*Original Article*

# Accuracy and reliability of palatal superimposition of three-dimensional digital models

**Dong-Soon Choi[a]; Young-Mok Jeong[b]; Insan Jang[c]; Paul George Jost-Brinkmann[d]; Bong-Kuen Cha[e]**

## ABSTRACT

**Objective:** To evaluate the accuracy of the superimposition of three-dimensional (3D) digital models using the palatal surface as a reference for measuring tooth movements.

**Materials and Methods:** Maxillary plaster models were selected from 20 patients. The right and left canines, premolars, and molars were individually cut underneath the gingival margins and set up in wax (plaster model 1 = PM1). The PM1s were scanned to create 3D digital models (digital model 1 = DM1). Teeth on the PM1s were randomly moved (plaster model 2 = PM2) and subsequently scanned to produce another set of 3D digital models (digital model 2 = DM2). DM1s and DM2s were superimposed using the palatal area as reference via surface-to-surface matching software, and the changes in tooth movement were calculated. In the plaster models, the tooth movements were directly measured using the Reference Measurement Instrument. A paired *t*-test and a correlation analysis were performed to determine whether the two measurement methods differed significantly.

**Results:** The means of the anteroposterior (x-axis), transverse (y-axis), and vertical (z-axis) tooth movements of the plaster models and the digital models did not differ significantly, and very high correlations were found between the plaster models and the digital models.

**Conclusion:** From a technical point of view, the superimposition of 3D digital models using the palatal surface provides accurate and reliable measurements, but it remains to be investigated how stable the palatal surface is longitudinally after growth and/or orthopedic treatment take place. (*Angle Orthod.* 2010;80:685–691.)

**KEY WORDS:** Three-dimensional digital model; Superimposition

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Accepted: December 2009. Submitted: October 2009.


## INTRODUCTION

Changes in tooth positions following orthodontic treatment have traditionally been evaluated by superimposition of serial cephalometric radiographs. However, this method has a number of drawbacks: difficulties in evaluating three-dimensional (3D) tooth movements, problems with identifying inherent landmarks,[1] tracing errors, and frequent radiation exposure.[2]

The plaster model is the traditional 3D patient record for measuring linear changes in the dental arch. To analyze tooth movements, accurate superimposition of serial models on a stable and identifiable structure is necessary. Many studies have reported on the stability of the palatal rugae as reference points for the comparison of the pretreatment and posttreatment conditions on plaster models.[3–7] Unfortunately, these studies did not provide important information about the structural and volumetric changes in the palate or regarding 3D orthodontic tooth movements.

Digital 3D models have become standard technology.[8,9] Digital models have a number of advantages in terms of storage, retrieval, diagnostic versatility, transferability, and durability.[10,11] Numerous studies have shown that 3D digital models can be used for model analysis and diagnosis,[10,12–16] treatment planning,[8,17] design and manufacture of orthodontic appliances,[18–20] and evaluation of tooth movement.[21–24] To date, however, studies of the reliability of computed superimposition of 3D digital models to assess the outcomes of orthodontic treatments have been limited.[22,23]

Our previous publication suggests that 3D digital model superimposition using the palatal surface as a reference is as reliable as cephalometric superimposition for assessing orthodontic tooth movement in maxillary premolar extraction cases.[22] Nevertheless, it remains to be investigated how accurate digital superimposition techniques are for the quantification of tooth movements. Consequently, it was the purpose of this study to evaluate the accuracy of mathematical superimposition using the constant palatal surfaces as a reference for measuring the changes in tooth movement on 3D digital models in comparison with the actual tooth movement in setup models.

