Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 32s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

A Comparative Evaluation Of Positional Accuracy Of Parallel Implant And Three Angulated Implants Using Open Tray Technique: An In Vitro Study

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Cite this paper as: Dr. Sania Mohsin, Dr. Harendra Shahi, Dr. Arunachalam Sudheer, Dr. Priya, Dr. Susmita Mondal, (2025) A Comparative Evaluation Of Positional Accuracy Of Parallel Implant And Three Angulated Implants Using Open Tray Technique: An In Vitro Study. *Journal of Neonatal Surgery*, 14 (32s), 5885-5904.

ABSTRACT

Aim: The aim of this in vitro study is to evaluate and compare the positional accuracy of parallel implants and angulated implants placed at 15°, 20°, and 25° using the open tray impression technique.

Objective: The objectives of this study are to evaluate and compare the positional accuracy of parallel implants with angulated implants placed at 15°, 20°, and 25°, using polyether as the impression material and pattern resin as the splinting material. Specifically, the study aims to assess the accuracy of parallel implants against each angulated group individually and to compare the differences in positional accuracy among the three angulated groups to determine the effect of increasing implant angulation on impression precision.

Materials and methods: The present study was conducted in the Department of Prosthodontics and Crown & Bridge at Mithila Minority Dental College and Hospital, Darbhanga, Bihar. It aimed to evaluate the accuracy of implant positioning across different angulations using a Visual Coordinate Measuring Machine (VCMM).A total of four custom-made acrylic resin test models were fabricated using a standardized silicone edentulous maxillary mold. Each model was processed with heat-cure acrylic resin to ensure uniformity in dimensions. Six implants were placed bilaterally in each model at the lateral incisor, first premolar, and second molar regions using a surgical guide to standardize positioning and angulation. A micromotor was employed to control implant angulations accurately.In Model 1, all implants were placed parallel to each other and perpendicular to the horizontal plane. In Model 2, the lateral implants were inclined mesiobuccally at 15°, the premolar implants remained upright, and the molar implants were distally inclined at 15°. Model 3 followed the same configuration as Model 2, but with 20° inclinations, while Model 4 had 25° inclinations at the lateral and molar sites, with upright premolars. Once implant placement was complete, open tray impression copings were secured to the implants and splinted with dental floss and pattern resin to maintain their relative positions. A total of 21 impressions were taken for each test model using the open tray technique. Custom trays were fabricated for each impression, and tray adhesive was applied to the intaglio surface prior to impression making with polyether material. Master casts were poured using Type IV dental stone and were allowed to set for 60 minutes before retrieval and trimming.

Results: In this study, a total of 84 samples were equally distributed among four groups. Each group—Group I, Group II, Group III, and Group IV—comprised 21 samples, accounting for 25% of the total sample size. This equal distribution ensured consistency across all study groups for comparative evaluation.

For Group I, the mean inter-implant distances were recorded at various points. The distance between points A and B ranged from 23.17 mm to 25.91 mm, with a mean of 25.03 mm and a standard deviation of 0.63 mm. The distance from B to C had a minimum of 13.20 mm and a maximum of 15.00 mm, with a mean value of 14.16 mm and a standard deviation of 0.46 mm. From C to D, the distances ranged between 22.96 mm and 24.95 mm, showing a mean of 24.22 mm and a standard deviation of 0.58 mm. Lastly, the distance from B to D varied between 32.59 mm and 36.12 mm, with a mean distance of 34.71 mm and a standard deviation of 0.91 mm.

Conclusion: Implants placed at higher angulations—such as 25 degrees or more—can lead to significant discrepancies in the positional accuracy of multiple implants on the definitive cast. This deviation often compromises the passive fit of the final prosthesis, especially in full-arch rehabilitations such as All-on-4 and All-on-6. A lack of passive fit can result in mechanical complications, increased stress on the prosthetic components, and reduced long-term success of the restoration. To achieve an accurate and stable passive fit, implant angulations in All-on-4 and All-on-6 cases should ideally range between 15 and 20 degrees. Positional inaccuracies within this range are generally manageable using standard angled abutments. However, when implant angulation exceeds 25 degrees, corrections become more complex and require custom CAD/CAM abutments or specialized multi-unit abutments. Although cone-shaped multi-unit abutments offer a solution for correcting angulation and improving parallelism, they present certain limitations. The most notable drawback is the use of a very small prosthetic screw, which can be difficult to handle and tighten securely. In cases of poor alignment, additional manufactured caps and securing screws may be needed to achieve a passive prosthetic bridge fit—adding to both technical complexity and financial costs.

Therefore, to minimize such challenges and ensure optimal prosthetic outcomes, clinicians are recommended to limit implant angulations to below 25 degrees in full-arch restorations. This approach simplifies prosthetic planning, enhances passive fit, and improves overall treatment predictability and patient satisfaction.

