A comparison of methods for predicting the size of unerupted permanent canines and premolars

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SUMMARY The aim of this study was to examine the reliability of eight methods for determining the mesio-distal crown diameters (MDD) of the permanent canines and premolars (C, P_1, and P_2). The study models of 120 children (60 boys and 60 girls) aged from 14 to 18 years treated in orthodontic clinics were measured using Seipel's method, with callipers accurate to 0.01 mm. The correlation coefficients were determined between the MDD of C, P_1, and P_2 measured on the study models and the sums calculated using various other methods.

The correlation coefficients derived by comparison with the methods of Moyers, Tanka and Johnston, Droschl *et al.*, Legović and Hauz, and Berendonk–Nawrath showed a tendency to over-estimate the MDD of C, P_1, and P_2, while the regression methods of Gross and Hasund, Bachmann, and Tränkmann *et al.* under-estimated the values. Bachmann's method appeared to give the most reliable results.

Introduction

During assessment of children in the mixed dentition, it is necessary to predict the width of the crowns of the unerupted canines and premolars (C, P_1, and P_2). The sum of the crown widths of these teeth has been reported to be lower than that of their predecessors (Brown *et al.*, 1980; Steigman *et al.*, 1982; Foster and Grundy, 1986; Löhr *et al.*, 1987).

There are four methods which are commonly used for prediction of the width of the mesio-distal crown diameters (MDD) of the unerupted C, P_1, and P_2.

1. Application of mean values for the MDD of C, P_1, and P_2 (Mühlreiter, 1874; Schwarz, 1931; Steigman *et al.*, 1982; Pancherz and Schäffer, 1999).
2. Correlation or regression methods (Ballard and Whylie, 1947; Rehak, 1960; Berendonk, 1965; Broechmann and Ahen, 1965; Nawrath, 1968; Mühlberg *et al.*, 1969; Fantoni, 1972; Moyers, 1973; Tanaka and Johnston, 1974; Droschl *et al.*, 1977; Bachmann, 1986; Gross and Hasund, 1989; Legović and Hautz, 1989; Tränkmann *et al.*, 1990).
3. Correlation and radiographic methods (Hixon and Oldfather, 1958; Stähle, 1958; Lutz, 1969; Herren and Reisfeld, 1970).
4. Radiographic methods (Nance, 1947; Foster and Whylie, 1958; Cohen, 1959).

Methods for predicting the MDD of unerupted canines and premolars vary even within countries. In Croatia, the method described by Moyers (1973) is most frequently used. However, the findings of Lapter and Slivijanovska (1974) and Papa (1979) demonstrated that it tends to be unreliable for the Croatian population. Legović and Hautz (1989) studied the reliability of predictions using the sum of the lower incisors as the known variable. Other authors (Bachmann, 1986; Gross and Hasund, l989; Tränkmann *et al.*, 1990) have used regression analysis for predicting the MDD of the unerupted canines and premolars. Using these methods, significantly more reliable results were achieved. The aim of this study was to examine eight methods of predicting the MDD of unerupted canines and premolars and, on the basis of the results, to determine the most reliable method for the Croatian population.

Materials and methods

The study models of 120 children (60 boys and 60 girls, aged 14 to 18 years), treated in orthodontic clinics in the city of Zagreb, were examined. The following selection criteria were used.

1. All subjects were in the permanent dentition in both arches.
2. No active caries or restorations.
3. No obvious anomalies regarding number, form, size, or structure.
4. The mesio-distal and bucco-lingual surfaces of the crowns of all permanent teeth were intact.
5. The arches were well aligned to allow relatively easy and consistent measurements

The mesio-distal and bucco-lingual dimensions of the first and second permanent incisors, the permanent canines, the first and second permanent premolars, and the first permanent molars were measured on the study models in all four quadrants.

The measurements were undertaken according to the method described by Seipel (1946) using a calibrated digital calliper with an accuracy of 0.01 mm. All measurements were carried out twice by one author (AN) and the mean of the two values was used. The correlation coefficient between the first and the second measurements ranged from $r = 0.85–0.99$. Assessment of the method error (ME) for the two measurements was based on the following formula:

$$ME = \sqrt{\frac{\sum d^2}{2n}},$$

where d is the difference between first and second measurement and n the number of double measurements.

Correlation coefficients were calculated between the sums of the MDD of C, P_1, and P_2 in both arches, as measured on the study models, and the predicted MDD of C, P_1, and P_2, using each of eight different methods.