## MATERIALS AND METHODS

The protocols of this study were reviewed and approved by the ethics committee of Gangneung-Wonju National University Dental Hospital (IRB 2009-11). Posttreatment maxillary plaster models of 20 patients were randomly selected from the archive of the Department of Orthodontics of Gangneung-Wonju National University Dental Hospital. The inclusion criterion were that the plaster models have (1) permanent dentition, (2) complete dentition from the central incisors to the second molars, and (3) no porosities on the teeth and the palatal surfaces. There was no consideration of age and gender. The right and left canines, premolars, and molars were individually cut underneath the gingival margins and set up in wax (plaster model 1 = PM1) (Figure 1). PM1s were scanned to reconstruct 3D digital models (digital model 1 = DM1). The teeth on the PM1s were randomly moved (plaster model 2 = PM2) and scanned again to produce another set of 3D digital models (digital model 2 = DM2). Measurements were performed on the cusp tip of the canines, the buccal cusp tip of the first premolars, and the mesiobuccal and mesiopalatal cusp tips of the first molars (Figure 1).

### Measurements on the Plaster Models

Measurements on the plaster models were performed with the Reference Measurement Instrument (RMI) (RMI 550, SAM Präzisionstechnik, Munich, Germany), which has three digital calipers with a resolution of 0.01 mm in the x-, y-, and z-axes and a cone-shaped measuring tip with a diameter of 0.5 mm (Figure 2). The plaster models were mounted on the RMI, while the occlusal plane was kept parallel to the floor of the RMI, and the midpalatal suture was fit into the x-axis of the RMI (Figure 2).

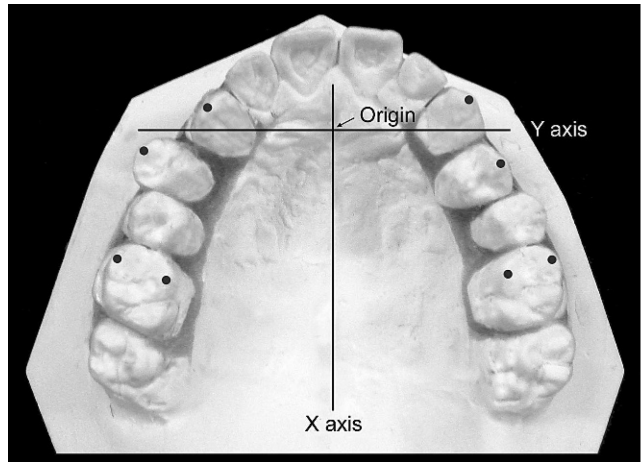


**Figure 1.** Measurement points (blue dots) and established coordinate system on a plaster model.

On each cast (PM1), a coordinate system was constructed according to Ashmore et al.,[21] with the junction of the incisive papilla and the palatine raphe as the origin (0, 0, 0), which resulted in the x-, y-, and z-axes (Figure 1). A movement in the positive direction along the x-axis indicated mesial movement. Positive values in the y- and z-axes indicated right and extrusive tooth movements, respectively (Figures 1 and 2). The cusp tip of the canine, the first premolar, and the first molar of the PM1 and the origin (0, 0, 0) were marked with black pencil. After the digital calipers were set in the x-, y, and z-axes at zero at the origin of PM1, the distances from the cusp tip of the canine, the first premolar, and the first molar to the origin were measured. PM1 was removed from the RMI, and PM2 was placed into the same position on the RMI. The distance from the cusp tips to the origin was measured again on PM2. The differences between PM1 and PM2 were calculated.

### Measurements on the 3D Digital Models

Three-dimensional scanning of the plaster models was performed using the Orapix 3D scanner (laser slit–type noncontact 3D scanner, Orapix Co Ltd, Seoul, South Korea; accuracy ± 20 μm) and a 3D reverse modeling software program (Rapidform 2002, INUS Technology Inc, Seoul, South Korea) (Figure 3). The same coordinate system that had been used for PM1

