Distribution Statement

Distribution A: Public Release.

UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
POSTGRADUATE DENTAL COLLEGE
SOUTHERN REGION OFFICE
2787 WINFIELD SCOTT ROAD, SUITE 220
JBSA FORT SAM HOUSTON, TEXAS 78234-7510
https://www.usuhs.edu/pdc

THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis: Correlation Between the Curve of Spee and Vertical Divergence in Skeletal Class I Patients

Name of Candidate: Mark D. Ryan
Master of Science Degree
March 3, 2023

THESIS/MANUSCRIPT APPROVED: DATE:

ANDERSON.WILLIAM.MICHAEL.1255749311 Digitally signed by ANDERSON.WILLIAM.MICHAEL.1255749311 Date: 2023.06.13 09:52:05 -05'00' — 6/13/23

CAPT William M. Anderson, Program Director
TRI-SERVICE ORTHODONTIC RESIDENCY PROGRAM, AFPDS
Committee Chairperson

KITSON.JACOB.LAWRENCE.1265159105 Digitally signed by KITSON.JACOB.LAWRENCE.1265159105 Date: 2023.06.13 09:21:55 -05'00' — 6/13/23

LTC Jacob L. Kitson, Research Advisor
TRI-SERVICE ORTHODONTIC RESIDENCY PROGRAM, AFPDS
Committee Member

Committee Member

Committee Member

Committee Member

Correlation Between the Curve of Spee and Vertical Divergence in Skeletal Class I Patients

Summary

The Curve of Spee (COS) is one of many factors that must be considered when treatment planning the orthodontic patient. The objective of this study was to determine if a correlation existed between skeletal Class I patients and their vertical skeletal divergence. This retrospective study analyzed 60 total Class I patients divided into 3 equal groups based on vertical skeletal divergence (hypodivergent, normodivergent, and hyperdivergent). From this population, measurements from cephalometric and pre-treatment study models were recorded. The data was aggregated and analyzed with Pearson Correlation Coefficient statistics. This study found that there was a statistically significant positive correlation between the COS and both overbite and overjet. However, no correlation was identified between the COS and vertical skeletal divergence in skeletal Class I patients.

Introduction

The Curve of Spee (COS) is a naturally occurring phenomenon found in the dentitions of humans as well as other mammals (1). It was first described by the German anatomist Ferdinand Graf von Spee in 1890 when he observed the natural curvature of the human dentition when viewed in the sagittal plane (2). His description of the curve started with the anterior surfaces of the mandibular condyles following the arc of a circle across the occlusal surfaces of the mandibular teeth (2). While this remains the definition of the COS in the Glossary of Prosthodontic Terms (3), in orthodontics, the COS is commonly used to describe the curved plane tangent to the incisal edges and buccal cusps of the mandibular posterior teeth (4). In his examination of the COS, Rozzi et al measured the COS by establishing points on the distobuccal cusp tips of the left and right second molars, and a midpoint at the center of the left and right central incisor edges (5). These tripod points defined the occlusal plane from which the greatest depth of the COS could be measured on the right and left sides (5). This same method was used to measure the COS in this study.

The functional significance of the COS varies among the literature and remains poorly understood (6). Von Spee postulated that this naturally occurring curve represented the most efficient arrangement of the teeth for maintaining maximal contact during mastication (2). More recently, studies by Osborn have suggested that the COS plays an important biomechanical role during mastication by increasing the crush-shear ratio amongst the posterior teeth, increasing occlusal efficiency (1,7). In prosthodontics, management of the COS may be necessary in establishing a mutually protected occlusion and possibly in the success of dental implants (4).

In orthodontics, however, the leveling of the COS has become a routine goal of treatment (8). In his landmark study, Andrews discovered that a flat to very slight COS was consistent among "ideal" occlusions. Further, he demonstrated that a relatively flat plane of occlusion was essential in establishing the best intercuspation of the dentition. His model demonstrated that with an increasingly greater COS, a progressively greater intercuspal error would occur. Conversely, a reverse COS would result in spacing in the maxillary teeth (9).

