0,75

The correlation coefficients between age and the multiple regression equation obtained by the methods of Johanson[5] and Rang & Ramm[6] are shown in Table 3. Comparison of the coefficients for our multiple regression of ATD with those obtained by Johanson's method revealed slightly stronger correlation for his method, except for maxillary canines. The computer terminated the stepwise regression after having included only three or fewer variables, as further inclusion of variables would be insignificant.

The figures obtained according to Bang & Ramm's method indicated a weaker correlation with age when compared with our multiple regression of ATD for all teeth except mandibular first premolars.

Table 4: Comparison of Pearson's correlation coefficients of age estimation based on measurement of translucent zone on sectioned teeth according to three methods

Tooth	*ATD*	*Method of Johanson*	*Method of Bang & Ramm*
11/21	0,77	0,77	0,56
12/22	0,81	0,78	0,66
13/23	0,83	0,70	0,73
14/24	0,75	0,81	0,73
15/25	0,70	0,78	0,69
41/31	0,59	0,60	0,51
42/32	0,57	0,58	0,50
43/33	0,69	0,78	0,75
44/34	0,68	0,73	0,70
45/35	0,74	0,79	0,71

Table 4 shows Pearson's correlation coefficients between age and the translucent zone, as scored by planigraph, by Johanson's method and by Bang & Ramm's method. It can be observed that Johanson's way of measuring translucent dentine showed a stronger correlation with age for maxillary premolars and all mandibular teeth. The difference between the coefficients obtained for ATD and the scores according to Johanson's method was smaller than that between the multiple regression coefficients as shown in Table 3. The coefficients derived from Bang & Ramm's method were weaker than the ATD measurements, except for mandibular canines and first premolars.

Discussion

The translucent zone in dentine is brought about by the deposition of minerals in the dentinal tubules. In addition to apical translucency, such zones can be caused by caries and dentinal attrition. In our investigation only the apical translucent zone was measured.

The junction between normal and translucent dentine may be difficult to distinguish in some teeth but observing specimens both dry and wet may assist in determining this junction. In the majority of cases the specimens were measured dry, but when in doubt the surface was moistened. Nevertheless, in some teeth the extent of the translucent zone could only be determined with difficulty.

Bang & Ramm[6] found no advantage in estimating the area of the translucent zone. Their specimens consisted of thin, dry tooth sections in which the junction between normal and translucent dentine may sometimes be indistinct. Repeated measurements of such translucent zones may therefore give varying results and lead to a rejection of this method of measurement.

Since the extent of the translucent dentine seems to be the best age-related dental change[4,6] measurement of its volume may be more closely related to age.[8] Limitations are at present imposed by a difficult technique requiring expensive equipment and the time-consuming measurement of a sufficient number of teeth. Measuring the area of translucent dentine on a sectioned tooth surface may therefore be a simpler procedure for relating age to translucent dentine.

For some teeth the squared figures of ATD with a negative sign contributed significantly to the multiple regression. This indicates that the rate of increase in size of the translucent dentine zone decreased with age. In forensic identification therefore where the age of an old person is to be estimated it would be preferable to use the maxillary incisors, canines and/or mandibular second premolars.

Since the sex is a negative factor in age formulae for maxillary laterals and mandibular centrals, the calculated age for female teeth will be respectively 8,28 and 9,74 years higher when compared to male teeth with the same size of the translucent zone. The speed of mineral deposition is therefore higher in male teeth which may be caused by the harder chewing habits of men.

In Johanson's method the extent of the translucent dentine is scored by comparing the sections with a graded series of diagrams showing translucency in longitudinal sections of the teeth. The differences between the scores in these drawings does not represent a linear scale in the increase of the translucent zone. The amount of translucent dentine may also be related to the size of the tooth. In our multiple regression formulae the factors TRA or TA were not accepted, except for maxillary central incisors. For practical purposes the extent of translucent dentine may therefore be considered to be a result of age, and only for maxillary centrals was the size of the translucent zone influenced by the total tooth area.