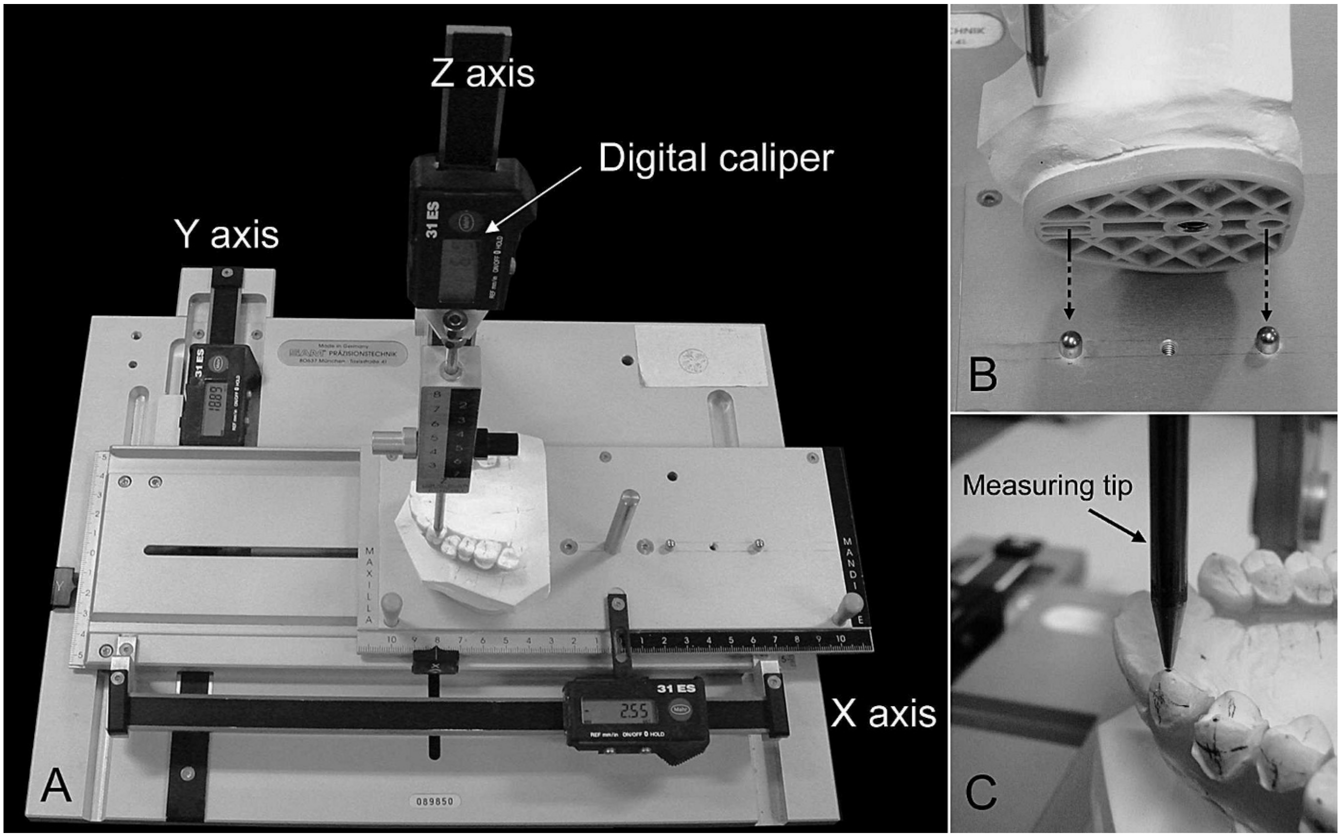


**Figure 2.** Measurement of the plaster model with the Reference Measurement Instrument (RMI). (A) Digital calipers in the x-, y-, and z-axes. (B) Plaster model, which could be placed repeatedly in the same position on the RMI. (C) Measuring tip on the canine.

was established on DM1 (Figure 3). To measure tooth movement, DM1 and DM2 were superimposed on the surface across the palate. The area of superimposition is presented in Figure 4. It included the first, second, and third palatal rugae, but the nasopalatine papilla was excluded. The lateral margins were located at least 5 mm from the gingival margins of the posterior teeth bilaterally. The distal margin did not extend distally beyond the line in contact with the distal surfaces of the maxillary second molars bilaterally. This procedure, designated as 3D surface-to-surface matching (best-fit method), employed a least-mean-square technique using a function of Rapidform 2002.[9,22,25,26] Analogous to what is shown in Figure 5, the distances of all eight measuring points described previously between DM1 and DM2 were calculated along the x-, y-, and z-axes.

