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A Manual for Space Analysis in the Mixed Dentition

Abstract: A review of the literature outlining the methods of space analysis and their efficacy was completed using PubMed. Four main methods of space analysis in the mixed dentition were explained and the advantages and limitations of each method was outlined. Prediction tables are effective when applied to the target population from which they were derived. In the case of patients who do not fit the population group from which the correlations are based, radiographic evaluation is the best approach, and computer analysis should be avoided unless a modified equation is available for that particular group. Practically, these modified equations offer the best approach, allowing for the early estimation of space utilizing the width of the mandibular incisors, hence not requiring the use of complex tables or radiographs. However, these methods do not take into account the changes in the anterior-posterior and transverse tooth positions. Moreover, some consider a universal figure for the mesial migration of the first permanent molars to be 1.7 mm, as proposed by Moyers, which has been disputed in the literature. There is evidence to support that the mesial migration of permanent molars following the loss of the primary dentition varies significantly between individuals. Overall, space analysis allows for the estimation of a child's treatment need in relation to crowding and provides a quantitative guideline for the decision to space maintain or extract, depending on the clinical scenario. Although there are several methods which have been developed over the past years, they all have their limitations and these limitations should be considered when space analysis methods are used.
Clinical Relevance: To provide a manual which will facilitate the prediction of the space requirement for unerupted permanent teeth, thus aiding in the diagnosis, treatment planning and management of crowding in the mixed dentition in children.
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Space analysis is the term used in dentistry to estimate the amount of space available within the arch and compare it to the amount of space needed to accommodate the permanent dentition. Space analysis can be used in both the permanent and during the mixed dentition phase. During the mixed dentition, the term space analysis is used to describe the method of estimating the amount of space which is likely to be required for the permanent teeth when they erupt. This paper will focus on the mixed dentition phase to estimate the space required for the erupting permanent dentition. Space analysis has a fundamental role in the treatment planning of the patient in the mixed dentition. It allows for the assessment of space available in the mid-arch region (canine and premolars) within both the upper and lower arches. In 1897, Black determined the average mesio-distal crown widths of all of the primary and permanent teeth.[1] According to Lee-Chan *et al* in 1998, the accurate analysis of space will allow for the treatment planning of serial extractions, the guidance of eruption, space maintenance, space regaining or just periodic observation of the patient until the eruption of the permanent dentition.[2] Ultimately, it is important to quantify the amount of space available within each arch, as treatment will vary depending on the severity of crowding. Nowadays, it is essential to be able to inform parents of the likelihood that their child will have crowded teeth and if intervention will be needed in the future. Classically, there are four main methods by which we analyse space in the orthodontic patient in the mixed dentition:

1. Radiographs, measuring the size of the erupted teeth;[3]
2. Proportionality tables, based on correlating the size of various teeth within the arch;[4,5]
3. Equations, which attempt to estimate the space required by the permanent

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Armamentarium:
- OPG or full series of peri-apical radiographs
- Digital callipers
- Formula (as seen below)

Method:

A. Measure space required using radiographs:

1. OPG, or full series peri-apicals of the patient are taken
2. Using the formula calculate the correction factor by:[12]

$$\frac{\text{Mesio-distal width first primary molar in mouth}}{\text{Mesio-distal width first primary molar on radiograph}} = \text{Correction factor}$$

3. Estimate the true widths of the teeth (unerupted canine and premolars) by:
   Sum of mesio-distal widths of canine and premolars on radiograph x Correction factor = Estimated widths

B. Measure the space available:
   Using dental casts and digital callipers measure the mesio-distal widths of the primary molars and canines

C. Compare the space required with the space available as this can help determine if the patient is likely to have crowding/spacing

Table 1. A manual for space analysis using radiographs.