Assessing the depth of the COS is important in the diagnosis and treatment protocol of an orthodontic patient, as the greater its depth, the greater the space required to flatten it, and the greater the risk for undesirable incisor protrusion (10, 11). One popular estimation of the space required is that 1 mm of arch circumference is needed for each millimeter of the COS (11). Baldridge (12) and Garcia (13) proposed different linear relationships between the COS and the space required for leveling. Germane et al mathematically determined the relationship to be non-linear and less than a one-to-one ratio for a COS of less than 9 mm (14).

The development and etiology of the COS has been studied by several researchers and is multi-factorial with both skeletal and dental components (4,15). It is thought to be affected by the growth of orofacial structures, the development of the neuromuscular system and the differential eruption of teeth, whereby the mandibular incisors and molars erupt earlier than their opposing counterparts (15). Veli et al found that the vertical eruption of the anterior teeth had a significant contribution to the depth of the COS in class I and Class III patients (15). Marshall et al found that the greatest increase in the development of the COS occurred with the eruption of the mandibular second molars, which on average, erupt 6 months before their maxillary antagonists (4). These findings would suggest a greater dental effect on the development of the COS. Farella et al found that the COS was significantly related to the horizontal position of the dentition to the condyle (O-M), to the sagittal position of the mandible with respect to the cranial base (SNB), and to the ratio of the anterior to posterior facial height (10). These findings would perhaps suggest a stronger skeletal influence.

While the effects of craniofacial morphology on the COS have been examined in other studies, systematic investigation is lacking (10). The aim of this study is to increase the knowledge and understanding of these potential relationships. More specifically, the goal of this study is to determine an average Curve of Spee in patients with a skeletal Class I relationship. The study further seeks to establish an average COS among 3 mandibular plane angle sub-groups, classified as either hyperdivergent, normodivergent, or hypodivergent. By comparing these averages, any potential differences can be identified. This information, when combined with the findings from 2 similar studies conducted by Dykes and Brockbank at the Tri-service Orthodontic Residency Program (TORP), hopes to provide a comprehensive source of data that will ultimately improve our base of knowledge on the COS and its etiology. The hypothesis being tested is that hypodivergent Class I skeletal patterns will exhibit the greatest COS and that there is a correlation between the mandibular divergence and the depth of the COS in patients with a class I skeletal malocclusion. The null hypothesis for this study is that that there is no correlation between mandibular divergence and the COS.

Materials and Methods

This retrospective study was conducted with records of patients who presented for treatment at the Tri-Service Orthodontic Program (Lackland AFB, San Antonio, TX). The following inclusion criteria were used:

1) A skeletal Class I profile (ANB between 0 and 4 degrees)
2) Available pre-treatment records to include dental casts and a lateral cephalogram

The following exclusion criteria were used:

1) An incomplete permanent dentition (excluding third molars)
2) Non-diagnostic records
3) A history of past orthodontic treatment (determined by review of the patient record)
4) The presence of periodontal disease
5) The presence of any craniofacial anomalies

From the list of patients who met these criteria, an additional search was performed to divide the potential records into three groups: hypodivergent (FMA less than 20 degrees), normodivergent (FMA between 20 and 29 degrees), and hyperdivergent (FMA greater than 29 degrees). From each of these groups, 20 patients were randomly selected to make up the total study population (60 patients).

For each patient, a lateral cephalogram was traced using Dolphin Imaging software (Dolphin Imaging, 11.95 Premium, Patterson Dental, Chatsworth, CA) and the following measurements were determined: SNA, SNB, ANB, A-N perpendicular, B-N perpendicular, Pogonion-N perpendicular, SN-MP, FMA, U1-NA, U1-SN, L1-NB, L1-MP, OP-MP, SN-OP. For the purposes of this study, a line extending through the overlapping cusps of the first molars and the first premolars established the functional occlusal plane (OP). The mandibular plane was measured from Menton to Constructed Gonion.