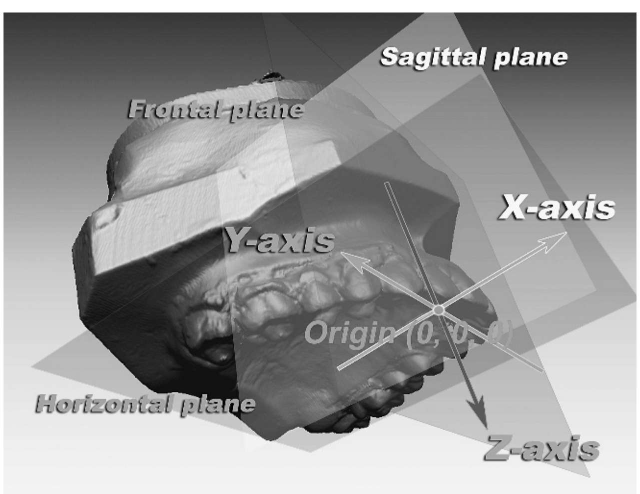


**Figure 3.** The three-dimensionally scanned digital model. The digital model and the plaster model employed the same coordinate system.

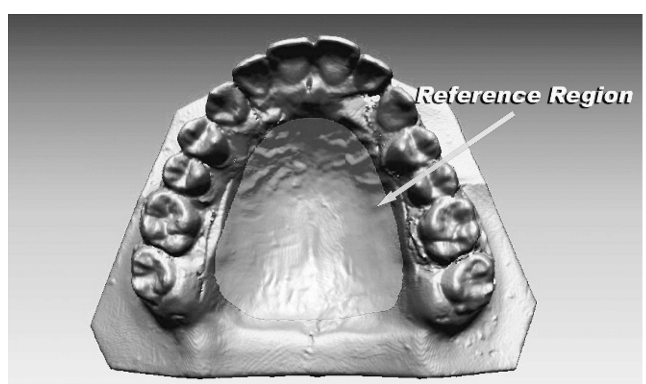


**Figure 4.** The reference region for the palatal superimposition.[22]

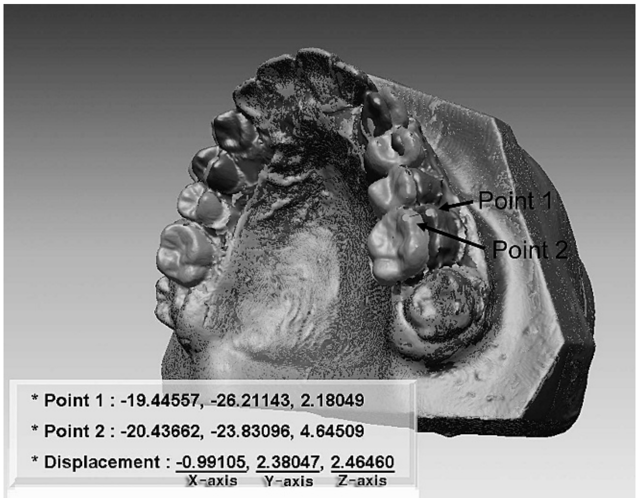


**Figure 5.** Measurement of the superimposed 3D digital models. Point 1 indicates the mesiobuccal cusp tip of the left first molar of first digital model (DM1); point 2 is that of the second digital model (DM2).