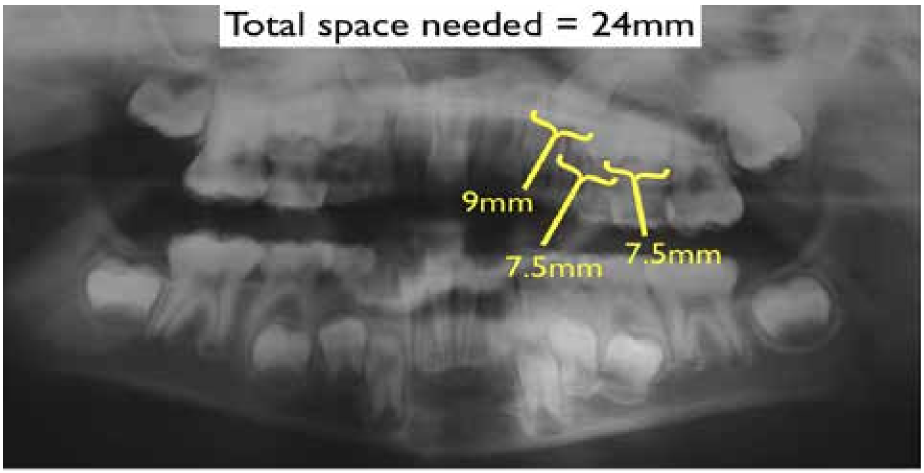

Figure 1. Measure the mesio-distal widths of the unerupted canine, first and second premolars on a radiograph (OPG or peri-apicals).

Figure 2. Measure (using a digital callipers) the mesio-distal widths of the primary canine and molars intra-orally.

canines and premolars;[4,1]

4. A combination of both proportionality tables and radiographs.[6,7]

Methods of space analysis

Radiographs

The method of measuring erupted teeth on radiographs has been used clinically for some time.[3] Specific methods for estimating the approximate size of erupted teeth from radiographs have been suggested by many authors.[4] Nance and others compared the mesio-distal widths of primary molars and canines on dental casts with the mesio-distal widths of the unerupted canines and premolars on periapical radiographs, using long cone paralleling techniques.[3,8] It is recommended that parallel peri-apical radiographs should be used, as paralleling peri-apical radiographs have more accuracy and less distortion than OPGs,[9] especially in the canine region, where the OPG has narrow focus margins, less focus and more distortion. Radiographs can be used to analyse space in both the maxilla and mandible in all ethnic groups, with accuracy being fair to good.[10] However, it can be difficult to produce an undistorted image of the canine, and often the method cannot account for rotated teeth or varied angulations. It is reported that the use of radiographs in space analysis can overestimate the predicted arch length by 3 mm, which has the potential to lead to the unnecessary extraction of teeth.[11] In the growing patient, it is also difficult to justify the radiation dose that is required for a full series of periapicals.[9] Cohen initially described a method which incorporated a correction factor for enlargement on radiographs.[12] The correction factor is calculated by measuring the mesio-distal width of the first primary molar intra-orally using digital callipers and then dividing this measurement by the width measured radiographically. The result is called the correction factor and can then be applied to the unerupted teeth (Figures 1–3, Table 1). However, little if any evidence about the accuracy of this method is available.[12]

Proportionality tables

Seipel was the first to attempt to predict the size of canines and premolars by using erupted teeth as a guide.[13] Proportionality tables attempt to develop a correlation between the teeth erupted in the mouth and the unerupted teeth. Initially, these were developed by attempting to find a correlation between the primary and the permanent unerupted teeth. When these attempts were unsuccessful there were further projects to correlate unerupted permanent teeth with the erupted first permanent molars, which also showed poor correlation.

$$\frac{\text{True width of primary molar}}{\text{Apparent width of primary molar}} = \frac{\text{True width of unerupted premolar}}{\text{Apparent width of unerupted premolar}}$$

