Mathematical Formulae to Predict the Horizontal Location of Maxillary Anterior Teeth in Edentulous People

LAITH MAHMOUD ABDULHADI AL-SAMAWI, HANAA AL-ANI
Department of Prosthetic Dentistry
Mahsa University
Jalan SP 2, Bandar Saujana Putra, 42610 Jenjarom Selangor
MALAYSIA

Abstract: -The arrangement of anterior teeth has a significant impact on the patient's looks, communication, and well-being. Maxillary prosthetic anterior teeth are put as close to their natural location as possible to maintain proper anatomophysiology.The purpose of this study was to assess the relationship between the placement of anterior teeth and the incisive papilla in dentate and then apply the findings to edentulous patients using linear regression analysis. 114 maxillary dentate casts were selected according to predetermined inclusion criteria. The antero-posterior length of the incisive papilla, the central and lateral incisors, and the intercanine line to the posterior limit of the incisive papilla were all measured directly on the casts. The Pearson correlation coefficient and linear regression analysis were used to verify the association and to develop linear regression equations to calculate the location of the anterior teeth depending on the length of the incisive papilla. The results showed that a significant positive linear relation was evident between the incisive papilla length and the horizontal distances that separated the incisive papilla from the central, lateral, and intercanine lines, respectively. As a result, three equations were formulated based on the linear model fit to calculate the horizontal placement of central, lateral incisors, and canine tips in an edentulous patient.

Key-Words: - Incisive papilla length, central incisor location, lateral incisor location, canines, teeth arrangement.

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1 Introduction

The achievement of natural look restoration is a constant challenge to dentists. It was postulated that the upper anterior teeth should be placed as close as possible to the position originally occupied by the natural teeth [1]. Topographically, the incisive papilla (IP) is a small, variable, round or pear-shaped soft tissue elevation indispensable for determining the suitable position of the maxillary anterior teeth in a horizontal plane for edentulous patients [2]. For a long time, the center of the papilla was commonly used as a starting reference point to arrange anterior artificial teeth [3], [4], [5], [6], [7], [8]. However, the IP undergoes length changes after tooth extraction; therefore, the posterior limit seems to be a more constant reproducible reference for comparing research compared to the midpoint [7], [8]. Due to the variability of the distance between the anterior teeth and the incisive papilla, one researcher in 1990 suggested and used the regression analysis to test the presence of linear correlation between the formerly mentioned marks and to formulate two mathematical equations to predict the location of the central incisor (CI), lateral incisor (LI), canine (C), and intercanine line (ICL) [7].

Other studies in 2001 and 2007 showed that the CIs were located 12 to 11.96±1.37 mm away from IP, respectively [5], [6]. 93.4% of the sample reported the intercanine line (ICL) to be within 2 mm of the IP center [5]. In the southern Chinese population, a study concluded that the ICL passed through the middle third of the incisive papilla in 57.3% [5]. On the other hand, in the Taiwan sample population, the ICL passed through the middle third of the incisive papilla in 72.84% of the population, and the distance was uninfluenced by the gender, age, and arch form [9]. It was stated that the location of the IP depends on the duration of teeth loss of the maxillary arch [10]. As a result of excessive bone loss in the anterior maxillary area after tooth extraction, the incisive papilla immigrates more anteriorly. Therefore, they suggested the use of an 8-mm horizontal distance between the incisal edge of the upper central incisor and the center of the incisive papilla. The objective of this study was to investigate the metric relationship between the IP length and the horizontal distances that separate

anterior teeth (CI, LI, and C) from the posterior border of the IP on dentate Malays and Chinese and to formulate simple equations to predict the tooth location in edentulous patients.

2 Problem Formulation

Following tooth loss, the dental arch undergoes atrophic changes due to bone resorption. To achieve a natural physiologic location of the replaced artificial teeth, the dentist uses certain anatomical landmarks like incisive papilla and functional traits like speech ability, swallowing, normal functioning, and feeling, in addition to other parameters like vertical dimension and reestablishment of natural look. Generally speaking, most researchers and practitioners used the average distance from the IP center to locate the CI and the connecting line of the cusp tips when arranging the teeth on the edentulous ridge. However, a more precise mathematical approach may offer better precision. A previous research work approved this formulation [7]. In this research, this postulation was tested on a sample of the Malaysian and Chinese populations.