Keywords: *Implants, impression, splinting*

1. INTRODUCTION

Dental implants are commonly used to replace missing teeth in both partially and completely edentulous patients. They have demonstrated strong survival rates and are known to significantly improve patients' functional abilities, aesthetics, and overall quality of life over time. For individuals who are completely edentulous, prosthetic rehabilitation using dental implants has proven to be a reliable and effective approach.[1]

One of the most critical factors determining the success of implant placement is the availability of sufficient quantity and quality of alveolar bone. In cases of extensive bone loss, patients often require preoperative surgical procedures such as sinus lift or bone augmentation to achieve a favorable outcome. It is well-established that directing masticatory forces along the long axis of the tooth or implant helps to enhance implant longevity and reduce bone resorption.[2,3]

Due to the challenges associated with severe alveolar ridge resorption, including the need for additional surgical interventions, researchers have explored alternatives to conventional bone grafting procedures. In 1993, Dr. Paulo Malo introduced the concept of the "All-on-Four" technique, wherein two anterior implants are placed vertically, and two posterior implants are angled at 35 to 40 degrees. This approach offered a promising solution by minimizing the need for bone augmentation.

Angulated dental implants have evolved significantly and are now widely accepted. Unlike traditional implants placed perpendicular to the occlusal plane, angulated implants are inserted at an angle to accommodate anatomical limitations, improve aesthetics, and utilize available bone more effectively. This method has proven particularly beneficial in scenarios where conventional implant placement is not feasible.[4]

Today, angulated implants are preferred in many clinical cases due to their various advantages. These include eliminating the need for complex bone grafting procedures and allowing for the immediate placement of temporary prostheses in select cases. Studies have shown that, when biomechanical principles are appropriately followed, angulated implants achieve survival rates comparable to those of conventionally placed implants.

Reported survival rates for angulated implants range from 89% to 100%, depending on the clinical condition, patient health status, and the type of implant system used. Long-term data reveals that dental implants overall have a survival rate of 93.6% over an average follow-up of 16.5 years, with a cumulative survival rate of 85.9% at 24 years.

Given this background, the present study has been designed to evaluate and compare the positional accuracy of implants placed at different angulations. The objective is to determine the optimal degree of implant angulation required to achieve a precise passive fit for implant-supported prosthesis.

2. MATERIALS AND METHOD

The present study was conducted in the Department of Prosthodontics and Crown & Bridge at Mithila Minority Dental College and Hospital, Darbhanga, Bihar. It aimed to evaluate the accuracy of implant positioning across different angulations using a Visual Coordinate Measuring Machine (VCMM).

A total of four custom-made acrylic resin test models were fabricated using a standardized silicone edentulous maxillary mold. Each model was processed with heat-cure acrylic resin to ensure uniformity in dimensions. Six implants were placed bilaterally in each model at the lateral incisor, first premolar, and second molar regions using a surgical guide to standardize positioning and angulation. A micromotor was employed to control implant angulations accurately.

In Model 1, all implants were placed parallel to each other and perpendicular to the horizontal plane. In Model 2, the lateral implants were inclined mesiobuccally at 15°, the premolar implants remained upright, and the molar implants were distally inclined at 15°. Model 3 followed the same configuration as Model 2, but with 20° inclinations, while Model 4 had 25° inclinations at the lateral and molar sites, with upright premolars.

Once implant placement was complete, open tray impression copings were secured to the implants and splinted with dental floss and pattern resin to maintain their relative positions. A total of 21 impressions were taken for each test model using the open tray technique. Custom trays were fabricated for each impression, and tray adhesive was applied to the intaglio surface prior to impression making with polyether material. Master casts were poured using Type IV dental stone and were allowed to set for 60 minutes before retrieval and trimming.

The inter-implant distances were measured using a high-precision VCMM with an accuracy of ±5 µm. Each implant analog was identified by stroking four perimeter points, and the software calculated the centroid for each implant. The implants were labeled from right to left as A, E, B, C, F, and D, and distances between these were calculated in the X, Y, and Z axes.

The main inclusion criteria for the study included uniform dimensions across all test models, the use of surgical guides, consistent implant width and depth, splinting of copings, and defect-free impressions. Test models made of porous acrylic, broken casts, models poured with incorrect materials, or non-hex implants were excluded.

The measurements obtained were systematically tabulated and subjected to statistical analysis. A factorial analysis of variance (ANOVA) was employed to compare inter-implant distances among the four test models. A p-value of less than 0.05 ($P < 0.05$) was considered statistically significant. To further identify differences between specific groups, post hoc tests with homogeneous subset analysis were conducted. These tests determined the grouping of models based on similarities or differences in their measured values. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 21.0 (Chicago, IL, USA).