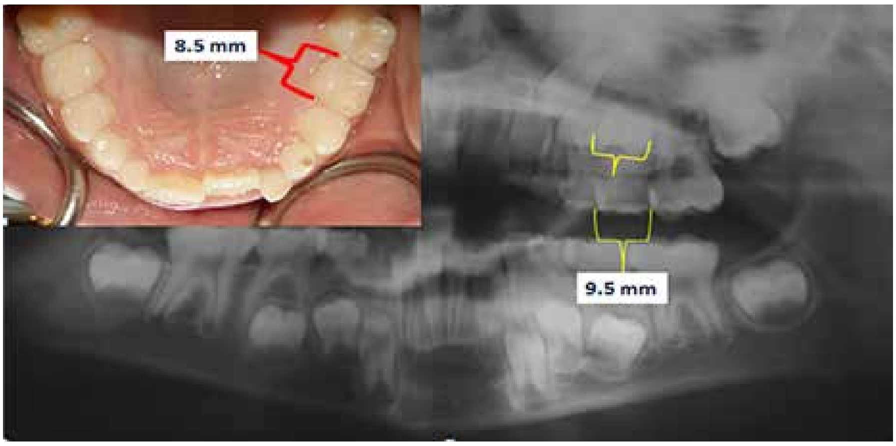

Figure 3. Multiply the correction factor* by the sum of the mesio-distal widths of the unerupted canine, first and second premolars to calculate the space required for these teeth when they erupt. *Correction factor (Cohen, 1959) = Divide the mesio-distal width of the primary first molar intra-orally by the mesio-distal width of first primary molar on the radiograph.

Armamentarium:
- Digital callipers
- Proportionality tables as below

Method:
1. Measure the mesio-distal widths of the mandibular incisors
2. Insert result into table to gain estimated widths of both maxillary and mandibular permanent canines and premolars

Table 2. A manual for space analysis using proportionality tables.

Singh and Nanda in a study of Indian children in 1972 concluded that the sum of the mesio-distal widths of the mandibular incisors showed a strong relationship to the widths of the other teeth.[14] Moyers and Jenkins developed a correlation table between unerupted canines, premolars and incisors which, unlike previous methods, had high correlations.[5,8] They constructed a correlation table which made allowances for different levels of probability. The probability level of 75% is the one which is recommended for clinical use, meaning that 75 out of 100 cases measured will be at the predicted value or less.[5,12] The Moyers prediction table is used by measuring the mesio-distal width of the lower incisors. This number is then compared to figures on the proportionality tables which predict the size of both the lower and upper unerupted canines and premolars. The lower incisors are the preferred reference, owing to the significant discrepancy in the size of the upper lateral incisors. Another advantage of using the lower incisors is their earlier eruption, allowing for prompt analysis (Figures 4–6, Table 2). This means of space analysis was reported by Irwin *et al* as the most likely method to be used as it is quick, simple to use and straightforward to interpret.[10] In addition, no radiograph is required to assess the widths of the developing permanent dentition.[10] A number of investigators have noted a trend towards an increase in tooth size in successive generations, implying that the values used in the tables tend to underestimate the sizes of the unerupted teeth in a modern population.[15,16] Moyers also advised that his table should be used with caution as there is a biological variation in the transition from primary to permanent dentition. The mesial movement of the first molars following the loss of the primary dentition varies significantly between individuals.[5,17]

Another limitation of this method was that the data were obtained from an unspecified number of white North American children. The authors gave very little detail about the participants, which is a major limitation of this study. The systems accuracy is reasonable when used with Northern European white children, however, its use with other ethnicities is limited. Thus, one of the limitations of this method is that it is race specific. Singh and Nanda, as a result, concluded that, owing to racial discrepancies in tooth size, data collected from one racial group for means of space analysis could not be transferred reliably or accurately to another ethnic group.[14] Several studies were then conducted on different racial populations to develop a correlation table that was specific to them. However, it is important to note that, although the data gained from these studies were often reported as significant and reliable, none of the studies was validated, casting doubt in relation to their accuracy. Therefore, more studies on the different ethnic groups are required to validate the proportionality tables.

Equation

In 1974, Tanaka and Johnston described an equation to assess the space available for the developing dentition.[4] Based on a European population, a formula was created which relates the widths of erupted teeth to that of unerupted teeth. They formulated a linear regression table similar to that of Moyers but were able to develop a newer equation which reached the 75% probability level. In this method, radiographs and tables are not required. The mesio-distal width of the four lower incisors are combined and then divided in two. In the mandible, 10.5 mm is then added, while in the maxilla 11 mm is added. The result equals the predicted widths of the canine and premolars. This method is arguably the quickest and easiest of all the methods of space analysis (Figure 7, Table 3).[11]

This equation has also been found to be ethnic specific, which is not a surprise since it was developed based on a white ethnic population table.