2.1 Hypothetical assumption

A mathematical relationship may exist between the length of IP and the direct distance separating the CI, LI, and C on the maxillary arch (Fig. 1). If the analysis estimates such mathematical correlation, a regression analysis is applied to generate an equation(s) to predict the horizontal location of the anterior teeth.

This postulation was applied before in 1990 on an Iraqi sample [7], and the results were encouraging. In this research work, the selected sample was composed of Malaysian and Chinese people to assess the applicability of previous hypotheses.

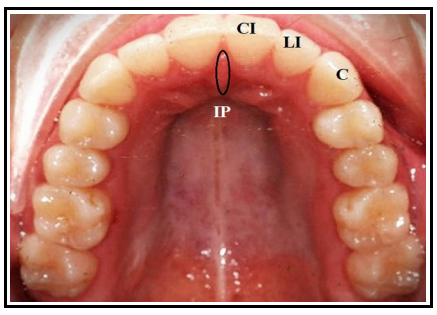

Fig. 1: The maxillary arch palatal topographic details

IP; incisive papilla, CI; central incisor, LI; lateral incisor, C; canine

2.2 Data collection

Data gathered from 114 casts of healthy 59 Malay and 55 Chinese subjects selected out of Malaysian dental students. Their age ranged between 18 and 25 years. Study models were composed of 43 men and 71 women. The inclusion criteria were the absence of any operative, prosthetic, orthodontic, orthognathic surgery, malalignment of the teeth, teeth abrasion, attrition, and dental anomalies. Subjects with Angle's class I maxillomandibular relationship were included in the study. Each cast base was trimmed in such a way to be parallel to the occlusal plane using simple campus to equally measure and trim the base so that the measurement of the distances and the IP length were done when the occlusal plane was oriented quasi parallel to the horizontal plane. Direct recording of the distances seems to be more consistent with later application of this method on edentulous casts compared with the photographic method demonstrated by other researchers due to the fact that 2D results should be re-corrected again during application of the image result to real casts [1], [2], [3], [4], [5], [7], [8], [9], [10], [11]. The following biometrical points were marked off using a mechanic pencil (Ø 0.5 m); the midpoint of the incisal edges of the right and left incisor teeth; the cusp tips of canines; and the anterior and posterior borders of (IP). The shape of (IP) was outlined, and the horizontal distances were measured directly using a soft metal ruler with ±0.5 mm increment; the length of (IP), the distances that separate the (CIs), (LIs), and (C) from the posterior limit of (IP), in addition to the distance separating the intercanine line (ICL or C-C line) from the posterior border of (IP) (Fig. 2).

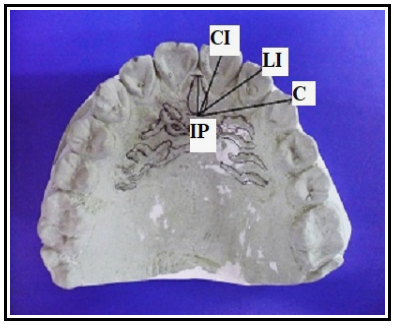

Fig. 2: The incisive papilla length (IP), and the measured lines from CI, LI, C to the posterior limit of the IP.