For the methods proposed by Moyers (1973), Legović and Hautz (1989), and Droschl *et al.* (1977) the predicted sum of the widths of the crowns of canines and premolars were taken from the relevant tables (Berendonk, 1965; Nawrath, 1968; Moyers, 1973; Tanaka and Johnston, 1974; Legović and Hautz, 1989), taking into account the incisor measurements from the study models.

The predicted sum of the widths of the canines and premolars according to the method of Gross and Hasund (1989) was determined according to the following formula:

Maxilla = $0.61 \times (22) + 0.80 \times (32) + 0.65 \times (VOD\,36) + 5.66$,
Mandible = $0.63 \times (22) + 0.84 \times (32) + 0.67 \times (VOD\,36) + 4.47$,

where 22 and 32 represent the MDD of the crowns of the upper and lower left lateral incisors and VOD 36 the vestibulo-oral diameter of the lower left first permanent molars measured on the casts.
Bachmann's (1986) method used the following formula:

Maxilla = $0.81 \times (22) + 0.54 \times (26) + 0.56 \times (32) + 6.98$,
Mandible = $0.71 \times (22) + 0.39 \times (26) + 0.86 \times (32) + 6.96$,

where: 22, 26, and 32 represent the MDD of the crowns of the upper and lower left lateral incisors and left upper first permanent molars.

Finally, the method proposed by Tränkmann *et al.* (1990) used the following formula:

Boys: maxilla = $0.93X + 5.50$, mandible = $0.94X + 5.06$;
Girls: maxilla = $0.99X + 4.47$, mandible = $0.96X + 4.43$,

where, X represents the sums of the widths of the crowns of the lateral incisor and first permanent molars in the maxilla or mandible.

Results

The results of the repeatability study showed a ME of 0.17 mm.

Since statistically relevant differences were observed between genders with respect to the mesio-distal and bucco-lingual diameters of the teeth (except for I_1), the sample was divided according to gender. The correlation coefficients between the same teeth on the left and right sides of the arch were high (girls: maxilla 0.72–0.95, mandible 0.78–0.93; boys: maxilla 0.88–0.97, mandible 0.88–0.96). The canonic correlation coefficients between the right and left side were greater than 0.97 in all cases. These findings justify the use of the size of teeth on either side (Staley *et al.*, 1979) and it was therefore decided to accept the measurements on the left side of the dentition.

Tables 1 and 2 show the order of reliability of the prediction methods for females and males. The results demonstrate generally lower correlations for females than for males. For females, the correlations were also lower for the mandible than the maxilla. For males, obvious differences were detected between the maxilla and mandible.

Table 1 Prediction coefficient (r) ranked according to the reliability of the sums of the mesio-distal diameters of C, P_1, and P_2 crowns in female patients.

Maxilla	r	Mandible	r
Bachmann (1986)	0.72	Tränkmann *et al.* (1990)	0.71
Tanaka and Johnston (1974)	0.70	Gross and Hasund (1989)	0.58
Droschl *et al.* (1977)	0.68	Tanaka and Johnston (1974)	0.54
Gross and Hasund (1989)	0.68	Legović and Hautz (1989)	0.53
Tränkmann *et al.* (1990)	0.67	Bachmann	0.51
Legović and Hautz (1989)	0.66	Droschl *et al.* (1977)	0.48
Moyers (1973)	0.62	Moyers (1973)	0.40
Berendonk (1965) and Nawrath (1968)	0.55	Berendonk (1965) and Nawrath (1968)	0.36

Table 2 Prediction coefficient (r) ranked according to the reliability of the sums of the mesio-distal diameters of C, P_1, and P_2 crowns in male patients.

Maxilla	r	Mandible	r
Bachmann (1986)	0.81	Bachman (1986)	0.81
Gross and Hasund (1989)	0.78	Gross and Hasund (1989)	0.79
Tränkmann *et al.* (1990)	0.76	Moyers (1973)	0.77
Tanaka and Johnston (1974)	0.72	Tanaka and Johnston (1974)	0.77
Droschl *et al.* (1977)	0.71	Legović and Hautz (1989)	0.75
Moyers (1973)	0.71	Tränkmann *et al.* (1990)	0.75
Legović and Hautz (1989)	0.68	Droschl *et al.* (1977)	0.71
Berendonk (1965) and Nawrath (1968)	0.67	Berendonk (1965) and Nawrath (1968)	0.65

The differences in millimetres between the measured and predicted values of the sum of the MDD of C, P_1, and P_2 with respect to the method used are shown in Tables 3, 4, 5, and 6.