In a study of Bengali children in 2012, Dasgupta and Zahir reported that the methods of space analysis adapted by Moyers and Tanaka and Johnston, although fairly comparable, were not as accurate in the Bengali population as it was for those of Northern European descent.[1] In this study, Dasgupta and Zahir designed an altered regression

4 Probability chart for predicting the sum of the widths of maxillary 3,4&5 using the sum of the widths of the mandibular incisors

21|12=	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
95%	21.6	21.8	22.1	22.4	22.7	22.9	23.2	23.5	23.8	24.0	24.3	24.6
85%	21.0	21.3	21.5	21.8	22.1	22.4	22.6	22.9	23.2	23.5	23.7	24
75%	20.6	20.9	21.2	21.5	21.8	22.0	22.3	22.6	22.9	23.1	23.4	23.7
65%	20.0	20.6	20.9	21.2	21.5	21.8	22.0	22.3	22.6	22.8	23.1	23.4
50%	20.2	20.3	20.6	20.8	21.1	21.4	21.7	21.9	22.2	22.5	22.8	23.0
35%	19.6	19.9	20.2	20.5	20.8	21.0	21.3	21.6	21.9	22.1	22.4	22.7
25%	19.4	19.7	19.9	20.2	20.5	20.8	21	21.3	21.6	21.6	21.9	22.4
15%	19.0	19.3	19.6	19.9	20.2	20.4	20.7	21.0	21.3	21.5	21.8	22.1
5%	18.5	18.8	19.0	19.3	19.6	19.9	20.1	20.4	20.7	21.0	21.2	21.5

Probability chart for predicting the sum of the widths of mandibular 3,4&5 using the sum of the widths of the mandibular incisors

21|12=	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
95%	21.1	21.4	21.7	22.0	22.5	22.6	22.9	23.2	23.5	23.8	24.1	24.4
85%	20.5	20.8	21.1	21.4	21.7	22.0	22.3	22.6	22.9	23.2	23.5	23.8
75%	20.1	20.4	20.7	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1	23.4
65%	19.8	20.1	20.4	20.7	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1
50%	19.4	19.7	20.0	20.3	20.6	20.9	21.2	21.5	21.8	22.1	22.4	22.7
35%	19.0	19.3	19.6	19.9	20.2	20.5	20.8	21.1	21.4	21.7	22.0	22.3
25%	18.7	19.0	19.3	19.6	19.9	20.2	20.5	20.8	21.1	21.4	21.7	22.0
15%	18.4	18.7	19.0	19.3	19.6	19.8	20.1	20.4	20.7	21.0	21.3	21.6
5%	17.7	18.0	18.3	18.6	18.9	19.2	19.5	19.8	20.1	20.4	20.7	21.0

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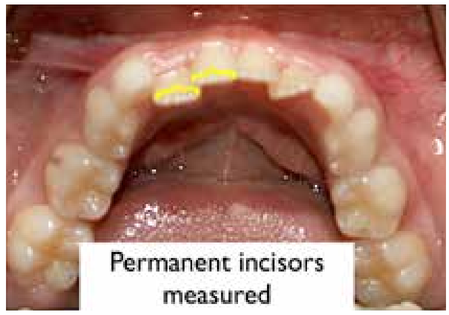

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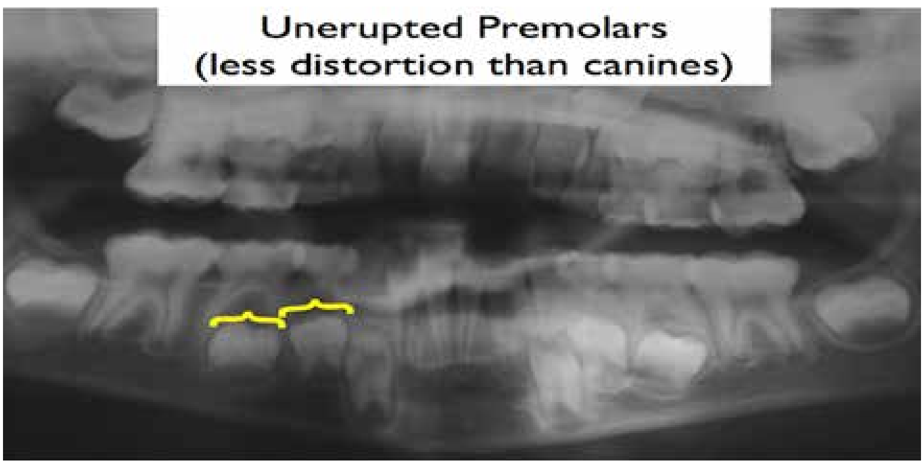