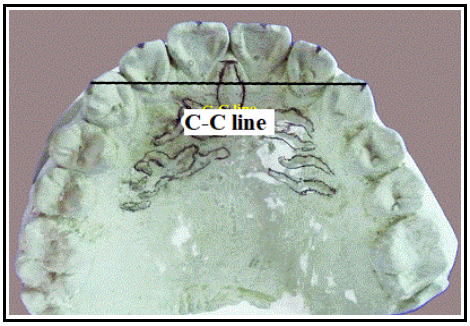

Fig. 3: C-C line; intercanine line located anterior to IP posterior limit

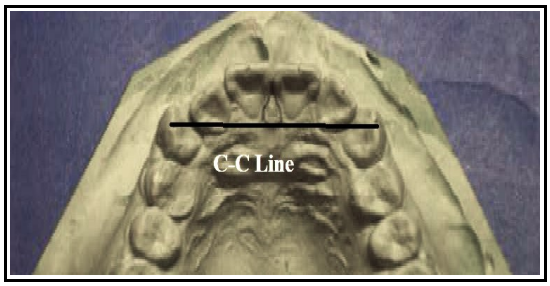

Fig. 4: C-C line; intercanine line intersects the posterior limit of IP

The distance between the ICL and posterior border of IP was charted as positive if the line was located anteriorly to the posterior limit of IP (Fig. 3). The distance between ICL and the posterior limit of IP was interpreted as zero when it intersects the posterior border of IP (Fig. 4). Finally, the distance between ICL and posterior border of IP is charted as negative if it was located back to posterior limit of IP.

Each measurement was recorded independently by two investigators. A reliability test was applied to ensure the consistency of the two examiner records.

Descriptive statistical analysis was used to explore the sample features and their normality of distribution. The Pearson correlation coefficient ($\rho \leq .05$) was used to investigate the linear relationship between the distances separating the anterior teeth from the posterior limit of IP and the length of IP. Linear regression analysis was applied to formulate the best model that fits the data to calculate the distance in edentulous patients using the incisive papilla length as a predictor. A t-test and Levene's test were used to estimate the difference between the ethnic groups, sides, and genders.

3 Problem Solution

3.1 Composition of the sample

The sample included the maxillary casts of faculty students of Malay ethnicity (59) and Chinese (55). It was composed of 43 men and 71 women. Their age was 18–25 years.

3.2 The features of the sample

The mean IP length was 6.98 ± 1.09 mm for the whole sample. The CIs (LI, RI) were located at 14.04 ± 1.43 mm and 13.93 mm ± 1.43 mm away from the IP, respectively. The other information is shown in Table 1.

Table 1. Descriptive features of the sample N; number, Min; minimum length, Max; maximum length, SD; standard deviation, IPL; incisive papilla length, toLI; distance IP to left central incisor, toRL; distance to right central incisor, toLLI; distance to left lateral incisor, toRLI; distance to right lateral incisor, toLC; distance to left canine, toRC; distance to right canine.

	N	Min	Max	Mean	SD	Skewness*	
IP L	114	4.25	9.50	6.98	1.09	.106	0.23
toLI	114	10	19.25	14.04	1.43	0.27	.226
toRI	114	9.00	18.75	13.93	1.43	.137	.226
toLLI	114	13.50	19.75	15.97	1.22	.475	.226
toRLI	114	12.75	20.00	15.82	1.23	-.008	.226
toLC	114	13.75	22.25	19.49	1.27	-.904	.226
toRC	114	12.00	22.00	19.41	1.38	-.805	.23
*The distribution is normal							

3.3 The inter-examiner reliability

The inter examiner's measurement reliability was significant (Pearson correlation = 0.98, Df= 226, one-tailed, $\rho \leq .05$) for the whole records gathered by the two investigators, independently.

3.4 Arch side and ethnicity difference

In Chinese, the mean IP length was 6.75±1.05 mm. While in Malay, it was 7.21±1.09mm (Table 2, Table 3). The IP length showed statistical differences between Malay and Chinese peoples. Left and right side teeth records for the whole sample indicated a statistically significant distance difference at ($\rho \leq .05$, CI 95%). However, the C records showed no difference between the two sides (Table 4), (Table5).

Table 2. Chinese results (in mm) of the IP length; IPL, distance; IP-CI (R; right, L left); IP-LI (RR; right, L; left); IP-C (R; right, L; left); M; mean record; SD; standard deviation, No; number

	IP L	IP- CI		IP- LI		IP-C	
Side	**-**	**R**	**L**	**R**	**L**	**R**	**L**
M	6.75	13.9	13.9	15.8	15.7	19.4	19.3
SD	1.05	1.46	1.52	1.24	1.17	1.4	1.6
No	55	55	55	55	55	55	55

Table 3. Malays records (in mm) of the IP length; IPL, distance; IP-CI (R; right, L; left), IP-LI(R; right, L; left), IP-C (R; right, L; left), M; mean record, SD; standard deviation, No; number.