Johanson's method for age estimation showed the best results in all types of teeth except for maxillary canines when compared to our multiple regression formulae for ATD measurements. This could be expected since his method included five age-related tooth changes in addition to apical translucent dentine. It should be noticed however that only three of his six factors made a significant contribution to the regression in any tooth type. Inclusion of further independent variables such as cementum apposition and root resorption which display an insignificant contribution to the regression, is not recommended.

In all types of teeth except mandibular first premolars the method of Bang & Ramm resulted in a significantly weaker multiple correlation coefficient when compared to our planigraphic measurement. Bang & Ramm's way of measuring the extent of translucent zone is an easy, but may be a more inaccurate method compared with the method of Johanson and the planigraphic measurement.

Conclusion

Measuring the area of the translucent zone is recommended as a method of age estimation. Other age-related changes such as attrition, secondary dentine, periodontal changes and cementum apposition could also be quantified, and together with apical translucency they could be used in a multiple regression method in order to achieve a more reliable age estimation.

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LAWYERS' REASONING AND SCIENTIFIC PROOF: A CAUTIONARY TALE IN FORENSIC ODONTOLOGY

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A Lecture given to the Eleventh International Meeting of Forensic Sciences in Vancouver on 6th August 1987 and to the First World Meeting of Police Surgeons and Police Medical Officers in Wichita on 12th August, 1987.

Insufficient attention has been given by forensic scientists to a recurring problem they face about the acceptance of their evidence in a court of law. I am not concerned here with a conflict between the evidence of experts, but rather with the acceptability of the quality and quantity of their testimony.

The Problem

A fact-finding tribunal is often required to understand the scientific detail of expert evidence even though it is uninitiated in that area of expertise. If the tribunal cannot understand the derivation of the relevant conclusions it must, like St. Thomas, remain a doubting tribunal and thus reject the evidence as inconclusive.

This situation is common in some scientific comparisons such as fingerprints, footprints and ballistics. Each juror becomes his own Sherlock Holmes.

Yet other areas of forensic expertise are not seen as calling for the same satisfaction, for example, questions on insanity, cause of death, time of death, identity of drugs, identity of stains and blood matching.

The case of *R v Carroll* is an Australian case in which three judges of the Court of Criminal Appeal quashed a jury's verdict of guilty because they were unconvinced of the reliability of three expert odontologists' opinions that the marks on the murdered baby's thighs were actually caused by Carroll's teeth.

The Facts

In *R v Carroll* a 17-month-old baby, Deidre Kennedy, was murdered. In 1973 during the night she was taken from a bedroom in her parents's flat. Her bruised and sexually abused body was found the following morning dumped on the roof of a toilet block approximately 500 yards away. When found she was dressed in a pyjama top, an adult half slip, a pair of adult panties and a pair of step-ins, all of which, apart from the pyjama top, had been stolen from the verandah of the next door house. The cause of death was strangulation.

An examination of the body revealed a superficial tearing of the vagina and some bruising around the anus, extensive bruising to the neck and head, abrasions near one eye and on the upper lip and significantly, a bruise pattern on the outside of the left thigh just above the knee. The pattern appeared as two curved lines of bruising each 1,5 cm long and about 2,5 cms apart. A forensic odontologist, Dr. R. concluded that this bruise pattern on the left thigh had been caused by a human bite and under his direction a series of photographs was taken of the mark on the day of the discovery of the body. These were to be the basis of later opinions.

His opinion at that time was that because of the meagre detail and the absence of definite indentations or impressions thereof it would be impossible to establish the identity of the biter.

Nearly nine years later the Women's Quarters of the Amberley Air Force Base, only a few miles away, were broken into. Ladies' underclothing had been stolen and in the laundry of the Quarters, photographs of a scantily clad airwoman had been lined up on an ironing board and items of women's underclothing damaged. In particular, the crotch and nipple areas had been cut out of the panties and brassieres respectively.

Suspicion focused on Carroll, a Royal Australian Air Force serviceman. His car had been sighted in the early hours of the morning by R.A.A.F. personnel adjacent to the quarters some distance off the road. He denied leaving his house after 11.30 pm that evening yet his thumb print was found on one of the photographs.