Figures 4, 5 and 6. Using Moyers and Jenkins tables (1973) the sum of the mesio-distal widths of the mandibular incisors are measured and inserted into a table to find the resultant estimated space required for the unerupted permanent canine, first premolar and second premolar within 75% probability.[5]

equation to allow for more accurate space analysis predictions for the Bengali populations. However, the sample size used in this paper was relatively limited.

In 2008, Al-Bitar *et al* examined the applicability of the Tanaka and Johnston method of space prediction in a specifically Jordanian population, and aimed to develop a modified table to be utilized if required.[18] This study involved analysis of children attending schools. Previous studies often only included data gained from a referred population, resulting in selection bias. It was concluded that the Tanaka and Johnston method of prediction overestimated the mesio-distal widths of both the maxillary and mandibular buccal segments when compared with measurements on study models using digital callipers. Therefore, this method of space analysis has limited value when applied to a Jordanian population. Interestingly, when they analysed the results for males and females separately, it became apparent that, in the male Jordanian population, patients demonstrated larger mandibular incisors, mandibular and maxillary canines and premolar segments. Therefore, any future attempts to predict space in the mixed dentition in such a population should divide subjects by gender before the application of the corresponding equation.[18]

Proportionality tables and radiographs

Proportionality tables and radiographs use a combination of measurements from erupted teeth and radiographs of unerupted teeth to estimate the space required relative to the space available. The two methods of analysis were combined as it was thought that this would provide a more accurate account of tooth size discrepancy.[19] In 1958, Hixon and Oldfather published a method for prediction of the mesio-distal widths of the mandibular canines and premolars only in mixed dentition patients.[7] Data from the Iowa Facial Growth Study was used to provide an equation to predict the future canine and premolar widths. The accuracy of the Hixon and Oldfather mixed dentition prediction method is subject to debate. Some limitations include that the space was analysed individually side-by-side

Tanaka and Johnston 1974[4]

Armamentarium:
- Digital callipers
- Formula (as seen below)

Method:
1. To determine mesio-distal widths of unerupted mandibular canine and premolars (in ONE quadrant): Measure the width of the mandibular incisors. Divide this result by half and add 10.5 mm

$$\frac{1}{2} \times \text{MD width of lower 2-2} + 10.5\text{ mm} = \text{mandibular 3, 4 \& 5}$$

2. To determine mesio-distal widths of unerupted maxillary canine and premolars (in ONE quadrant): Measure the width of the mandibular incisors. Divide this result by half and add 11 mm

$$\frac{1}{2} \times \text{MD width of lower 2-2} + 11\text{ mm} = \text{maxillary 3, 4 \& 5}$$

Table 3. A manual for space analysis using regression equations.

Probability table for predicting the widths of maxillary canines, first premolars and second premolars from mandibular lateral and central incisors in millimeters.

	Mandibular lateral and central incisors (mm)													
mm	20.5	21.0	21.5	22.0	22.5	23.0	23.0	24.0	24.5	25.0	25.5	26.0	26.5	27.0
95%	22.2	22.5	22.7	23.0	23.2	23.5	23.7	23.9	24.2	24.5	24.7	25.0	25.2	2.5.5
85%	21.7	21.9	22.2	22.4	22.7	22.9	23.2	23.4	23.7	24.0	24.2	24.5	24.7	25.0
75%	21.4	21.6	21.9	22.1	22.4	22.6	22.9	23.1	23.4	23.6	23.9	24.1	24.4	24.7
65%	21.1	21.4	21.6	21.9	22.1	22.4	22.6	22.9	23.1	23.4	23.6	23.9	24.2	24.4
50%	20.8	21.0	21.3	21.5	21.8	22.1	22.3	22.6	22.8	23.1	23.3	23.6	23.8	24.1
35%	20.5	20.7	21.0	21.2	21.5	21.7	22.0	22.2	22.5	22.7	23.0	23.5	23.5	23.7
25%	20.2	20.5	20.7	21.0	21.2	21.5	21.7	22.0	22.2	22.5	22.7	23.0	23.2	23.5
15%	19.9	20.1	20.4	20.7	20.9	21.2	21.4	21.7	21.9	22.2	22.4	22.7	22.9	23.2
5%	19.4	19.6	19.9	20.1	20.4	20.6	20.9	21.1	21.4	21.7	21.9	22.2	22.4	22.7

Probability table for predicting the widths of mandibular canines, first premolars and second premolars from mandibular lateral and central incisors in millimeters.