	IP L	IP- CI		IP- LI		IP-C	
Side	**-**	**R**	**L**	**R**	**L**	**R**	**L**
M	7.21	14.17	14.01	16.12	15.94	19.59	19.47
SD	1.09	1.41	1.35	1.20	1.28	1.14	1.15
No	59	59	59	59	59	59	59

The t-test for the difference between arch sides in Malays and Chinese revealed the following results: for the IP-CI, the difference was significant in Malay only. The IP-LI difference was not significant for the two ethnic groups. However, IP-C distance indicated an absence of difference in the two groups (Table 4).

Table 4. The statistical analysis result of records on sides of the arch for each ethnic group.
TD; tooth distance, Stat; statistical analysis, T-Sc; t-score, P-value; probability, Sig; significant value, Ns; non significant value.

TD	Stat	Chinese	Malay
IP-CI	T-Sc	.000	-2.715
	P-value	1.000	.0076
	Significance	Ns	Sig
IP-LI	T-Sc	1.98	1.98
	P-value	.664	.432
	Significance	Ns	Ns
IP-C	T-Sc	-1.98	1.98
	P-value	.728	.887
	Significance	Ns	Ns

For the whole sample, the paired sample t-test revealed a statistical difference ($\rho \leq .05$, and at 95% CI) between the right and left sides for central and lateral incisor distances to the IP. However, the canine's location did not show any significant difference (Table 5).

Table 5. The difference between IPL in Malaya and Chinese and the distances that separate the teeth (CI, LI, C) and IP on the right and left sides of the arch for the whole sample, MD; mean difference, SD; standard deviation, SE; standard error, CI; confidence interval, DF; degree of freedom, Sig(2S); significance 2 sided

	MD	SD	SE	L 95% CI U		DF	Sig. (2S)
IPL	-.46	1.07	.201	-.857	-.062	112	.024*
CI	.105	.44	.0419	.022	.19	112	.013*
LI	.153	.70	0.07	.022	.284	112	.022*
C	.081	.88	.0828	-.083	.245	112	.330
*Significant difference at $\rho \leq .05$							

3.5 Gender effect on the records

No statistical difference was estimated between women and men measurements, including the IP length (95% CI of the difference) (Table 6).

Table 6. The results of statistical test for difference between the male (M) and female (F) records of the following: IPL; incisive papilla length, IP-21; incisive papilla to left central incisor line, IP-11; incisive papilla to right central incisor line, IP-12; incisive papilla to left lateral incisor line, IP-22; incisive papilla to right lateral incisor line, IP-23; incisive papilla to left canine line, IP-13; incisive papilla to right canine line, G; gender, N; number, M; mean, SD; standard deviation, SEM standard error of the mean, t-stat; t-statistics

	G	N	M	SD	SE M	t-stat	ρ-value
IP L	**M**	43	6.97	1.262	.192	-.088	.929*
	F	71	6.99	.98	.117		
IP-21	**M**	43	14.11	1.73	.263	-.396	.6930*
	F	71	14.00	1.23	.146		
IP-11	**M**	43	14.08	1.63	.248	-.867	0878*
	F	71	13.84	1.30	.155		
IP-22	**M**	43	16.10	1.41	.215	-.887	.3771*
	F	71	15.89	1.10	.131		
IP-12	**M**	43	15.99	1.38	.211	-1.184	.2390*
	F	71	15.71	1.12	.133		
IP-23	**M**	43	19.71	1.20	.183	-1.475	.1431*
	F	71	19.35	1.30	.155		
IP-13	**M**	43	19.62	1.35	.206	-1.280	.2034*
	F	71	19.28	1.39	.165		
*The difference is not significant at ρ≤.05							

3.6 The relationship between the length of IP and distance separates the the anterior teeth

The records of IPL and the lines separate the anterior maxillary teeth were correlated using the Pearson correlation test [7]. Results showed that the IP length was significantly and linearly correlated to the distances of IP-CIs and IP-LIs, except for the C (Table 7).

Table 7. The linear Pearson correlation between the IP length and distance IP to anterior teeth except canines. IPL&P-C; incisive papilla length and Pearson correlation, IP-21; incisive papilla to left central incisor distance, IP-11; incisive papilla to right central incisor distance, IP-22; incisive papilla to left lateral incisor distance, IP-12; incisive papilla to right lateral incisor, Sig-2T; significant 2-tailed, N; number.