Secondly, dental casts for each patient were scanned and digitized (R2000, 3Shape A/S, Copenhagen, Denmark). The digitized 3-dimensional casts were measured and analyzed using the scanner's software (Orthoanalyzer, 3Shape A/S, Copenhagen, Denmark). All reconstructed cephalometric tracings and digital cast measurements were completed by a single rater (M.R).

The COS was measured following the method previously applied by Rozzi (5). The mandibular occlusal plane was established by selecting three points: the distobuccal cusp of each mandibular second molar, and an anterior point created at the midpoint of the incisal edge of the central incisors (Figure 1). Any discrepancy in vertical position of the incisal edges of the central incisors was rectified by selecting a point halfway between the two edges. The depth of each cusp tip to this occlusal reference plane was measured. Cusp tips that were not in occlusal contact with an antagonist were not included in the measurements. From these values, the deepest cusp measurement for both the left and right side was recorded. These two values (left and right COS) were averaged for each patient and this value was used for the COS depth.

Overjet and overbite were measured following a method previously applied by Veli (15). Overjet was a horizontal measurement between the incisal edge of the facial surface of the mandibular central incisor and the incisal edge of the facial surface of the maxillary central incisor. The most facially positioned maxillary central incisor was selected whenever there was a discrepancy between the two central incisors (Figure 2). Overbite was a vertical measurement between the incisal edges of the maxillary central incisor to the mandibular central incisor (Figure 2). The COS, overbite, and overjet measurements were all recorded in millimeters.

Statistical Analysis

Data was analyzed with descriptive and correlation statistics. A one-way ANOVA was performed to assess for significant differences in the COS depth between the three skeletal divergence groups. Additionally, Pearson's correlation coefficient calculations were accomplished to look for correlations between the multiple measured variables to the COS. To test the reliability of the measurements, 20 sets of records (3-D casts and lateral cephalograms) were randomly selected to have the procedure repeated 1 month later by the same rater (M.R.).

Results

The sample included 60 patients, composed of 23 females and 37 males. The racial composition was 31 Caucasian, 14 African American, 12 Hispanic, and 3 Asian patients. The age of the patients ranged from 11.8-62.8 years, with an average age of 25.1 years. The COS average was deepest in hypodivergent patients (2.33mm), and shallowest in hyperdivergent (1.91mm), however the differences were not significant ($P > 0.05$) (Table 1).

The intra-rater reliability scores for each measured variable ranged between 0.99 and 0.92, qualifying each measured variable as having an excellent intra-rater reliability (30).

The correlation analysis found that when looking at the full sample (n=60), the COS had a moderate positive correlation to both overbite ($r = 0.38$; $P = 0.003$) and overjet ($r = 0.39$; $P = 0.002$) (Table 2). Separating the patients by skeletal divergence, in the hypodivergent group, the COS was positively correlated to overbite only ($r = 0.49$; $P = 0.03$). No other statistically significant correlations were found between the COS and the other measured variables within the mandibular divergence groups (Table 2).

Discussion

The results of this study failed to accept the hypothesis that the COS depth would be increased in hypodivergent skeletal Class I patients. In fact, no correlation was found to skeletal divergence (FMA or SN-MP). This finding contradicts the findings of other studies within the literature (16-19). Many studies have found a negative COS to be associated with hyperdivergent (dolichofacial), anterior open bite patients, while a deep COS has been associated with hypodivergent (brachyfacial), deepbite patients (16). Shannon et al found that the mandibular plane angle (FMA) was negatively correlated to the COS (17). Uzuner et al found a significant negative correlation between SN/GoGN and the COS (18). In his investigation of the relationship between the FMA and the COS, Fawaz et al, concluded that the COS is affected by the vertical skeletal pattern with smaller COS measurements in hyperdivergent patients (19). However, it is noteworthy that he found no difference between normodivergent and hypodivergent patients (19).