	Mandibular lateral and central incisors (mm)													
mm	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0
95%	21.6	21.9	22.1	22.4	22.7	22.9	23.2	23.5	23.7	24.0	24.3	24.5	24.8	25.2
85%	21.1	21.3	21.6	21.9	22.1	22.4	22.7	23.0	23.2	23.5	23.8	24.0	24.3	24.6
75%	20.8	22.1	21.3	21.6	21.8	22.1	22.3	22.6	22.9	23.2	23.4	23.7	24.0	24.3
65%	20.5	20.8	21.1	21.3	21.6	21.9	22.1	22.4	22.7	22.9	23.2	23.5	23.7	24.0
50%	20.2	20.5	20.7	21.0	21.3	21.5	21.8	22.1	22.4	22.7	22.9	23.2	234	23.7
35%	19.9	20.1	20.4	20.7	2-.9	21.2	21.5	21.7	22.0	22.3	22.6	22.9	23.5	23.3
25%	19.6	19.9	20.1	20.4	20.7	21.0	21.2	21.5	21.8	22.0	22.3	22.6	22.8	23.1
15%	19.3	19.6	19.8	20.1	20.4	20.6	20.9	21.2	21.5	21.7	22.0	22.3	22.5	22.8
5%	18.8	19.0	19.3	19.6	19.9	20.1	20.4	20.7	20.9	21.2	21.5	21.7	22.0	22.3

Figure 7. Probability tables for predicting the widths of maxillary and mandibular canines, first premolars and second premolars from mandibular lateral and central incisors in millimeters.[4]

rather than as a whole arch. Also, they only considered information gained from the mandibular arch. Generally nowadays, it is accepted that this method routinely underestimates actual tooth size. Furthermore, the sample size was small and the population was not well represented.[5,11]

In 1980, Stayley and Kerber revised the Hixon and Oldfather graph in order to increase the sample size and to gain data from a clearly defined population type (Figures 8–10, Table 4).[6] The use of callipers allowed for measurement to the nearest 0.05 mm, making the findings more accurate than those gained with the Boley gauge used by Hixon and Oldfather. In addition, Stayley and Kerber had the opportunity to use computer technology to analyse data and chose to exclude teeth which were rotated. They also considered measurements from both sides of the arch, where Hixon and Oldfather had only considered data from the left side of the mouth. Following this the Stayley and Kerber method was shown to be a more predictable and reliable means of space analysis.[10] It is completed by measuring the mesio-distal widths of the unerupted mandibular canine and premolar using peri-apical radiographs taken with a long-cone technique. This is then compared with the mesio-distal widths of the mandibular incisors. Although this method has been shown to be reliable, it is thought to underestimate the space required by 0.2–0.4 mm and does require peri-apical radiographs for analysis.[6]

Conclusion

Space analysis is a valuable adjunct in the treatment planning of the patient in mixed dentition. The prediction tables work well when applied to the target population from which they were derived. If the patient is of North European origin, the predictions based on the combined study-model/radiographic method have the least variable overall validity.[12] This makes the Stayley-Kerber method the most accurate reported, followed by the Tanaka-Johnston, and then that of Moyers.[12]

In the case of the patient who does not fit the population group from which the correlations are based, radiographic evaluation is the best approach, and computer analysis should be avoided unless a modified equation from Tanaka-Johnston is available for that particular group. However, Luu *et al* in 2011 reported that polymorphisms based on ethnicity, jaw, sex or side of mouth did not significantly influence the validity of the results of the space determination.[8]