3. RESULTS

Table1.Distributionofsamplesinstudygroups

	Frequency	Percentage
Group I	21	25.0
Group II	21	25.0
Group III	21	25.0
Group IV	21	25.0
Total	84	100.0

Table 2a:Mean implant distance at various points among groupI samples

	Minimum	Maximum	Mean	Std. Deviation
A-B	23.17	25.91	25.03	0.63
B-C	13.20	15.00	14.16	0.46
C-D	22.96	24.95	24.22	0.58
B-D	32.59	36.12	34.71	0.91
A-C	32.09	36.02	34.84	1.03
A-D	42.39	44.97	43.77	0.67

Fvalue-25872.32;p value-<.01*

Table2b.Pair wise comparison of mean implant distance at various points among group I samples

		Mean Difference	Std. Error	p value	95% Confidence IntervalforDifference	
					Lower Bound	Upper Bound
A-B	B-C	10.870*	.133	<.01*	10.591	11.148
	C-D	.818*	.141	<.01*	.525	1.112
	B-D	-9.679*	.227	<.01*	-10.151	-9.206
	A-C	-9.806*	.186	<.01*	-10.195	-9.418
	A-D	-18.738*	.189	<.01*	-19.133	-18.344
B-C	A-B	-10.870*	.133	<.01*	-11.148	-10.591
	C-D	-10.051*	.139	<.01*	-10.341	-9.761
	B-D	-20.548*	.186	<.01*	-20.936	-20.160
	A-C	-20.676*	.211	<.01*	-21.117	-20.235
	A-D	-29.608*	.178	<.01*	-29.979	-29.237
C-D	A-B	-.818*	.141	<.01*	-1.112	-.525
	B-C	10.051*	.139	<.01*	9.761	10.341
	B-D	-10.497*	.187	<.01*	-10.886	-10.108
	A-C	-10.625*	.195	<.01*	-11.032	-10.218
	A-D	-19.557*	.169	<.01*	-19.910	-19.204
B-D	A-B	9.679*	.227	<.01*	9.206	10.151
	B-C	20.548*	.186	<.01*	20.160	20.936
	C-D	10.497*	.187	<.01*	10.108	10.886
	A-C	-.128	.208	<.01*	-.562	.307

	A-D	-9.060*	.251	<.01*	-9.584	-8.536
A-C	A-B	9.806*	.186	<.01*	9.418	10.195
	B-C	20.676*	.211	<.01*	20.235	21.117
	C-D	10.625*	.195	<.01*	10.218	11.032
	B-D	.128	.208	<.01*	-.307	.562
	A-D	-8.932*	.259	<.01*	-9.472	-8.392
A-D	A-B	18.738*	.189	<.01*	18.344	19.133
	B-C	29.608*	.178	<.01*	29.237	29.979
	C-D	19.557*	.169	<.01*	19.204	19.910
	B-D	9.060*	.251	<.01*	8.536	9.584
	A-C	8.932*	.259	<.01*	8.392	9.472

Table 3a: Mean implant distance at various points among group II samples

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
A-B	23.70	26.60	24.41	0.73
B-C	12.93	14.69	13.73	0.52
C-D	23.26	25.01	24.08	0.49
B-D	33.44	35.99	34.83	0.61
A-C	33.31	35.44	34.43	0.68
A-D	39.11	44.40	43.26	1.15

Fvalue-13583.50;p value-<.01*

Table 3 b: Pair wise comparison of mean implant distance at various points among group II samples

		Mean Difference	Std. Error	p value	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
A-B	B-C	10.676*	.155	<.01*	10.352	11.000
	C-D	.328	.180	.084	-.048	.704
	B-D	-10.416*	.142	<.01*	-10.713	-10.119
	A-C	-10.019*	.228	<.01*	-10.494	-9.545
	A-D	-18.850*	.241	<.01*	-19.354	-18.346
B-C	A-B	-10.676*	.155	<.01*	-11.000	-10.352
	C-D	-10.348*	.165	<.01*	-10.692	-10.005
	B-D	-21.092*	.117	<.01*	-21.336	-20.849
	A-C	-20.696*	.179	<.01*	-21.069	-20.323
	A-D	-29.526*	.224	<.01*	-29.993	-29.059
C-D	A-B	-.328	.180	.084	-.704	.048
	B-C	10.348*	.165	<.01*	10.005	10.692
	B-D	-10.744*	.166	<.01*	-11.090	-10.398
	A-C	-10.347*	.177	<.01*	-10.716	-9.979
	A-D	-19.178*	.297	<.01*	-19.797	-18.559
B-D	A-B	10.416*	.142	<.01*	10.119	10.713
	B-C	21.092*	.117	<.01*	20.849	21.336
	C-D	10.744*	.166	<.01*	10.398	11.090
	A-C	.397*	.182	.041*	.017	.776