The COS depth was found to be positively correlated to both overbite and overjet measurements in the total Class I sample ($P = 0$). However, this same correlation lacked statistical significance when examined within each of the three mandibular divergence groups. The one exception was within the hypodivergent group, where the COS was found to be positively correlated to overbite. This finding is consistent with other studies. El-Dawlatly et al concluded that an exaggerated COS and a decreased gonial angle were the greatest contributing factors to a deepbite malocclusion (20). Baydas et al similarly found that overbite was significantly larger in individuals with a deep COS. (8). Regarding the positive correlation found between the COS and overjet in the overall class I sample, this is also consistent with the findings from other studies (16, 21-23).

The COS was found to be highly variable across each sample, ranging from -0.9 mm to 4.96 mm. As might be expected, the highest value occurred in the hypodivergent group (range = 0.33 - 4.96 mm) while the lowest value occurred in the hyperdivergent group (range = -0.9 – 3.27 mm). Also as expected, the lowest average COS occurred in the hyperdivergent group (1.91 mm), while the largest average occurred in the hypodivergent group (2.33 mm). The normodivergent group had intermediate values (mean = 2.02 mm ; range = 0.28 - 3.3 mm). However, these differences in the average COS were not statistically significant. One reason for this may be due to an insufficient sample size. Perhaps a larger sample size would have yielded a more statistically significant correlation between the COS and skeletal divergence.

This study did not attempt to compare differences between the left and right-side COS, as many other studies have concluded there to be no significant differences (4,15,24). Other potential confounding variables such as gender, age, and ethnicity were not taken into consideration for sample selection. The literature has shown that any gender differences in the COS are negligible (6,21,23,25). Therefore, it is unlikely that the 37:23 male to female ratio had any effect on the results. Several studies have found that once the COS has been established in adolescence, it remains relatively stable into adulthood (4,26,27). Therefore, the large range in patient ages (11.8 – 62.8 years) should not have affected the results. The authors are unaware of any studies looking directly at differences in COS measurements among ethnic groups, therefore, it cannot be known whether this variable had any effect on the data.

A potential weakness of this study was the use of ANB to define a skeletal Class I relationship. It has been demonstrated that ANB can be a misleading measurement for skeletal classification, as it is highly sensitive to the anterior/posterior position of the jaws relative to nasion, as well as to the rotation of the jaws relative to the anterior cranial base (28). One potential solution to this concern could be to also consider the Wits analysis when selecting patients for a study sample. An exclusion of patients whose Wits measurements would have classified them as either Class II or Class III may have resulted in a more reliable skeletal Class I sample for this study. Another problem with using ANB measurements to define a skeletal Class I relationship is that there are recognized differences in racial norms for skeletal classification (29). As race and ethnicity were not considered for patient selection, this could have acted as a confounding variable when attempting to identify the appropriate Class I patient sample.

Finally, this study did not consider patients based on their Angle molar relationship. Rather, only their skeletal relationship was considered. For this reason, it is quite possible that some patients in the study sample may have presented with Angle Class II or Class III dental relationships. Future studies may benefit from considering both skeletal and dental relationships when selecting a Class I sample.

Conclusion

- The COS depth was not correlated to the skeletal divergence in skeletal Class I patients.
- The COS depth was positively correlated to both overbite and overjet in the total sample.
- The COS was positively correlated with overbite within the hypodivergent sample.

Acknowledgements

Thanks to Dr. Barrington Dykes DDS, MS for developing this study design while conducting his research on a skeletal Class II sample. Thanks to Dr. David Brockbank DDS for his collaboration while conducting his research on a skeletal Class III sample. Finally, the authors would like to thank Dr. Jisuk Park, PhD, CTR for her help with the statistical analysis.