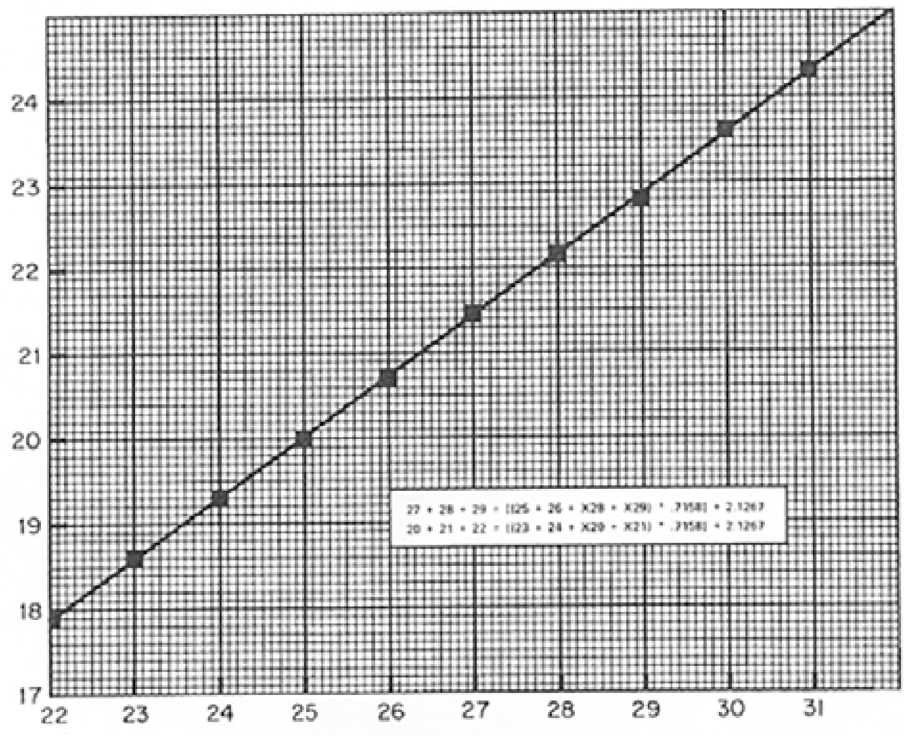
Practically, Tanaka-Johnston offers the best approach, allowing the early estimation of space by using the mandibular incisors, while not requiring the use of complex tables or radiographs.[4] On the other hand, the methods listed assume that the anterior-posterior and transverse positions of the teeth will remain constant as growth continues, making it more of a 'snapshot in time' rather than a prediction of what is to come.[8] It is generally accepted that inter-canine growth will continue to the age of nine in the mandible and up to 13 or 14 in the maxilla.[20,21] These methods also make no allowances for anomalies in tooth size and the majority do not account for individuals of variable ethnic backgrounds. It is also possibly naive to assume a universal figure for the mesial migration of the first molar to be 1.7 mm, as proposed by Moyers, as a study by Bishara *et al* reported that only 50% of first permanent molars shifted mesially during the transition from primary to permanent dentition.[17] While space analysis has some predictive value, other factors that must be considered are the depth of the curve of Spee, the cephalometric anterior-posterior position of the lower incisors, the Angle relationship of the permanent molars, and the buccopalatal position of the molars in the arch.[6] Overall, space analysis is a useful method to estimate a child's treatment need in relation to crowding. It also provides a means of quantifying the possibility that orthodontic intervention may or may not be required. Depending on the results obtained, it has the possibility of influencing the decision to space maintain or extract, depending on the clinical scenario.

References

1. Dasgupta B, Zahir S. Comparison

8

HIXON AND OLDFATHER PREDICTION GRAPH
(STALEY AND KERBER REVISION)