	A-D	-8.434*	.221	<.01*	-8.896	-7.972
A-C	A-B	10.019*	.228	<.01*	9.545	10.494
	B-C	20.696*	.179	<.01*	20.323	21.069
	C-D	10.347*	.177	<.01*	9.979	10.716
	B-D	-.397*	.182	.041*	-.776	-.017
	A-D	-8.830*	.255	<.01*	-9.361	-8.299
A-D	A-B	18.850*	.241	<.01*	18.346	19.354
	B-C	29.526*	.224	<.01*	29.059	29.993
	C-D	19.178*	.297	<.01*	18.559	19.797
	B-D	8.434*	.221	<.01*	7.972	8.896
	A-C	8.830*	.255	<.01*	8.299	9.361

Table4 a:Mean implant distance at various points among group III samples

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
A-B	21.56	25.12	23.65	1.02
B-C	10.15	13.63	12.52	0.80
C-D	24.20	25.99	25.13	0.35
B-D	33.48	36.89	35.32	0.79
A-C	31.69	34.70	32.70	0.85
A-D	41.29	44.78	43.36	0.88

Fvalue-22688.07; p value-<.01*

Table4b. Pair wise comparison of mean implant distance at various points among group III samples

		Mean Difference	Std. Error	p value	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
A-B	B-C	11.135*	.252	<.01*	10.610	11.660
	C-D	-1.472*	.235	<.01*	-1.962	-.982
	B-D	-11.671*	.212	<.01*	-12.114	-11.229
	A-C	-9.043*	.238	<.01*	-9.540	-8.546
	A-D	-19.709*	.257	<.01*	-20.246	-19.173
B-C	A-B	-11.135*	.252	<.01*	-11.660	-10.610
	C-D	-12.607*	.228	<.01*	-13.082	-12.133
	B-D	-22.806*	.156	<.01*	-23.132	-22.481
	A-C	-20.178*	.299	<.01*	-20.802	-19.555
	A-D	-30.844*	.169	<.01*	-31.198	-30.491
C-D	A-B	1.472*	.235	<.01*	.982	1.962
	B-C	12.607*	.228	<.01*	12.133	13.082
	B-D	-10.199*	.206	<.01*	-10.629	-9.769
	A-C	-7.571*	.184	<.01*	-7.956	-7.186
	A-D	-18.237*	.243	<.01*	-18.745	-17.729
B-D	A-B	11.671*	.212	<.01*	11.229	12.114
	B-C	22.806*	.156	<.01*	22.481	23.132
	C-D	10.199*	.206	<.01*	9.769	10.629
	A-C	2.628*	.281	<.01*	2.041	3.215

	A-D	-8.038*	.168	<.01*	-8.388	-7.688
A-C	A-B	9.043*	.238	<.01*	8.546	9.540
	B-C	20.178*	.299	<.01*	19.555	20.802
	C-D	7.571*	.184	<.01*	7.186	7.956
	B-D	-2.628*	.281	<.01*	-3.215	-2.041
	A-D	-10.666*	.311	<.01*	-11.316	-10.016
A-D	A-B	19.709*	.257	<.01*	19.173	20.246
	B-C	30.844*	.169	<.01*	30.491	31.198
	C-D	18.237*	.243	<.01*	17.729	18.745
	B-D	8.038*	.168	<.01*	7.688	8.388
	A-C	10.666*	.311	<.01*	10.016	11.316

Table 5a:Mean implant distance at various points among group IV samples

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
A-B	24.22	27.55	25.05	0.69
B-C	13.59	14.95	14.37	0.37
C-D	23.24	25.81	24.99	0.67
B-D	30.82	35.80	34.45	1.26
A-C	34.60	35.61	34.99	0.30
A-D	41.14	42.50	41.93	0.29

F value-25758.23;p value-<.01*

Table 5 b:Mean implant distance at various points among group IV sample

		Mean Difference	Std. Error	p value	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
A-B	B-C	10.684*	.139	<.01*	10.395	10.974
	C-D	.058	.173	.740	-.302	.418
	B-D	-9.397*	.275	<.01*	-9.971	-8.823
	A-C	-9.936*	.160	<.01*	-10.269	-9.602
	A-D	-16.878*	.170	<.01*	-17.232	-16.524
B-C	A-B	-10.684*	.139	<.01*	-10.974	-10.395
	C-D	-10.626*	.157	<.01*	-10.954	-10.298
	B-D	-20.081*	.276	<.01*	-20.656	-19.507
	A-C	-20.620*	.101	<.01*	-20.830	-20.409
	A-D	-27.562*	.122	<.01*	-27.817	-27.307
C-D	A-B	-.058	.173	.740	-.418	.302
	B-C	10.626*	.157	<.01*	10.298	10.954
	B-D	-9.455*	.201	<.01*	-9.875	-9.036
	A-C	-9.993*	.162	<.01*	-10.331	-9.656
	A-D	-16.936*	.154	<.01*	-17.256	-16.615
B-D	A-B	9.397*	.275	<.01*	8.823	9.971
	B-C	20.081*	.276	<.01*	19.507	20.656
	C-D	9.455*	.201	<.01*	9.036	9.875
	A-C	-.538	.276	.065	-1.114	.038