References

1. Osborn JW. Orientation of the masseter muscle and the curve of Spee in relation to crushing forces on the molar teeth of primates. *Am J Phys Anthropol*. Sep 1993;92(1):99-106. doi:10.1002/ajpa.1330920108
2. The gliding path of the mandible along the skull. Ferdinand Graf Spee (1855-1937), prosector at the Anatomy Institute of Kiel. *J Am Dent Assoc*. May 1980;100(5):670-5.
3. The glossary of prosthodontic terms. *J Prosthet Dent*. Jul 2005;94(1):10-92. doi:10.1016/j.prosdent.2005.03.013
4. Marshall SD, Caspersen M, Hardinger RR, Franciscus RG, Aquilino SA, Southard TE. Development of the curve of Spee. *Am J Orthod Dentofacial Orthop*. Sep 2008;134(3):344-52. doi:10.1016/j.ajodo.2006.10.037
5. Rozzi M, Mucedero M, Pezzuto C, Lione R, Cozza P. Long-term stability of curve of Spee levelled with continuous archwires in subjects with different vertical patterns: a retrospective study. *Eur J Orthod*. May 24 2019;41(3):286-293. doi:10.1093/ejo/cjy065
6. Xu H, Suzuki T, Muronoi M, Ooya K. An evaluation of the curve of Spee in the maxilla and mandible of human permanent healthy dentitions. *J Prosthet Dent*. Dec 2004;92(6):536-9. doi:10.1016/j.prosdent.2004.08.023
7. Osborn JW. Relationship between the mandibular condyle and the occlusal plane during hominid evolution: some of its effects on jaw mechanics. *Am J Phys Anthropol*. Jun 1987;73(2):193-207. doi:10.1002/ajpa.1330730206
8. Baydaş B, Yavuz I, Atasaral N, Ceylan I, Dağsuyu IM. Investigation of the changes in the positions of upper and lower incisors, overjet, overbite, and irregularity index in subjects with different depths of curve of Spee. *Angle Orthod*. Jun 2004;74(3):349-55. doi:10.1043/0003-3219(2004)074<0349:Iotcit>2.0.Co;2
9. Andrews LF. The six keys to normal occlusion. *Am J Orthod*. Sep 1972;62(3):296-309. doi:10.1016/s0002-9416(72)90268-0
10. Farella M, Michelotti A, van Eijden TM, Martina R. The curve of Spee and craniofacial morphology: a multiple regression analysis. *Eur J Oral Sci*. Aug 2002;110(4):277-81. doi:10.1034/j.1600-0722.2002.21255.x
11. Braun S, Hnat WP, Johnson BE. The curve of Spee revisited. *Am J Orthod Dentofacial Orthop*. Aug 1996;110(2):206-10. doi:10.1016/s0889-5406(96)70110-5