	IP-21	IP-11	IP-22	IP-12	Significance
IPL&P-C	0.73*	0.73*	.61*	0.58*	*Significant correlation at ρ≤.001
Sig-2Tail	.00	.00	.00	.00	
N	114	114	114	114	

3.7 Regression analysis of the IP length and teeth distances for (CI, LI)

Two equations were formulated based on the linear model fit to calculate the location of central and lateral incisors measured from the posterior limit of the incisive papilla in edentulous patients.

Formula no. 1 is used to predict the location of the CI in the horizontal plane after measuring the IP length in mm. For the lateral incisor,

Distance IP-CI in mm = IP length× 0.956 mm +.7.359... (1)

Formula no. 2 is used in the same manner.

Distance IP-LI in mm = IP length× 0.684 mm + 11.196... (2)

An example of the validity of using formulas 1 and 2. Some CID and LID records (real and expected) were displayed in Table 7. The difference between the expected and the real values was clinically acceptable, and it ranges between 0.13 and 3.05 mm. The average estimation error was 10.45% (Table 8). In certain disciplines of dentistry, for example, removable rehabilitation and especially in partial and total rehabilitation, some variability is acceptable in clinical practice due to the presence of many biological and physiological tolerances and the need for compensation of aging changes in the tissues.

Table 8. The real and estimated records of central incisor distance and lateral incisor distance.

CID; central incisor distance, LID; lateral incisor distance, RD; real records, EXD; expected record, Diff; the difference between the real and expected record

Tooth	RD	EXD	Diff	E %
CID	10	11.4	1.4	14
CID	11.4	12.43	1.03	9
CID	16.25	19.25	3	18.4
CID	20.5	17.45	3.05	14.8
LID	14.72	13.85	0.78	5.2
LID	14.72	14.85	0.13	0.8
LID	19.75	17.7	2.05	10.3
LID	20.75	18.44	2.31	11.1

3.8 The relation between the ICL location and the IP length

Because a mathematical relationship could not be established between the IPL and the IP-C distance. The line connecting the right and left canine's tips, ICL, was used to locate the canines in relation to the IP posterior limit. The ICL was found to intersect the posterior limit of the IP in only 8.77% of the total casts. However, nearly 80% of the cases had their ICL passed 0–4 mm away from the posterior IP limit (Table 9).

Table 9. Location of ICL to posterior border of IP, ICL-IP Lo; intercanine line to incisive papilla location, D. ICL-IP; distance intercanine line to incisive papilla posterior border

ICL- IP Lo	D. ICL- IP (mm)	%
Anterior to posterior border of IP	8.1 to 10.0	0.17
	6.1 to 8.0	0.08
	4.1 to 6.0	10.53
	2.1 to 4.0	39.47
	0.1 to 2.0	32.46
At limit of IP	0	8.77
Posterior to limit of IP	-0.1 to -2.0	4.38
	-2.1 to -4.0	1.75

3.9 The location of ICL in relation to ethnicity

The mean distance between the canine cusp tips line and the posterior limit of IP was 2.45 mm and 2.11 mm in Malay and Chinese, respectively. No statistical difference has been estimated between the two records (Table 10).

Table 10. The mean distance between the ICL and the IP in Malays and Chinese

Ethnic	N	Mean	SD	SE Mean
Malay	59	2.45	2.23	.29
Chinese	55	2.12	1.62	.218
t=0.8984, Df = 112 , ρ-value= 0.3709				

3.10 The relationship between the ICL and IP posterior limit distance

The line was located at a variable distance from the posterior border of IP, and it was statistically correlated to the IPL (Table 11).