The murder of Deidre Kennedy in 1973 exhibited deviant behaviour with stolen women's underwear. Carroll's family home in 1973 was in the same immediate area as Deidre's home, and where her body was found. The deviant behaviour by Carroll with stolen women's clothing invited inquiry concerning his possible involvement in the old murder.

In October of 1983 Carroll agreed to provide Queensland police with dental impressions from which casts were made. Carroll's dentition was a class II division I malocclusion with an anterior open bite. The upper jaw had a V-shaped arch with a high palatal vault. The lower jaw had a square shaped arch and the lower anterior teeth were close together and even, arranged in an almost straight line. The upper central incisor teeth had had two large synthetic fillings inserted on both disto-incisal surfaces.

When questioned Carroll insisted that on the day of the death of the child (13th or 14th April 1973) he was at the R.A.A.F. base at Edinburgh, South Australia.

He commenced a recruit's course on 9th February 1973 and he claimed that on graduation he travelled from Edinburgh to New South Wales. At no time between 9th February 1973 and 19th April did he leave Edinburgh to go to Ipswich (the home town of the Kennedy family).

Carroll's former wife for a period of 18 months told police that the principal reason for leaving her husband in 1975 was his behaviour with regard to their female child. Once their daughter had turned 13 months Carroll used to abuse her and would, on occasions, bite his daughter's thighs. She also told police that when she was pregnant with this child he told her that if the baby was female he wanted her named Deidre.

A number of recruits from Carroll's course could remember his leaving Edinburgh on compassionate grounds three days before the murder, ample time for him to travel to Ipswich and arrive there by 13th April.

Carroll's dental history held by the R.A.A.F. indicated that in September, 1976, between the murder and when the dental impressions were made, repair work had been performed on his upper central incisors. Both were shown to have disto-incisal composite restorations.

The forensic odotologist examined Carroll's teeth in February 1984 at the Ipswich Police Station and was able to confirm that the 1983 plaster casts were indeed those of the suspect. He then made duplicates of the original casts and used them as working models on an articulator. He removed the disto-incisal fillings to simulate the condition of the teeth prior to the restorative work and with the aid of photographs, a macroscope and superimpositions Dr. R. and two other internationally known forensic odontologists, Dr. S. of the University of London Medical School and Dr. B. of the University of Adelaide, South Australia, were able to testify that the bite-mark was made by the accused Carroll and no other.

At the trial all evidence relating to the events at the Women's Quarters at Amberley in 1982 was excluded. The evidence of Carroll's former wife was admitted after objections.

At the conclusion of all the evidence the trial judge directed the jury as to the law to be applied to the facts and then referred to some of the salient features of the expert evidence. In March 1985 Carroll was convicted by the jury of the murder of the child.

The Appeal

Carroll subsequently appealed to the Court of Criminal Appeal on his conviction. The appeal was allowed, the verdict was quashed and the accused was acquitted.

The court ruled that the evidence of Carroll's wife should not have been admitted and that the evidence of the forensic odontologists could not safely support the jury's verdict. It was argued on Carroll's behalf that the opinion of the three experts was insufficient because there were areas of disagreement between them. Two of the experts, Drs. R. and B., associated the upper bruise pattern with all four upper central teeth while Dr. S. associated the bruise patterns with three of the four central teeth. Further, Drs. R. and S. associated the upper bruise pattern with the incisal edges while Dr. B. associated the bruise pattern with the palatal edges of the upper teeth and further still, Dr. R. associated the lower bruise pattern with all four lower central teeth while Dr. S., associated the same bruise pattern with only three of the lower central teeth. Dr. B. was not pressed for an opinion on this point.

There was no real difference between the experts in their general approach which involved defining the biting edges of Carroll's teeth. Drs. R. and S. utilised the incisal edges in making a comparison while

Dr. B. utilised the palatal aspects of the teeth. Both of these fracture edges were exposed by removal of the fillings to recreate the dental conditions of 1973.