The Berendonk–Nawrath method proved to be least reliable for both genders and for both arches, with correlation coefficients ranging from 0.36 to 0.55 for females and from 0.65 to 0.67 for males. The predicted values were higher than the measured values in 68.3 per cent of cases in the maxilla and in 63.3 per cent of cases in the mandible. The discrepancies were between 1.00 and 1.50 mm in the maxilla and 1.50 and 2.00 mm in the mandible.

The method of Tanaka and Johnston proved to be the most reliable with correlations between 0.54 and 0.77. The predicted values were higher than the measured values in 85 per cent of cases in the maxilla and in 77.5 per cent of cases in the mandible. The positive differences ranged from 0.01 to 2.00 mm, and the negative differences from 1.00 to 0.01 mm in the maxilla, and from 0.50 to 0.01 in the mandible.

The correlation coefficients between predicted and measured dimensions using the method of Legović and Hautz were between 0.53 and 0.75. The predicted values were higher than the measured values by 84.2 per cent in the maxilla and by 70.8 per cent in the mandible. Positive differences were most found frequently, ranging from 0.01 to 1.50 mm in both arches and negative differences from 0.50 to 0.01 mm.

The correlation coefficients between the method of Droschl et al. and the true values ranged from 0.48 to 0.71. In 73.3 (maxilla) and 82.5 (mandible) per cent of the cases the predicted values were higher than those measured. The differences in the maxilla ranged between 0.01 and 1.50 mm for positive differences or between 1.00 and 0.01 mm for negative differences. In the mandible, the differences ranged from 0.50 to 2.00 mm.

In the maxilla, the correlation coefficients between the measured dimensions and those predicted when applying Moyers' method were 0.62 mm for females and 0.71 mm for males. In the mandible, the values were 0.4 and 0.77 mm, respectively. With this method, the predicted values were higher than the measured values in 86.7 per cent cases in the maxilla and 82.5 per cent cases in the mandible. The differences in the maxilla ranged from 1.00 to 2.00 mm, and in the mandible from 1.00 to 2.50 mm.

The Gross and Hasund regression method showed relatively high correlation coefficients between the measured and the predicted MDD of the crowns of C, P_1, and P_2. For females, the correlation was 0.68 in the maxilla and 0.79 in the mandible. The predicted values were lower than the measured values in 59.2 per cent of cases in the maxilla and in 68.3 per cent of cases in the mandible. Positive values in both jaws ranged from 0.01 to 1.00 mm and negative values from 1.50 to 0.1 mm in the maxilla and 2.50 to 0.01 mm in the mandible.

Bachmann's method showed the highest correlations for both the maxilla and mandible for males and in the maxilla for females. The predicted values were lower than the

Table 3 Differences between the measured and predicted values of the sums of the mesio-distal diameters of the maxillary C, P_1, and P_2 crowns with regard to the prediction procedure ($N = 120$).

Maxilla Differences (mm)	Moyers (1973) N	%	Legović and Hautz (1989) N	%	Droschl et al. (1977) N	%	Berendonk (1965) and Nawrath (1968) N	%	Tanaka and Johnston (1974) N	%	Gross and Hasund (1989) N	%	Tränkmann et al. (1990) N	%	Bachmann (1986) N	%
Under −3.01	0	—	0	—	0	—	0	—	0	—	0	—	1	0.83	0	
−3.00 to −2.51	0	—	0	—	0	—	0	—	0	—	0	—	1	0.83	1	0.83
−2.50 to −2.01	0	—	0	—	0	—	0	—	0	—	3	2.50	1	0.83	1	0.83
−2.00 to −1.51	0	—	4	3.33	3	2.50	3	2.50	3	2.50	3	2.50	5	4.17	6	5.00
−1.50 to −1.01	8	6.67	4	3.33	8	6.67	12	10.00	6	5.00	14	11.67	14	11.67	12	10.00
−1.00 to −0.51	8	6.67	11	9.17	21	17.50	21	17.50	9	7.50	13	10.83	26	21.67	27	22.50
−0.50 to −0.01	0	—	0	—	0	—	0	—	0	—	38	31.67	29	24.17	26	21.67
0	25	20.83	17	14.17	0	—	0	—	24	20.00	2	1.67	0	—	0	—
0.01 to 0.50	27	22.50	33	27.50	28	23.33	21	17.50	32	26.67	31	25.83	28	23.33	33	25.50
0.51 to 1.00	32	26.67	33	25.50	28	23.33	33	27.50	28	23.33	9	7.50	12	10.00	10	8.33
1.01 to 1.00	11	9.17	10	8.33	21	17.50	13	10.83	11	9.17	5	4.17	2	1.67	3	2.50
1.51 to 2.00	5	4.17	2	1.67	5	4.17	7	5.83	2	1.67	1	0.83	0	—	1	0.83
2.01 to 2.50	4	3.33	3	2.50	2	1.67	5	4.17	5	4.17	1	0.83	0	—	0	—
2.51 to 3.00	0	—	3	2.50	3	2.50	2	1.67	0	—	0	—	0	—	0	—
Over 3.01	0	—	3	2.50	1	0.83	1	0.83	0	—	0	—	1	0.83	0	—

Table 4 Differences between the measured and predicted values of sums of mesio-distal diameters of the mandibular C, P$_1$, and P$_2$ crowns with regard to the prediction procedure (N = 120).