12. Baldridge DW. Leveling the curve of Spee: its effect on mandibular arch length. JPO J Pract Orthod. 1969 Jan;3(1):26-41. PMID: 5250875
13. Garcia R. Leveling the curve of Spee: a new prediction formula. J Charles H. Tweed Int Found. 1985 Apr;13:65-72. PMID: 3861700.
14. Germane N, Staggers JA, Rubenstein L, Revere JT. Arch length considerations due to the curve of Spee: a mathematical model. Am J Orthod Dentofacial Orthop. 1992 Sep;102(3):251-5. doi: 10.1016/S0889-5406(05)81060-1. PMID: 1510050.
15. Veli I, Ozturk MA, Uysal T. Curve of Spee and its relationship to vertical eruption of teeth among different malocclusion groups. *Am J Orthod Dentofacial Orthop*. Mar 2015;147(3):305-12. doi:10.1016/j.ajodo.2014.10.031
16. Trouten JC, Enlow DH, Rabine M, Phelps AE, Swedlow D. Morphologic factors in open bite and deep bite. Angle Orthod. 1983 Jul;53(3):192-211.
17. Shannon KR, Nanda RS. Changes in the curve of Spee with treatment and at 2 years posttreatment. Am J Orthod Dentofacial Orthop. 2004 May;125(5):589-96.
18. Uzuner FD, Aslan BI, Dinçer M. Dentoskeletal morphology in adults with Class I, Class II Division 1, or Class II Division 2 malocclusion with increased overbite. Am J Orthod Dentofacial Orthop. 2019 Aug;156(2):248-256.e2.
19. Fawaz P, Amm E, Khoury E. The curve of Spee and its levelling in different vertical skeletal patterns: A 3D set-up study. *Int Orthod*. Aug 31 2021;doi:10.1016/j.ortho.2021.08.003
20. El-Dawlatly MM, Fayed MM, Mostafa YA. Deep overbite malocclusion: analysis of the underlying components. Am J Orthod Dentofacial Orthop. 2012 Oct;142(4):473-80
21. Orthlieb JD. The curve of Spee: understanding the sagittal organization of mandibular teeth. *Cranio*. 1997;15(4):333-340.
22. Kumari N, Fida M, Shaikh A. Exploration of variations in positions of upper and Lower incisors, overjet, overbite, and irregularity Index in orthodontic patients with dissimilar depths of Curve of spee. J Ayub Med Coll Abbottabad. 2016 Oct-Dec;28(4):766-772.
23. Halimi A, Benyahia H, Azeroual MF, Bahije L, Zaoui F. Relationship between the curve of Spee and craniofacial variables: A regression analysis. Int Orthod. 2018 Jun;16(2):361-373. doi: 10.1016/j.ortho.2018.03.025. Epub 2018 Apr 21. PMID: 29685399.
24. Sayar G, Oktay H. Assessment of curve of spee in different malocclusions. *Eur Oral Res*. 2018;52 (3):127-130.
25. Ferrario VF, Sforza C, Miani A Jr, Colombo A, Tartaglia G. Mathematical definition of the curve of Spee in permanent healthy dentitions in man. *Arch Oral Biol*. 1992;37(9):691-694.
26. Carter GA, McNamara JA Jr. Longitudinal dental arch changes in adults. Am J Orthod Dentofacial Orthop. 1998 Jul;114(1):88-99. doi: 10.1016/s0889-5406(98)70243-4. PMID: 9674686.
27. Bishara SE, Jakobsen JR, Treder JE, Stasi MJ. Changes in the maxillary and mandibular tooth size-arch length relationship from early adolescence to early adulthood. A longitudinal study. Am J Orthod Dentofacial Orthop. 1989 Jan;95(1):46-59. doi: 10.1016/0889-5406(89)90135-2. PMID: 2910026.
28. Radiographic Cephalometry: From Basics to Videoimaging (1995). Alexander Jacobson (Ed). Publisher: Quintessence Publishing Co. Inc., London
29. Johnson PF. Racial norms: esthetic and prosthodontic implications. J Prosthet Dent. 1992 Apr;67(4):502-8. doi: 10.1016/0022-3913(92)90081-k. PMID: 1507134.

30. Koo TK, Li MY (June 2016). "A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research". *Journal of Chiropractic Medicine*. 15 (2): 155–63. doi:10.1016/j.jcm.2016.02.012. PMC 4913118. PMID 27330520

Table 1

Divergency Group	**COS**		
	Mean	**Std Dev**	**Range**
Hyperdivergent	1.91	0.91	-0.9 – 3.27
Normodivergent	2.02	0.73	0.28 – 3.3
Hypodivergent	2.33	1.09	0.33 – 4.96