Table 11. The Pearson-correlation (P.C) between the ICL; intercanine distance and IPL; incisive papilla length

	ICL to IP	Sig.2-Tailed
IPL	P.C=0.504	Significant at ρ≤.001
N	114	

3.11 Regression analysis between the ICL location and IPL

The regression analysis of ICL and IPL results in a linear equation that predicts the distance between the ICL location using IPL length as a predictor. The equation is as follows:

IC-IP distance = 0.0282 × (IP length) + 6.343.... (3)

4 Discussion

The mean distance between the CIs and posterior border of IP was close to that found by Lassila et al. [4], Abd Al-Hadi [7], Ortman, and Taso [11], but was markedly different from others [10]. This variability is due to the use of different data collection techniques, ethnic groups in the experiment, or different measuring methods and points on the IP. If we consider the methods used for data collection, the researchers used variable tools to measure the distances. Some used photographs; others used direct measurement or even 3D. Another factor that contributes to discrepancy is the use of a starting point for measurement. Some authors considered the midpoint of IP; others used the posterior border of IP. We used the posterior border of IP in this study because it is more fixed, stable, and less susceptible to change after tooth loss compared to the anterior border and center of the incisive papilla, which may

be shortened after the tooth removal, affecting the papilla length and its center location as a result. The arrangement of anterior teeth is a dynamic process that depends on many parameters like the facial expression normalization, speech proficiency, stability of dentures during rest and function, and the amount of alveolar bone resorption. Therefore, as a solution for the tooth location in the horizontal plane, this method was developed and tried on variable populations to prove its application validity. For the estimation of the amount of bone resorption, a mathematical method that was described by the author a long time ago can be added to enhance the applicability of this method.

The location of central and lateral incisors can be predicted using the two proposed equations, while the locations of the canine tips can be predicted either using the proposed equation or the intercanine line can be placed 2.4 mm in front of the posterior border of the IP as simple way. The regression analysis enhanced the precision in tooth arrangement as much as possible because the teeth will be located in a more natural location. The arrangement of the anterior teeth using this method is very simple. First, the edentulous working cast is placed parallel to the horizontal plane. The antero-posterior length of the incisive papilla is marked and measured in mm using a simple flexible ruler. By replacing the IP length in the equations, the position of the CIs, LIs, and Cs tips can be located. There are some limitations to using this method in daily practice due to the time-consuming calculation of the anterior tooth location. Moreover, anterior tooth placement should be made according to a compromise between many factors like patient desire, aesthetic requirements, speech, amount of alveolar ridge bone resorption, and relation to the primary denture support zone [3], [6]. Therefore, this method can be used as a preclinical technique to place the anterior teeth by the dental technician and later animated and modified inside the patient's mouth by the dentist according to the other functional tests [3]. In some maxillary casts, the incisive papillae are absent or showed pinpoint size, which limits the application of this hypothesis [7]. However, this represents a very low total of human arches. A future study will suggest the construction of a maxillary model in edentulous patients. Taking into consideration the use of mathematical analysis, especially the regression analysis, in assessing the eventuality of a geometrical relationship between the related biological parameters to simplify the establishment of lost size or location of many components in the oral cavity during rehabilitation procedures is the first step of preparation for the treatment in edentulous patients. The previous equations can be incorporated into a subroutine to generate a 2D or 3D model for the maxillary arch before starting the treatment. This model can also be used in legal practice to reconstruct a more precise maxillofacial frame of the cadaver using the available remaining anatomical landmarks. [7], [12], [13], [14], [15].

5 Conclusion

Within the scope of this study, the average length of IP in Malay was 7.21±1.09 mm, whereas in Chinese it was 6.75±1.05 mm, respectively. The mean distances of right and left IP-CIs were 13.94mm and 14.04mm, respectively; the right and left IP-LIs distances were equal to 15.82mm and 15.98mm, respectively; and the right and left IP-Cs were 19.41mm and 19.49mm, respectively. In 41.2% of the population, the intercanine line distance to the posterior border of IP was between 0 and 2 mm.

A statistical difference between Malays and Chinese was evident for IPL. While gender has no influence on the teeth location in horizontal plane except for the canines. A substantial positive linear association was found between IP length and distance for IP-CIs, IP-LIs, and ICLs, respectively. Three formulae are used to determine the distance IP-CI in mm:

IP length multiplied by 0.956 mm + 7.359... (1)

IP-LI distance in mm is calculated by multiplying IP length by 0.684 mm and adding 11.196... (2)

ICL-IP distance equals 0.0282xIP length + 6.343... (3)

A recommendation for future research is to include the data in a 3D model and utilize the equations to forecast tooth positions on the maxillary arch.

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The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

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