The so-called discrepancies appeared when the experts were cross-examined and asked to superimpose certain marks on photographs of the upper bruise pattern. On examination of these photographs it was clear that Dr. R. was prepared to see an area of bruising associated with the left central incisor to the left of the marks associated with the two front central incisors while Dr. B. was uncertain whether there was an area of bruising on the photographs which could be associated with the left central incisor because he placed a question mark over the letter he marked, intended to represent the left lateral incisor. Dr. S. was not prepared to see in the photographs of the bruise pattern an area of bruising associated with the left lateral incisor. This apparent discrepancy was, at its worst, ambiguous but not inconsistent. The fundamental premise of the experts' evidence was that Carroll had a unique dentition at the time of the offence. Carroll's teeth were unusual even to the untrained eye. A number of his fellow recruits spoke of his 'protruding' or 'buck' teeth. The forensic experts also found Carroll's dentition exhibited significant characteristics which left a unique pattern on the thigh of the deceased child. The process of comparison and identification involved complex judgements involving a large number of variables and it is important to note that the attitude of all the experts was that the comparison was between a dentition and an area of bruising.

The second criticism relied on by the Court of Criminal Appeal was that Drs. R. and B. related all four upper incisors to the area of bruising while Dr. S. related only three of the four upper incisors to the same area of bruising. Each of the experts prepared clear acetate tracings using the casts modified by Dr. R. as their source. It can easily be confirmed that all the tracings are consistent by superimposing one over the other and observing that there were common mid-points and biting lines. In making the comparison between the tracing and a photograph of the bruise each expert was in agreement on the position of the upper right lateral incisor. As a matter of logic if all three fixed the same position by reference to the same mark then, as all tracings were consistent in defining the biting edges of the teeth, it is impossible for the experts to have got the teeth into completely inconsistent positions in marking the various photographs of the bruise.

Although the experts' respective reasons for their conclusions did not coincide in all respects, these so-called discrepancies did not affect the basis of their conclusions that Carroll was responsible for biting the deceased child 's thigh. No other person gave evidence to the contrary.

One Judge in his judgement held:

"The matter has given me a great deal of difficulty. But in the end result I have concluded that a properly instructed jury, properly considering the matter, could not be satisfied beyond a reasonable doubt on this evidence that the accused was guilty." He based this on the following criticisms —

(1) The concession by Dr. S. that
"There is a body of eminent opinion which holds that valid identifications cannot be made by reference only to bruise marks or that they should be referred only for the purpose of excluding suspects and not for positive identification."
(2) The absence of satisfactory explanation for discrepancies.
(3) The unsatisfactory explanation given by Dr. R. for his change of opinion between 1973 and 1985.

His judgement amounted to disagreement with the jury's conclusion. Criticisms (2) and (3) were put to the jury and by implication rejected by them. Criticism (1) was also before them.

Another judge in his judgement held:

"Concerning the linchpin evidence of the three forensic odontologists there are areas of disagreement between the three men in what I regard as vital matters. I refer particularly to the evidence of Dr. S. and his frank statement that in the bruise pattern from the upper teeth a mark from the left lateral incisor does not appear while the other two men say that such a mark does not appear.

These three men relied on the bruise pattern shown in certain black and white photographs — the photographs did not reproduce any curve in the skin surface of the leg. Thus it was not a case of the experts each placing his transparency on the actual bruise mark.

The plaster cast (as altered) did not accurately reproduce the state of the appellant's dentition and especially the four upper incisors as at April 1973. This plaster cast was of course one of the basic pieces of evidence on which each of the three experts founded his opinion. Admittedly Dr. R. has since 1973 become more experienced with bitemarks — this however was his first bite-mark case and as I have already mentioned he stated in October 1973 that "it would be impossible to establish with any degree of certainty as to who would be responsible for this bite-mark to the dead child. Despite the eminence of Dr. S. in his particular field and bearing in mind that a jury has to accept only one of these experts I am still left with an uneasy feeling about their evidence. This is because of the discrepancies between them occurring on their respective paths towards identification of certain bruise marks with certain teeth. I accept that each man was concerned only with the pattern of bruising. I am conscious also that I must be careful not to let myself become an expert by viewing the exhibits and substituting my opinion for those of these three men."