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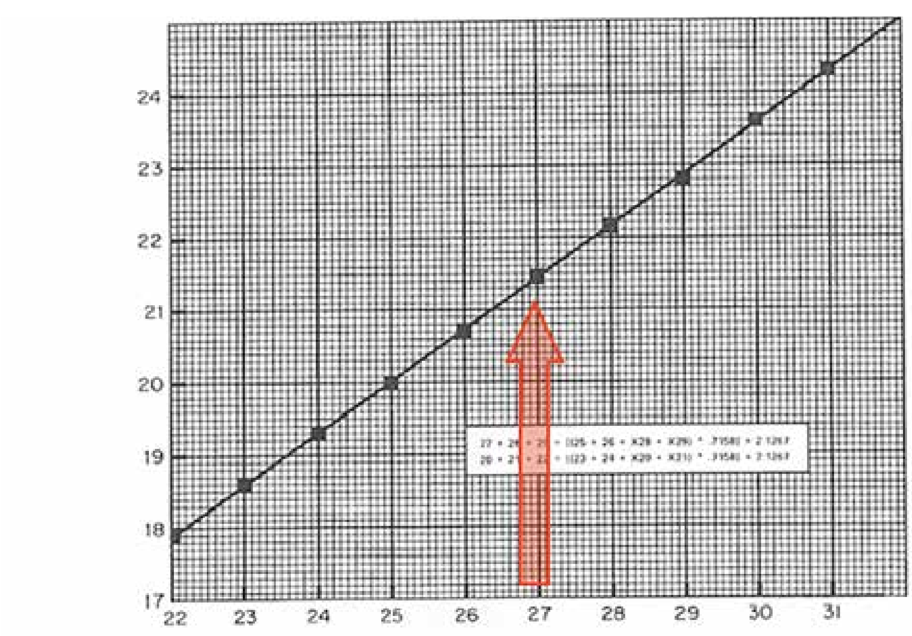
HIXON AND OLDFATHER PREDICTION GRAPH
(STALEY AND KERBER REVISION)



Sum (UE premolars) & (central and lateral incisors)

Figures 8, 9 and 10. The modification of the Hixon and Oldfather prediction graph, as produced by Stayley and Kerber in 1980, may be used by calculating the sum of the mesio-distal widths of the unerupted premolars added with the sum of the mesio-distal widths of the erupted central and lateral incisors. This figure is then inserted into the prediction table and the result found on the y-axis is the estimated space required for the unerupted canine, first premolar and second premolar.[6]

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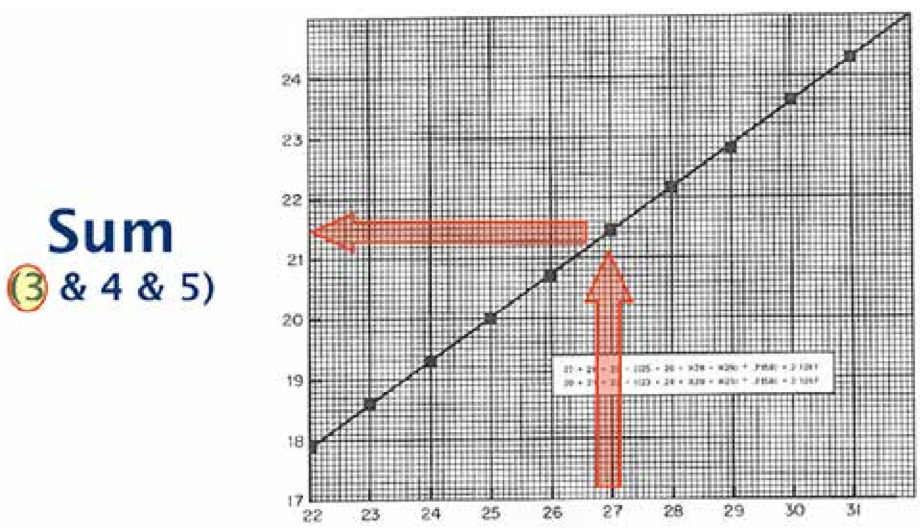
10

HIXON AND OLDFATHER PREDICTION GRAPH
(STALEY AND KERBER REVISION)



Sum (UE premolars) & (central and lateral incisors)

Armamentarium:
- Digital callipers
- Peri-apical radiographs of the unerupted first and second premolars
- Prediction table

Method:
1. Measure the space available using a digital callipers from the mesial surface of the mandibular permanent molars to the distal of the lateral incisors
2. Measure the lower left lateral and central permanent incisor, and correspond it to the space available on the same side for eruption of the permanent canines and premolars
3. Measure the lower right lateral and central permanent incisor, and correspond it with the table to the space available on the same side for the eruption of the right canine and premolar

Table 4. A manual for space analysis using proportionality tables and radiograph.