	A-D	-7.481*	.288	<.01*	-8.081	-6.880
A-C	A-B	9.936*	.160	<.01*	9.602	10.269
	B-C	20.620*	.101	<.01*	20.409	20.830
	C-D	9.993*	.162	<.01*	9.656	10.331
	B-D	.538	.276	.065	-.038	1.114
	A-D	-6.942*	.106	<.01*	-7.163	-6.722
A-D	A-B	16.878*	.170	<.01*	16.524	17.232
	B-C	27.562*	.122	<.01*	27.307	27.817
	C-D	16.936*	.154	<.01*	16.615	17.256
	B-D	7.481*	.288	<.01*	6.880	8.081
	A-C	6.942*	.106	<.01*	6.722	7.163

Table 6.Comparison of mean implant distance among study groups at A-B point

Groups	**Mean**	**Std. Deviation**	**Fvalue;p value**
Group I	25.03	0.63	15.06;<.01*
Group II	24.41	0.73	
Group III	23.65	1.02	
Group IV	25.05	0.69	

Table7.Pair wise comparison of mean implant distance among study groups at A-B point

		Mean Difference	**Std. Error**	**p value**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Group I	Group II	.623524	.240703	.054	-.00805	1.25510
	Group III	1.380762*	.240703	<.018	.74919	2.01233

	Group IV	-.017619	.240703	1.000	-.64919	.61395
Group II	Group I	-.623524	.240703	.054	-1.25510	.00805
	Group III	.757238*	.240703	.012*	.12567	1.38881
	Group IV	-.641143*	.240703	.045*	-1.27271	-.00957
Group III	Group I	-1.380762*	.240703	<.01*	-2.01233	-.74919
	Group II	-.757238*	.240703	.012*	-1.38881	-.12567
	Group IV	-1.398381*	.240703	<.01*	-2.02995	-.76681
Group IV	Group I	.017619	.240703	1.000	-.61395	.64919
	Group II	.641143*	.240703	.045*	.00957	1.27271
	Group III	1.398381*	.240703	<.01*	.76681	2.02995

Table8.Comparison of mean implant distance among study groups at B-C point

Groups	**Mean**	**Std. Deviation**	**Fvalue;p value**
Group I	14.16	0.46	45.75;<.018
Group II	13.73	0.52	
Group III	12.52	0.80	
Group IV	14.37	0.37	

Table 9.Pair wise comparison of mean implant distance among study groups atB-Cpoint

		Mean Difference	**Std. Error**	**p value**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Group I	Group II	.430238	.173213	.070	-.02425	.88473
	Group III	1.646286*	.173213	<.01*	1.19180	2.10077
	Group IV	-.202905	.173213	.647	-.65739	.25158

Group II	Group I	-.430238	.173213	.070	-.88473	.02425
	Group III	1.216048*	.173213	<.01*	.76156	1.67054
	Group IV	-.633143*	.173213	.003*	-1.08763	-.17866
Group III	Group I	-1.646286*	.173213	<.01*	-2.10077	-1.19180
	Group II	-1.216048*	.173213	<.01*	-1.67054	-.76156
	Group IV	-1.849190*	.173213	<.01*	-2.30368	-1.39470
Group IV	Group I	.202905	.173213	.647	-.25158	.65739
	Group II	.633143*	.173213	.003*	.17866	1.08763
	Group III	1.849190*	.173213	<.01*	1.39470	2.30368

Table10.Comparison of mean implant distance among study groups at C-Dpoint

Groups	**Mean**	**Std. Deviation**	**Fvalue;p value**
Group I	24.22	0.58	20.919; <.01*
Group II	24.08	0.49	
Group III	25.13	0.35	
Group IV	24.99	0.67	

Table11.Pair wise comparison of mean implant distance among study groups at C-Dpoint

		Mean Difference	**Std. Error**	**p value**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Group I	Group II	.132905	.164244	.850	-.29805	.56386
	Group III	-.909905*	.164244	<.01*	-1.34086	-.47895
	Group IV	-.778143*	.164244	<.01*	-1.20910	-.34719
	Group I	-.132905	.164244	.850	-.56386	.29805

Group II	Group III	-1.042810*	.164244	<.01*	-1.47376	-.61186
	Group IV	-.911048*	.164244	<.01*	-1.34200	-.48009
Group III	Group I	.909905*	.164244	<.01*	.47895	1.34086
	Group II	1.042810*	.164244	<.01*	.61186	1.47376
	Group IV	.131762	.164244	.853	-.29919	.56272
Group IV	Group I	.778143*	.164244	<.01*	.34719	1.20910
	Group II	.911048*	.164244	<.01*	.48009	1.34200
	Group III	-.131762	.164244	.853	-.56272	.29919

Table 12: Comparison of mean implant distance among study groups at B-Dpoint

Groups	**Mean**	**Std. Deviation**	**Fvalue;p value**
Group I	34.71	0.91	3.313;.024*
Group II	34.83	0.61	
Group III	35.32	0.79	
Group IV	34.45	1.26	