Mandible Differences (mm)	Moyers (1973)		Legović and Hautz (1989)		Droschl et al. (1977)		Berendonk (1965) and Nawrath (1968)		Tanaka and Johnston (1974)		Gross and Hasund (1989)		Tränkmann et al. (1990)		Bachmann (1986)	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Under −3.01	0	—	0	—	0	—	0	—	0	—	0	—	1	0.83	0	—
−3.00 to −2.51	0	—	0	—	0	—	0	—	0	—	0	—	1	0.83	1	0.83
−2.50 to −2.01	0	—	0	—	0	—	0	—	0	—	3	2.50	1	0.83	1	0.83
−2.00 to −1.51	0	—	0	—	0	—	2	—	0	—	3	2.50	5	4.17	6	5.00
−1.50 to −1.01	1	—	4	3.33	3	2.50	3	2.50	3	1.67	14	11.67	14	11.67	12	10.00
−1.00 to −0.51	8	6.67	4	3.33	8	6.67	12	10.00	6	2.50	13	10.83	26	21.67	27	22.50
−0.50 to −0.01	8	6.67	11	9.17	21	17.50	21	17.50	9	10.00	38	31.67	29	24.17	26	21.67
0	0	—	0	—	0	—	0	—	0	17.50	2	1.67	0	—	0	—
0.01 to 0.50	25	20.83	17	14.17	28	23.33	21	17.50	24	23.33	31	25.83	28	23.33	33	25.50
0.51 to 1.00	27	22.50	33	27.50	28	23.33	33	27.50	32	23.33	9	7.50	12	10.00	10	8.33
1.01 to 1.50	32	26.67	33	25.50	21	17.50	13	10.83	28	17.50	5	4.17	2	1.67	3	2.50
1.51 to 2.00	11	9.17	10	8.33	5	4.17	7	5.83	11	4.17	1	0.83	0	—	1	0.83
2.01 to 2.50	5	4.17	2	1.67	2	1.67	5	4.17	2	1.67	1	0.83	0	—	0	—
2.51 to 3.00	4	3.33	3	2.50	3	2.50	2	1.67	5	4.17	0	—	0	—	0	—
Over 3.01	0	—	3	2.50	1	0.83	1	0.83	0	—	0	—	1	0.83	0	—

measured values in 60.8 per cent of cases in the maxilla and in 68.3 per cent in the mandible. The differences were in the range of −1.50 to 1.00 mm in the maxilla and −2.00 to 1.00 mm in the mandible.

Using the method described by Tränkmann et al., the correlations between predicted and measured dimensions were as follows—for females: maxilla 0.67 and mandible 0.71, and for males: maxilla 0.76 and mandible 0.75. The predicted values were lower than measured values in the maxilla in 64.2 per cent and in the mandible in 71.7 per cent of cases. In the maxilla, positive differences ranged from 0.01 to 1.00 mm and from −2.00 to 1.00 mm in the mandible.

Discussion

These results of this study show that all methods of predicting the crown widths of C, P$_1$, and P$_2$ had limitations. Moyers' method, which is frequently used in practice, tended to over-predict the values and was shown to be less reliable for females. Many authors have reported over-prediction of values when this method is used in different populations (Seipel, 1946; Foster and Whylie, 1958; Lapter and Slivijanovski, 1974; Papa, 1979; Bachmann, 1986; Gross and Hasund, 1989; Tränkmann et al., 1990; Schirmer and Wiltshire, 1997). According to Droschl et al. (1977), when the sum of the lower incisors is below 22.0 mm, Moyers' predicted values tend to be below the true value. In contrast, when the sum is above 24.6 mm, the predicted value is higher.