The Lesson

The outcome of this trial in which the expert evidence of three eminent scientists was rejected by an appeal court, demonstrates the real danger of judges (or jurors) playing Sherlock Holmes in an area beyond their competence and expertise. The evidence of a forensic expert is only admissible, being opinion evidence, where the field of knowledge in which the witness professes expertise is outside the ordinary experience of man and whether the witness has sufficient expertise in such field as would enable him to assist the tribunal.

It is a fundamental illogicality in the judicical system that a tribunal should need to call for the testimony of an expert yet reject such expert's opinion on the basis of its lay expertise and its lay assessment of the evidence. In my view the trial judge adopted the correct approach to this problem when referring the jury to expert evidence. He said:

"Some of the exhibits may assist you greatly in the determination of the matter; some of them may not be of very much assistance at all. You may be assisted by making the same sort of comparison between the tracings and the photographs of the cast as were made by the various experts who gave evidence, remembering that the conclusions of Dr. R., Dr. S. and Dr. B. were opinions of persons of great expertise which none of us here has.

Also bear in mind that there was use of a comparison macroscope. None of us can hope to become instantaneous experts in a field of forensic odontology and you must, to a certain extent, assess the weight that you give to the opinion evidence in this case.

Remember that you are not experts in the field of forensic odontology and the comparisons that you make must be comparisons of the type that the forensic odontologists made."

R v Carroll demonstrates that there can sometimes be a considerable gulf between scentific conclusion of experts who are eminent in their fields and whose expertise cannot be seriously challenged and the acceptance by lawyers who are truly lay people when it comes to forensic science. This was a case where the Court of Criminal Appeal judges substituted their judgement for that of the experts. Because the material did not satisfy them they concluded that it did not possess the requisite cogency and credibility to justify a conviction. Why should finger prints, shoe patterns, ballistic comparisons and teeth marks have to possess a conclusion demonstrable to a lay man, when questions of mental illness, cause of death and existence of medical states often do not require demonstration of their scientific correctness sufficient to convince lay minds?

R v Carroll demonstrates that expert scientific evidence does not always satisfy a court, indeed, may satisfy one court and be rejected in an appeal. The lesson to expert witnesses is that unless their evidence is unshakable and totally unanimous, judges and jurors may not feel inclined to accept it. The evidence of Drs. R., B. and S. was clearly fundamentally unanimous but subject to doubt because of small, more superficial points of difference. It therefore happened that the outcomes of the trial and appeal were each dependent upon the view of the particular jury, and the Appeal Court.

It must be recognised however that the function of a Court of Appeal is to see that injustice is not done, and a cautious approach to difficult scientific evidence is perhaps understandable.

FRACTURE POTENTIAL OF THE MANDIBLE

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Introduction

Prediction of the ways in which the facial bones will respond to trauma and explaining the mechanisms involved, is a routine but extremely difficult part of forensic practice. The biological variability of the human body and the many ways in which trauma is applied make rigid opinions both hazardous and undesirable. However the courts expect guidance from experts so that they can reach logical conclusions. This paper looks at some of the evidence concerning fractures of the facial bones with particular reference to the mandible, from the point of view of its biological strength.

The Maxilla

The maxilla is a fragile bone which shows a high degree of adaptation to function. With the nose it comprises what is potentially the most vulnerable bone in the body to injury. Like the zygoma but unlike the mandible, it tends not to displace after fracture.[1] Whilst the nose is the most commonly broken facial bone, the maxilla, has approximately the same frequency of fracture as the mandible. It is in the middle third of the face, that the greater number of fractures are missed.[1] They may be difficult to demonstrate radiologically because of the denser skull bones lying behind them. Although common in adults, they are rare in childhood. About 1 in 16 of all childhood facial fractures involve the middle third.[2]

The maxilla consists of a delicate latticework of bones which surround and make up the maxillary outline. They are largely arranged vertically, though there are cross-members. These act as a series of struts, arches and buttresses related to the base of the skull.