Table 2

		Total N=60	**Hyper N=20**	**Hypo N=20**	**Normo N=20**
		COS			
SNA	Pearson Correlation	0.0829	0.28013	-0.22655	0.10066
	P Value	0.5289	0.2316	0.3368	0.6729
SNB	Pearson Correlation	0.0278	0.25114	-0.31501	0.02778
	P Value	0.833	0.2855	0.1761	0.9075
ANB	Pearson Correlation	0.22186	0.0743	0.305	0.24319
	P Value	0.0884	0.7556	0.191	0.3015
ANPerp	Pearson Correlation	-0.05944	-0.02721	-0.11548	-0.19774
	P Value	0.6519	0.9093	0.6278	0.4033
BNPerp	Pearson Correlation	-0.11599	-0.03854	-0.19866	-0.31983
	P Value	0.3775	0.8718	0.4011	0.1692
PogNPerp	Pearson Correlation	-0.08021	-0.00993	-0.2574	-0.30452
	P Value	0.5424	0.9669	0.2733	0.1917
SNMP	Pearson Correlation	-0.2468	-0.53506	0.38259	-0.41526
	P Value	0.0573	0.0151	0.0959	0.0686
FMA	Pearson Correlation	-0.18878	-0.3037	0.26815	-0.11503
	P Value	0.1486	0.193	0.253	0.6292
U1NA	Pearson Correlation	0.14224	0.11295	0.19187	0.16969
	P Value	0.2783	0.6354	0.4177	0.4745
U1SN	Pearson Correlation	0.12748	0.1859	0.02592	0.14699
	P Value	0.3317	0.4326	0.9136	0.5363
L1NB	Pearson Correlation	-0.0463	0.03523	-0.04696	0.03944
	P Value	0.7254	0.8828	0.8442	0.8689
L1MP	Pearson Correlation	0.15537	0.04337	-0.03727	0.22019
	P Value	0.2359	0.8559	0.876	0.3509
Overbite	Pearson Correlation	**0.37842**	0.30707	**0.48731**	0.16207
	P Value	**0.0029**	0.1879	**0.0293**	0.4948
Overjet	Pearson Correlation	**0.38883**	0.26808	0.36788	0.43166
	P Value	**0.0021**	0.2531	0.1105	0.0574

Figure 1

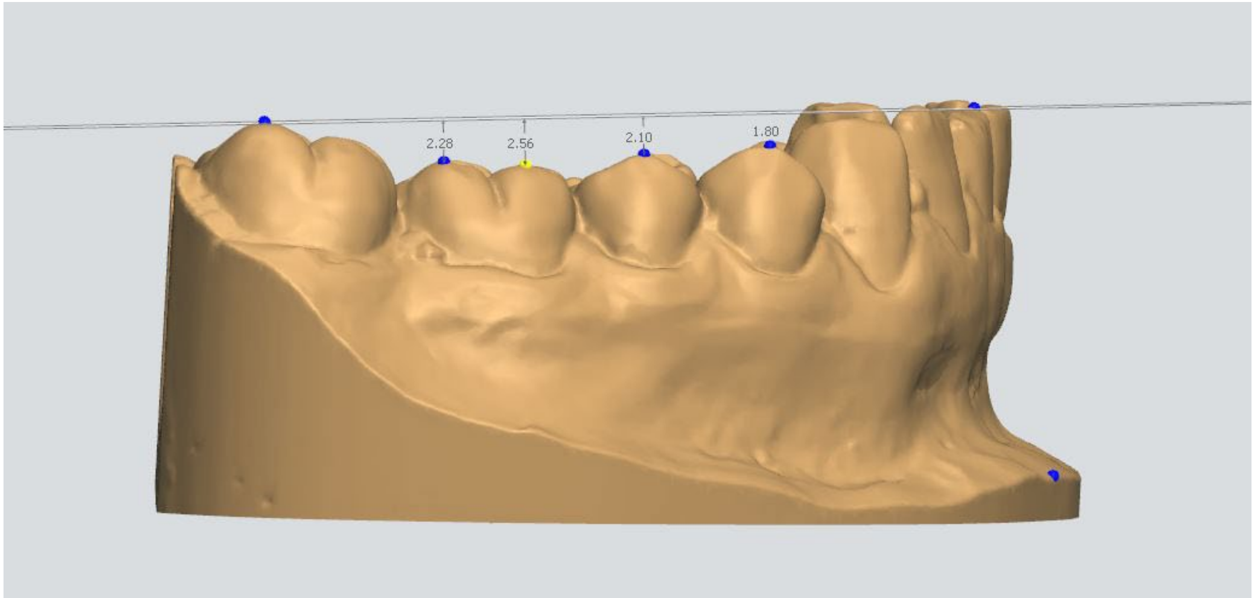

Figure 2