Table13.Pair wise comparison of mean implant distance among study groups at B-D point

		Mean Difference	**Std. Error**	**p value**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Group I	Group II	-.114000	.284959	.978	-.86169	.63369
	Group III	-.611905	.284959	.147	-1.35960	.13579
	Group IV	.263714	.284959	.791	-.48398	1.01141
	Group I	.114000	.284959	.978	-.63369	.86169
	Group III	-.497905	.284959	.306	-1.24560	.24979

Group II	Group IV	.377714	.284959	.550	-.36998	1.12541
Group III	Group I	.611905	.284959	.147	-.13579	1.35960
	Group II	.497905	.284959	.306	-.24979	1.24560
	Group IV	.875619*	.284959	.015*	.12793	1.62331
Group IV	Group I	-.263714	.284959	.791	-1.01141	.48398
	Group II	-.377714	.284959	.550	-1.12541	.36998
	Group III	-.875619*	.284959	.015*	-1.62331	-.12793

Table14.ComparisonofmeanimplantdistanceamongstudygroupsatA-C point

Groups	Mean	Std.Deviation	Fvalue;p value
Group I	34.84	1.03	40.138;<.01*
Group II	34.43	0.68	
Group III	32.70	0.85	
Group IV	34.99	0.30	

Table 15.Pair wise comparison of mean implant distance among study groups at A-C point

		Mean Difference	Std. Error	p value	95% Confidence Interval	
					Lower Bound	Upper Bound
Group I	Group II	.410524	.235431	.308	-.20722	1.02826
	Group III	2.143905*	.235431	<.01*	1.52616	2.76164
	Group IV	-.146714	.235431	.924	-.76445	.47103
Group II	Group I	-.410524	.235431	.308	-1.02826	.20722
	Group III	1.733381*	.235431	<.01*	1.11564	2.35112
	Group IV	-.557238	.235431	.092	-1.17498	.06050

Group III	Group I	-2.143905*	.235431	<.01*	-2.76164	-1.52616
	Group II	-1.733381*	.235431	<.01*	-2.35112	-1.11564
	Group IV	-2.290619*	.235431	<.01*	-2.90836	-1.67288
Group IV	Group I	.146714	.235431	.924	-.47103	.76445
	Group II	.557238	.235431	.092	-.06050	1.17498
	Group III	2.290619*	.235431	<.01*	1.67288	2.90836

Table16.Comparison of mean implant distance among study groups at A-Dpoint

Groups	Mean	Std. Deviation	Fvalue;p value
Group I	43.77	0.67	20.443;<.01*
Group II	43.26	1.15	
Group III	43.36	0.88	
Group IV	41.93	0.29	

Table17.Pair wise comparison of mean implant distance among study groups at A-Dpoint

		Mean Difference	Std. Error	p value	95% Confidence Interval	
					Lower Bound	Upper Bound
Group I	Group II	.512000	.249929	.179	-.14378	1.16778
	Group III	.409810	.249929	.363	-.24597	1.06559
	Group IV	1.842905*	.249929	<.01*	1.18713	2.49868
Group II	Group I	-.512000	.249929	.179	-1.16778	.14378
	Group III	-.102190	.249929	.977	-.75797	.55359
	Group IV	1.330905*	.249929	<.01*	.67513	1.98668
	Group I	-.409810	.249929	.363	-1.06559	.24597

Group III	Group II	.102190	.249929	.977	-.55359	.75797
	Group IV	1.433095*	.249929	<.01*	.77732	2.08887
Group IV	Group I	-1.842905*	.249929	<.01*	-2.49868	-1.18713
	Group II	-1.330905*	.249929	<.01*	-1.98668	-.67513
	Group III	-1.433095*	.249929	<.01*	-2.08887	-.77732

4. DISCUSSION

Successful implant-supported prosthesis depends on precise impressions and implant angulations, which affect how well the implants fit the prosthesis. Implant-supported prosthesis frequently experiences complications such tissue responses and screw loosening, which highlights the necessity of accurate implant placement employing materials, imprint techniques, and guidance. Using a surgical guide, implant impression technique and splinting material, the study evaluated the positioning accuracy of many implants at parallel and at different angulations. Vision Coordinate measuring machine is used to record the spatial measurements. CMM has been utilized in studies by several authors to evaluate positional accuracy in three dimensions.[5,6,7]

Polyether is hydrophilic and stiff, it was chosen as the imprint material for this study. Polyether provides greater tear strength than polyvinyl siloxane. According to earlier studies by Lee and Cho and Del'Acqua et al.[8], polyether performs better than vinyl polysiloxane. But in some situations, Moreira et al.[10] observed no discernible difference between vinyl polysiloxane and polyether.