The mandible is freely mobile, routinely withstanding forces of up to 34 lbs per sq inch during mastication. Eskimos who eat tough foodstuffs regularly subject their molar regions to forces of up to 700 lbs per square inch.[3] These forces are directly transmitted to the maxilla and because it is a comparatively flimsy structure which articulates with the base of the skull, they are dispersed. The arched palate acts like a flying buttress. The abutments through the frontal, zygomatic and ethmoidal sutures and the maxilla spread masticatory forces over a wide area.

Posteriorly further transmission of force is achieved via the junction with the pyramidal process of the palatine bone and the pterygoid laminae of the sphenoid and superiorly via the nasal, vomer and the vertical plate of the ethmoid.[4]

The maxilla is held still, whilst the mandible moves against it and the middle third of the face is primarily designed to withstand vertically applied forces. As these are usually at their most intense when they are applied to the alveolar region this is the strongest area. They gradually diminish as they pass along the various parts of the upper jaw. Although superiorly the maxilla is relatively flimsy this is not poor design as the potential for sequential collapse confers protection. When structures collapse they use up energy leaving less force to damage other areas.

Whilst the upper jaw withstands upwardly directed forces well its antero-posterior crushing strength is reduced because there is little available to dissipate the force. Consequently an impact in this direction is felt locally. Comminution of the nasal bones may involve the floor of the orbit and, if the impact force is strong enough, the whole middle third may be pushed backwards, causing a lot of adjacent damage and the base of the skull may fracture. Usually though, the middle third of the face acts as a highly efficient buffer zone, preserving the cranial contents from direct damage.[5]

The Zygoma

Fractures of the zygoma are potentially much more serious than is often realised, as they may interfere with vision and mastication.[6] The zygoma is reportedly the second most commonly injured facial bone.[1]

Fractures are said not to be painful and do not usually show any tendency to progressive displacement following the primary injury, in contrast to the mandible.[1]

The zygoma is a dense bone, shaped like a four-pointed star, articulating with the frontal bone, the temporal bone and the maxilla. It is at its thickest at the zygomatico-maxillary suture, medial to which is the thin-walled antrum.[4] It is clearly designed to accept and dissipate forces over as wide an area as possible.

It is probably misleading to talk in terms of fractures of the zygoma, as the zygoma becomes separated from the neighbouring bones, either by fracture or by separation from them at the suture lines. Medial breakage is usually due to fracture of the maxilla which may involve the floor of the orbit and the maxillary antrum, laterally by fracture of the zygomatic process of the temporal bone and above and behind by separation of the suture lines with the frontal bone and the greater wing of the sphenoid.[6]

The zygomatic arch is structurally much smaller than its more robust body. Nahum *et al.*[7] and Nahum[8] have confirmed this experimentally and showed that the bones in females were less tolerant to impact than males.

The Mandible

The mandible is a sturdy structure having been designed to withstand masticatory forces which, as it is prominently placed in the face is exposed to violence. It has developed into a hinged, U-shaped, tooth bearing bone, suspended from the skull and the middle third of the face by ligaments and muscles. Age and function confer considerable structural variation which are not just changes in mineral content. In childhood the angle subtended by the vertical ramus with the horizontal ramus is obtuse, tending towards 90° in youth and early adulthood, thereafter becoming obtuse again, especially in the edentulous. It consists of outer plates of dense compact bone surrounding a spongy medulla which vary in different parts of the mandible. The alveoli which are truly U-shaped sit on the top of the horizontal rami carrying the teeth. Their cortical plate is thin and has little strength, breaking easily. Once the teeth have been shed the alveoli are resorbed. This process may be so extensive that little of the horizontal rami may be left.

As the horizontal rami diverge posteriorly where the alveoli are properly U-shaped they are offset, particularly in the molar region. This means that the mandible has to be particularly strong here to withstand masticatory forces.