### Statistical Analysis and Error Test

The mean anteroposterior (x-axis), transverse (y-axis), and vertical (z-axis) tooth movements measured on the plaster models were compared with those measured on the superimposed 3D digital models. A paired *t*-test and a correlation analysis were performed to determine whether the two measurement methods differed significantly.

To determine identification errors of the same points on the plaster model and the digital model, one examiner measured the 3D distance from the origin to the cusp tip of the right and left canines, first and second premolars, and first and second molars (total of 10 points) and repeated the measurements 2 weeks later. The mean differences on the plaster model were 0.04 mm, 0.07 mm, and 0.08 mm along the x-, y-, and z-axes, respectively. On the digital model, the mean difference was 0.01 mm along all three axes.

## RESULTS

Table 1 shows the mean differences between the measurements of the plaster models and the digital models. The *P* values from the paired *t*-test assessed whether or not the plaster and digital models yielded equivalent mean values of the tooth movements. The *P* values indicated that the means of the anteropos-

**Table 1.** Differences in the Tooth Movements Evaluated on Superimposed 3D Digital Models and Plaster Models, Paired *t*-Tests, and Pearson Correlation Coefficients

| | Difference (plaster model – digital model) | | Paired *t*-Test | | Pearson Correlation | |
|---|---|---|---|---|---|---|
| Location[a] | Mean (mm) | SD (mm) | *t* | *P* | *r* | *P* |
| Anteroposterior (x-axis) | | | | | | |
| Right canine | −0.02 | 0.15 | −0.695 | .495 | 0.991 | .000 |
| Right first premolar | −0.04 | 0.17 | −1.139 | .269 | 0.985 | .000 |
| Right first molar (MB) | −0.03 | 0.17 | −0.751 | .462 | 0.984 | .000 |
| Right first molar (MP) | 0.05 | 0.19 | 1.258 | .224 | 0.979 | .000 |
| Left canine | 0.03 | 0.12 | 1.097 | .286 | 0.995 | .000 |
| Left first premolar | 0.04 | 0.20 | 0.941 | .359 | 0.969 | .000 |
| Left first molar (MB) | −0.04 | 0.12 | −1.504 | .149 | 0.994 | .000 |
| Left first molar (MP) | −0.04 | 0.14 | −1.149 | .265 | 0.986 | .000 |
| Transverse (y-axis) | | | | | | |
| Right canine | −0.03 | 0.00 | −0.800 | .434 | 0.994 | .000 |
| Right first premolar | 0.01 | 0.18 | 0.174 | .864 | 0.995 | .000 |
| Right first molar (MB) | 0.00 | 0.20 | 0.076 | .940 | 0.991 | .000 |
| Right first molar (MP) | −0.01 | 0.15 | −0.393 | .699 | 0.996 | .000 |
| Left canine | 0.04 | 0.20 | 0.940 | .359 | 0.994 | .000 |
| Left first premolar | 0.03 | 0.19 | 0.620 | .543 | 0.988 | .000 |
| Left first molar (MB) | −0.03 | 0.14 | −1.050 | .307 | 0.998 | .000 |
| Left first molar (MP) | 0.07 | 0.17 | 1.785 | .090 | 0.996 | .000 |
| Vertical (z-axis) | | | | | | |
| Right canine | 0.00 | 0.17 | −0.104 | .918 | 0.988 | .000 |
| Right first premolar | 0.01 | 0.14 | 0.305 | .764 | 0.996 | .000 |
| Right first molar (MB) | −0.02 | 0.11 | −0.868 | .396 | 0.994 | .000 |
| Right first molar (MP) | −0.01 | 0.14 | −0.275 | .787 | 0.983 | .000 |
| Left canine | −0.01 | 0.13 | −0.193 | .849 | 0.996 | .000 |
| Left first premolar | 0.03 | 0.16 | 0.751 | .462 | 0.994 | .000 |
| Left first molar (MB) | −0.01 | 0.12 | −0.520 | .609 | 0.995 | .000 |
| Left first molar (MP) | 0.02 | 0.12 | 0.590 | .562 | 0.985 | .000 |

[a] MB indicates mesiobuccal cusp; MP, mesiopalatal cusp.

terior (x-axis), transverse (y-axis), and vertical (z-axis) tooth movements of the plaster and digital models did not differ significantly.