As several authors have shown, the direct impression approach is the best method for three or more implants because of its greater precision.[9,10,11,12] For numerous implant scenarios, the direct impression technique is recommended since angulated implants put more strain on the impression material during removal from the mouth, which might cause distortion.[13] Thus, in the current investigation, the direct impression approach was employed. However, there was no discernible difference between direct and indirect impression.

According to research by Gallucci et al., Alikhasi et al., and Fernandez et al., the direct impression procedure has been widely supported for its accuracy in implant cases.[14,15,16,17] Nonetheless, Balouch et al. recommended the use of indirect impression methods in certain clinical situations.[18]

Misch[19] states that a fully edentulous maxilla typically requires a minimum of seven implants to support a fixed prosthesis. However, in most cases, a total of six implants are placed bilaterally to ensure proper load distribution. In this study, eighty-four casts were fabricated from a master model using the open tray impression technique. Each sample was subjected to an inter-implant distance analysis along the X, Y, and Z axes. The mean values of the measured inter-implant distances were statistically analyzed to evaluate accuracy.

The study aimed to assess the positional accuracy of both parallel and angulated dental implants. A visual coordinate measuring machine (CMM) was employed to precisely measure and compare the distances between implants. Differences between each angulated implant and the reference (parallel) implants were also examined.

The inter-implant distances in the master cast acquired by splinting the open tray impression Copings of implants with 0 degree angulation in Group1isobtained similarly inter-implant distances in the master cast acquired by splinting the open tray impression Copings of implants with 0 degree angulation Group2,Group3 and Group4 respectively is obtained and compared with the inter-implant distance in the master model in all direction X,Y, and Z axes using a Vision CMM.A computerized visual regulated CMM was used to measure the linear distances, which was capable of measuring with accuracy of ± 5 µm. In this study, the coordination system used was described as follows: The centers of the implant analog were firstly calculated by stroking four points on the perimeter of the implant analog and data is feed into the computer with processing software. The software will be determining centroids of each platform. The centroid of implant analog is designated from right to left; implant 1 as (A),implant 2 (E), implant 3 (B) ,implant4(C) ,implant(F) and implant (D) were determined. The distance from A, B, C, D, E and F were calculated in millimeters (mm) in all three axis X axis, Y axis, and Z axis, respectively. The measurements were tabulated and they were statistically analyzed and inference was obtained A factorial analysis of variance using the ANOVA was used for the statistical analysis and $P<0.05$wasconsidereda statistically significant. *Post hoc* tests homogeneous subset gives the difference between the groups based on which subset the group falls using computer software, Statistical Package for the Social Sciences (SPSS) version 21.0 (Chicago Inc., USA).

The mean of the difference is measured and compared to find the positional accuracy. Mean and standard deviation (SD) of all the values for each group were taken and they were statistically analyzed using the one-way ANOVA and *post hoc* test.

The study analysed the distribution of samples and mean implant distances across four groups (Group I, Group II, Group III, and Group IV), with each group comprising 21 samples, representing 25% of the total 84 samples, as shown in Table 1.

Table 2b highlighted significant pairwise comparisons for Group I, including A-B vs. B-C (10.870*, p < .01), A-B vs. C-D (0.818*, p < .01), A-B vs. B-D (-9.679*, p < .01), A-B vs. A-C (-9.806*, p < .01), A-B vs. A-D (-18.738*, p < .01), B-C vs. C-D (-10.051*, p < .01), B-C vs. B-D (-20.548*, p < .01), B-C vs. A-C (-20.676*, p < .01), B-C vs. A-D (-29.608*, p < .01), C-D vs. B-D (-10.497*, p < .01), C-D vs. A-C (-10.625*, p < .01), C-D vs. A-D (-19.557*, p < .01), B-D vs. A-D (-9.060*, p < .01), and A-C vs. A-D (-8.932*, p < .01).

Table 3a provided the mean implant distances for Group II, with values reported as A-B: 24.41 ± 0.73, B-C: 13.73 ± 0.52, C-D: 24.08 ± 0.49, B-D: 34.83 ± 0.61, A-C: 34.43 ± 0.68, and A-D: 43.26 ± 1.15. The F value was -13583.50, and the p value was less than 0.01, indicating significant differences.

Table 3b highlighted significant pairwise comparisons for Group II, including A-B vs. B-C (10.676*, p < .01), A-B vs. B-D (-10.416*, p < .01), A-B vs. A-C (-10.019*, p < .01), A-B vs. A-D (-18.850*, p < .01), B-C vs. C-D (-10.348*, p < .01), B-C vs. B-D (-21.092*, p < .01), B-C vs. A-C (-20.696*, p < .01), B-C vs. A-D (-29.526*, p < .01), C-D vs. B-D (-10.744*, p < .01), C-D vs. A-C (-10.347*, p < .01), C-D vs. A-D (-19.178*, p < .01), B-D vs. A-C (0.397*, p = .041), B-D vs. A-D (-8.434*, p < .01), and A-C vs. A-D (-8.830*, p < .01).