The thickness of the cortical plate is greatest and strongest in the third molar region and the mental protruberance. As the vertical rami do not need to be so sturdy their cortical plates are thinner and the cancellous medulla is less bulky, producing a line of potential structural weakness at the junction. In this, the mandible, like the other facial bones, has definite points of weakness through which fractures should be anticipated.[1]

There is a clear understanding between form and function in the mandible although some paradoxes may be seen in the quoted incidence of fractures. Mandibular fractures in children under 6 years comprise less than 1% of the total reported incidence.[9] Between 0 - 14 years incidences of up to 6% has been recorded by some authors.[2] Although children are adventurous and are involved in all kinds of accidents the low incidence is not surprising but it is not completely accounted for by bone elasticity. The facial skeleton is a comparatively small part of the "the head" in young children, who have a prominent cranial vault, the prominence of which exposes it to injury in preference to the jaws. After the age of 5 years the paranasal sinuses develop. There is a downward and forward growth of the jaws, and so the face gradually becomes more prominent. It is partially as a result of this, combined with increased vigorous activity that the quoted four-fold increase in facial fractures is seen.

Mandibular tolerance varies in different parts of the jaw. This can be seen from the different regional incidences of fractures of the mandible. These are crude measurements which may not accurately reflect variable structural strength and have been the cause of much speculation about the mechanism of mandibular fracture. Huelke and Patrick[10] reviewed much of the experimental work ranging from Messerer's experiments in 1880 which showed that pressure on the chin could produce bilateral condyler fractures, to more sophisticated bioengineering studies.

Discussion

A variety of explanations for the observed features of facial fractures have been put forward. Early work suggested that the location of fractures following chin impacts was dependant upon whether or not the mouth was closed at impact. Later it was suggested that most injuries were caused by bending, the fracture beginning opposite the point of impact. Thus contact at the chin flattens it, broadening the arch.

Stress/strain techniques have shown that bone is weaker in tension than it is in compression. Thus if a bone develops areas of high tensile strain, these are more critical from the point of view of fracture formation. Using these techniques, Huelke and Patrick[10] showed that the subcondylar region and the lingual cortical plate exhibit high tensile strain on direct chin impact. Tensile forces tend to pull objects apart or lengthen them whilst compressive forces push them together or shorten them.

Evans,[11] who reviewed the literature and examined the mandible, has looked at the stress and strain patterns produced. Originally it was thought that the highest area of tensile strain was to be found in the middle of the body, parallel with the long axis. Later work suggested that the pattern was changed by loss of the teeth but other workers held that the observed patterns were merely variations within the normal range. Evans[11] showed that, following static chin loading parallel to the long axis, tensile strain was produced parallel to the lower border and at the condyle. When a load perpendicular to the long axis was used it gave lines of tensile strain parallel to the mylohyoid line and at the top of the mandibular notch.

Since the 19th century various workers have expressed interest in the mechanical significance of bone architecture. This is controversial and many of the ideas regarding the role played by stress and strain in bone modelling are not proven. However, it seems logical to suggest that the trabecular pattern of spongy bone can be explained in terms of a trajectorial pattern due to function and genetic predisposition. As these tend to follow long axes and as compact bone is strongest in compression, intermediate in tension and weakest in shear, this supports the trajectorial theory. Moreover the fact that spongy bone is weaker than compact bone compressively, strengthens this opinion.

Huelke and Patrick[10] showed that the subcondylar areas and the lingual aspect of the chin were high tensile strain regions. However, the lingual cortical plate does not reach as high a level as does the somewhat narrower subcondylar area. Since none is weaker in tension than it is in compression, points of high tensile strain are more critical than equivalent compressed areas. Thus it is to be expected that following chin impacts, fractures would be produced in the lingual aspect of the chin and in the subcondylar region.