The Pearson correlation coefficients of the plaster and digital models are shown in Table 1. The correlation analysis revealed that the *r* values of all the variables were very high (highest [0.998] for the y-axis movement of the left first molar and lowest [0.969] for the x-axis movement of the left first premolar). Figure 6 shows a scatter plot and regression lines for the tooth movements along each axis, as determined on the plaster and digital models. Good correlations were revealed again for all the tooth movements. This means that the measurements of the tooth movements were the same whether they were measured directly from the plaster models or by palatal superimposition on the 3D digital models.

## DISCUSSION

Traditional two-dimensional cephalometric radiographs have played an important role in evaluating the results of orthodontic treatment. However, cephalometric evaluation involves difficulties in measuring tooth movements and identifying inherent landmarks in all three dimensions.[1,2]

Plaster models have been an essential component of 3D diagnostic records in the orthodontic treatment procedure. The palatal rugae form their pattern by the 12th to 14th week of prenatal life and are reasonably stable during a person's growth.[27] Thus they may serve as a suitable reference structure when studying serial models. Many authors have investigated the use of the palatal rugae as reference points for measuring tooth movements on serial dental casts[3–7] and on 3D digital models.[21,23,24] In a study of changes occurring in 15 patients who underwent extraction of four premolars, Peavy and Kendrick[6] reported that the lateral ends of the rugae close to the teeth followed the teeth in the sagittal plane, while the so-called O point on the midsagittal plane was least affected. Van der Linden[7] evaluated changes in rugae and interrugal dimensions in 65 normally growing children (aged 6 to 16 years) and in six orthodontically treated patients. The author noted little or no change in the length of the individual rugae and interrugal distances. Almeida et al.[3] suggested that the transverse offsets and distances between the medial rugae points are generally stable, particularly for the first rugae. Hoggan and Sadowsky[5] reported that the medial and lateral ends of the third palatal rugae could be used as reliably as cephalometric superimposition to assess anteroposterior tooth movements. However, the evaluation of tooth movements on plaster models has many clinical drawbacks, such as difficulties in establishing reference points, the complicated measurement process, and two-dimensional measurement of the 3D curvature of the palatal vault.[22,25] Ashmore et al.[21] employed a mechanical 3D digitizer for a 3D analysis of molar movements during headgear treatment. Miller et al.[24] superimposed 3D digital models to evaluate orthodontic treatment outcomes in three dimensions, again using the palatal rugae as a reference structure.

There seems to be no consensus on the stability of the palatal rugae as to the effect of growth or treatment. Friel[28] demonstrated in a study that the teeth move forward in relation to the palatal rugae in conjunction with growth of the jaws. Simmons et al.,[29] in a longitudinal study (from primary dentition to young adult) of the anteroposterior stability of the medial rugae region, concluded that the medial rugae landmarks did not appear to be stable reference points for investigation of tooth migration. Future research should evaluate the 3D positional stability of the palatal rugae using another stable reference plane. The orthodontic miniscrew may serve as an alternative reference landmark, but only in a limited number of cases.[22,23,25] Jang et al.[23] evaluated the stability of palatal rugae using digital models superimposed on three miniscrews as registration landmarks and concluded that the medial points of the third palatal rugae and the shape of the palatal vault were stable throughout orthodontic treatment with premolar extraction.

In the present study, only a few rugae points[21,24] were not used, but the entire palatal vault including the rugae[22,23,25] was used as a reference landmark to support the hypothesis that the so-called best-fit method using the palatal surface could be used for accurate superimposition of serial 3D digital models. Advanced technologies such as 3D scanning, 3D reverse technology for the construction of the digital model, and surface-to-surface matching technology were applied in this study.