Margane (1996) used the method described by Pancherz and Schäffer (1999) and found that the calculated values were larger than those obtained when using Moyers' method. Pancherz and Schäffer (1999) suggested the use of a mean value of 22.0 mm for the crown widths of C, P$_1$, and P$_2$, as this value had a confidence level of 83.5 per cent in predicting space deficiency in the maxilla and mandible. This value appeared more accurate and, at the same time, less complex, than Moyers' method. Although Proffit and Fields (1992) acknowledged that the predicted crown widths using Moyers' method were over-estimated, they still recommended the method for children in northern Europe.

The methods described by Droschl et al. (1977) and Legović and Hautz (1989) are similar to Moyers' method although Droschl et al. (1977) adapted their tables according to the gender of the child. Their study found that the predicted values were higher compared with the actual values measured on the models. However, it has been claimed that both methods are as reliable as Moyers' method.

In the present study, the Berendonk–Nawrath method proved to be the least reliable for both genders and in both arches. This is in agreement with Bachmann (1986) and Tränkmann et al. (1990) who also drew attention to the high predicted values using this method.

Table 5 Frequency of positive and negative differences between the measured and predicated values of the sums of the mesio-distal diameters of C, P_1, and P_2 crowns in the maxilla ($N = 120$).

Maxilla

Author	Positive differences		Negative differences	
	N	%	N	%
Moyers (1973)	104	86.7	16	13.3
Legović and Hautz (1989)	101	84.2	19	15.8
Droschl et al. (1977)	88	73.3	32	26.7
Berendonk (1965) and Nawrath (1968)	82	68.3	38	31.7
Tanaka and Johnston (1974)	102	85.0	18	15.0
Gross and Hasund (1989)*	47	39.2	71	59.2
Tränkmann et al. (1990)	43	35.8	77	64.2
Bachmann (1986)	47	39.2	7	60.8

*According to Gross and Hasund (1989) there were no differences between the measured and predicted values in two cases in the maxilla.

Table 6 Frequency of positive and negative differences between the measured and predicted values of sums of mesio-distal diameters of C, P_1, and P_2 crowns in the mandible ($N = 120$).

Mandible

Author	Positive differences		Negative differences	
	N	%	N	%
Moyers (1973)	99	82.5	21	17.5
Legović and Hautz (1989)*	85	70.8	34	28.3
Droschl et al. (1977)	99	82.5	21	17.5
Berendonk (1965) and Nawrath (1968)*	76	63.3	43	35.8
Tanaka and Johnston (1974)*	93	77.5	26	21.7
Gross and Hasund (1989)	38	31.7	82	68.3
Tränkmann et al. (1990)*	33	27.5	86	71.7
Bachmann (1986)	38	31.7	82	68.3

*According to the authors, in one case for each of them, there were no differences between the measured and predicted values.

The method suggested by Tanaka and Johnston (1974) proved more reliable. However, even with this method, the predicted values were often over-estimated, which was also noted in earlier studies by Gardner (1979) and Al-Khadra (1993). Its poor reliability for the Chinese population was shown by Yuen et al. (1998), as well as by Lee-Chan et al. (1998).

The methods proposed by Bachmann (1986), Gross and Hasund (1989) and Tränkmann et al. (1990) all use regression equations in predicting the crown widths of C, P_1, and P_2. These methods proved to be more reliable in this study than the correlation methods and the most reliable among them was the Bachman method.

Bachman (1986) and Gross and Hasund (1989) used the MDD of the upper lateral incisor as one of the predictive variables for both the maxilla and mandible, and Tränkmann et al. (1990) for the maxilla only. Those authors related the smaller MDD of this tooth to the smaller MDD of the lower canines and upper second premolars. Additional predictive variables with these methods include the VOD of the lower left first permanent molar (VOD 36) in the Gross and Hasund (1989) method; the mesio-distal width of the crowns of the upper left first permanent molars in Bachmann's (1986) method and the maxillary or mandibular first permanent molars in the method of Tränkmann et al. (1990).

Gross and Hasund (1989) found greater correlations between the widths of the crowns of C, P_1, and P_2 and the VOD of 36 than with the MDD of the same tooth. As reported by Gross and Hasund (1989), greater correlation has been found between the VOD of the upper first molar than the MDD of that tooth.

Conclusions

1. The method proposed by Bachmann (1986) proved to be the most reliable in this study.
2. The prediction methods of Moyers (1973), Droschl et al. (1977), Tanaka and Johnston (1974), Berendonk (1965), Nawrath (1968), and Legović and Hautz (1989) tended to over-estimate the sums of the crown widths of C, P_1, and P_2 in both arches.
3. The prediction methods of Gross and Hasund (1989), Bachmann (1986), and Tränkmann et al. (1990) showed a tendency to under-estimate the sums of crown widths of C, P_1, and P_2.

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