The clinical relevance of this can be gauged by relating it to the incidence of fractures. This is not as easy as it would appear, because of different methods of classification. Generally it seems that the condylar region is the most frequently fractured area, followed by the body and the angle of the mandible.[4,12,13] However, Kelly and Harrigan[14] relegate the condyle to third place. This may be a result of differences in classification. Some authors have used angle, condyle, molar, canine and incisor to designate regions of the mandible. As Halazonitis[12] says, "this, 'anatomical' division is arbitrary and works best in the dentulous jaw". Other workers have used divisions such as symphysis, body angle, ramus, condyle, coronoid and alveolar. Because of difficulties in identifying these regions radiologically and the variation in definition, such as the width of the angle which is regarded as being wider by some authors than others, the various series are not strictly comparable. Also difficulties may be caused by oblique fractures in dentate areas and the problem of stating exactly the region involved in the edentulous mandible.

It is important to look at the edentulous and dentate mandibles separately because they are mechanically different. Fractures are common in the edentulous after the application of apparently small amounts of force. It is said that clenching the teeth in occlusion may help to mitigate against fracture.[13] However, the elderly, who have the highest incidence of edentulous and severely resorbed mandibles, have fewer mandibular fractures. They are not so physically active and their dentures may absorb some of the forces.[15] Fracture incidence is not necessarily the best index of structural strength because it takes no account of the direction of impact. Fractures may occur at the point of impact or at a distant part. Severe forces, especially those applied to small areas usually produce fractures at the point of impact, but they may also cause others at distant sites. This is seen particularly when the chin is hit where the force is transmitted back along the body of the mandible to the condyles. Moderate impacts over larger areas are more likely to produce fractures at distant sites.

Huelke *et al.*[16] showed that impacts to the chin, irrespective of the state of the dentition, produced subcondylar fractures in more than 50% of cases. Edentulous individuals hit to the side of the chin developed fractures at the angle or in the body of the mandible whereas those with a deciduous or mixed dentition sustained fractures at the impact site. This would be expected because here a large part of the bone is taken up by the developing teeth. Impacts to the angle and/or the body of the mandible tend to produce more fractures there than they do in the subcondylar region, irrespective of the state of the dentition.

Halazonitis[1] found that about one third of all mandibular fractures occurred in the subcondylar region, whilst nearly half were situated in the angle and body areas. He concluded that, when single fractures occurred, the angle was the "weakest" region and that where multiple fractures were produced the subcondylar site was the "weakest" in dentate mandibles. In edentulous mandibles the molar region was the weakest especially when more than one fracture occurred.

This bears out theoretical suggestions based on the mandible's structure, helping to explain some of the clinical and pathological observations made, but it is not a complete explanation, for many factors may influence the nature and pattern of fractures. Children whose bone is "soft" tend to produce greenstick fractures with minimal displacement. In adults the fragments may be widely separated depending upon the path taken by the fracture line and the various distracting forces applied. Considerable displacement is seen in fractures of the body of children's mandibles. Here the fracture tends to be long, and to run obliquely downwards and forwards from the upper boundary of the mandible. In adults they usually run downwards and backwards. High condylar fractures, which are fortunately not common, may damage the growth centre.

Experimental studies have shown that considerable variation exists in the force needed to produce fractures as a result of antero-posterior impacts, due to the complex geometry of the lower jaw.[17] Tolerance increased in proportion to the relative size and area of the mandible. It required about 1,29 times as much force to produce bilateral subcondylar fractures as it did single lesions and 1,29 to 2,12 times as much force to fracture the symphysis. In lateral impacts the body showed a wide range of tolerances, ranging from 1,42 times weaker than the condylar area to being 1,8 times stronger.

It was also shown that the way in which the mandible fails depends upon how it interacts with the skull. In true antero-posterior impacts the mandible rotates backwards so that the neck tissues absorb some of the force. If the force is directed from a more submental position, then condylar fracture is more likely.

Conclusions

The facial bones are commonly injured in accidents and assaults, and therefore are potentially of considerable dento-legal significance. Little work seems to have been done to establish those features which may be relevant in this context. Whilst the anatomical proximity of other facial bones to the mandible makes their involvement likely, the structural differences make them suitable for individual study. This is especially so because of confusion in the way in which different mandibular fractures are classified.

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