In the present study, the mean anteroposterior, horizontal, and vertical tooth movements measured by the palatal superimposition in the 3D digital models did not statistically differ from those directly obtained from the plaster models (Table 1). Moreover, there was a high correlation between the two methods (Table 1 and Figure 6). These results suggest that the superimposition of 3D digital models using surface-to-surface matching technology in the palatal area can result in accurate and reliable measurements for the assessment of orthodontic tooth movements. The present study investigated the accuracy of the best-fit method when identical palatal surfaces were scanned twice and superimposed. Whether similar accuracy can be achieved when repeated impressions are made in growing patients remains to be determined.

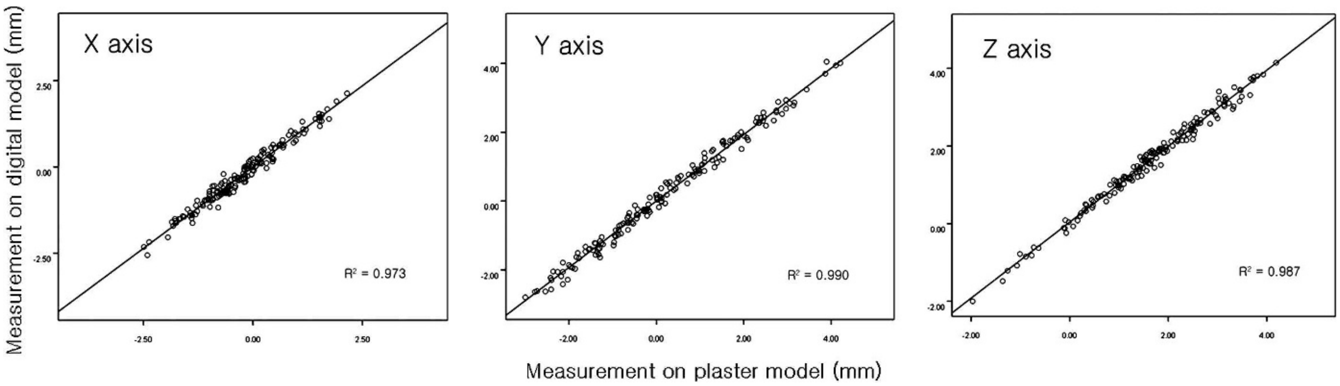


**Figure 6.** Scattergrams and regression lines for the tooth movements measured on the plaster models and the 3D digital models.

Some doubt remains about the validity of direct measurement by means of the RMI. Further cephalometric studies may be required to assess actual tooth movement in animals after orthodontic tooth movement and directly by instruments such as the RMI device. In addition, the growth-dependent stability of the palatal surface in growing patients, as well as evidence of the stability of the area in subjects treated with expansion mechanics or in the mandible, have not yet been fully explained. We are studying a possible landmark for the superimposition of mandibular digital models.

Virtual study models can replace conventional study casts for many purposes, such as model analysis, diagnosis, diagnostic setup, and treatment planning. Moreover, with the superimposition method used in the present study, it seems promising that, in the future, a simple mouse click will enable computer-assisted evaluation of 3D tooth movements. This knowledge will form the basis for future studies of the effects of multiple impressions or intraoral optical scans and growth of the palatal vault on the appropriateness of using the palatal vault for best-fit superimposition.

## CONCLUSIONS

The best-fit mathematical superimposition method of maxillary casts on the identical palatal vault is very accurate and allows for 3D evaluation of tooth movement. It remains to be investigated how stable the palatal surface is longitudinally after growth and/or orthopedic treatment take place.

## ACKNOWLEDGMENT

This study was supported by the 2007 research fund of Gangneung-Wonju National University (2007-0102).

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