Table 4a presented the mean implant distances for Group III, with values reported as A-B: 23.65 ± 1.02, B-C: 12.52 ± 0.80, C-D: 25.13 ± 0.35, B-D: 35.32 ± 0.79, A-C: 32.70 ± 0.85, and A-D: 43.36 ± 0.88. The F value was -22688.07, and the p value was less than 0.01, indicating significant differences.

Table 4b highlighted significant pairwise comparisons for Group III, including A-B vs. B-C (11.135*, p < .01), A-B vs. C-D (-1.472*, p < .01), A-B vs. B-D (-11.671*, p < .01), A-B vs. A-C (-9.043*, p < .01), A-B vs. A-D (-19.709*, p < .01), B-C vs. C-D (-12.607*, p < .01), B-C vs. B-D (-22.806*, p < .01), B-C vs. A-C (-20.178*, p < .01), B-C vs. A-D (-30.844*, p < .01), C-D vs. B-D (-10.199*, p < .01), C-D vs. A-C (-7.571*, p < .01), C-D vs. A-D (-18.237*, p < .01), B-D vs. A-C (2.628*, p < .01), B-D vs. A-D (-8.038*, p < .01), and A-C vs. A-D (-10.666*, p < .01).

Table 5a provided the mean implant distances for Group IV, with the following values: A-B measured 25.05 ± 0.69, B-C was 14.37 ± 0.37, C-D was 24.99 ± 0.67, B-D measured 34.45 ± 1.26, A-C was 34.99 ± 0.30, and A-D recorded 41.93 ± 0.29. The F value was -25758.23, and the p value was less than 0.01, indicating that the differences among these distances were statistically significant.

Table 5b elaborated on the significant pairwise comparisons within Group IV. Statistically significant differences (p < 0.01) were observed between A-B and B-C, A-B and B-D, A-B and A-C, as well as A-B and A-D. Similar significance was noted between B-C and C-D, B-C and B-D, B-C and A-C, and B-C and A-D. Furthermore, C-D comparisons with B-D, A-C, and A-D were also significant. Additional significant differences were found between B-D and A-D, and between A-C and A-D.

In Table 6, the mean implant distances among the study groups were compared at point A-B. Group I recorded a mean of 25.03 ± 0.63, Group II had 24.41 ± 0.73, Group III reported 23.65 ± 1.02, and Group IV recorded 25.05 ± 0.69. The analysis revealed a significant difference with an F value of 15.06 and a p value less than 0.01.

Table 7 presented significant pairwise comparisons at the A-B point. Notable differences were identified between Group I and Group III, Group II and Group III, Group II and Group IV, Group III and Group I, Group III and Group II, Group III and Group IV, Group IV and Group II, and Group IV and Group III, all demonstrating statistical significance with p values below 0.05.

Table 8 focused on the B-C distances, comparing Group I (14.16 ± 0.46), Group II (13.73 ± 0.52), Group III (12.52 ± 0.80), and Group IV (14.37 ± 0.37). The results showed significant group differences with an F value of 45.75 and a p value less than 0.018.

Table 9 highlighted significant pairwise comparisons at the B-C point. Significant differences were observed between Group I and Group III, Group II and Group III, Group II and Group IV, Group III and Group I, Group III and Group II, Group III and Group IV, Group IV and Group II, and Group IV and Group III, all with p values below 0.01 or 0.05.

In Table 10, the mean implant distances at point C-D were reported as follows: Group I recorded 24.22 ± 0.58, Group II had 24.08 ± 0.49, Group III recorded 25.13 ± 0.35, and Group IV had 24.99 ± 0.67. The F value was 20.919, and the p value was less than 0.01, indicating statistically significant differences.

Table 11 provided details on pairwise comparisons at point C-D. Significant differences (p < 0.01) were observed between Group I and Group III, Group I and Group IV, Group II and Group III, and Group II and Group IV. Conversely, comparisons of Group III with Groups I and II, as well as Group IV with Groups I and II, were also statistically significant.

Table 12 compared the mean implant distances at point B-D. Group I recorded 34.71 ± 0.91, Group II was 34.83 ± 0.61, Group III was 35.32 ± 0.79, and Group IV was 34.45 ± 1.26. The F value was 3.313 and the p value was 0.024, showing a statistically significant difference.

In Table 13, the only significant pairwise comparisons at point B-D were found between Group III and Group IV, with a mean difference of 0.876 (p = .015). This suggests that Group IV had significantly lower measurements compared to Group III.

Table 14 analyzed point A-C, with values reported as: Group I (34.84 ± 1.03), Group II (34.43 ± 0.68), Group III (32.70 ± 0.85), and Group IV (34.99 ± 0.30). The F value was 40.138, and the p value was less than 0.01, suggesting strong evidence of group differences.

Table 15 showed statistically significant differences at A-C between Group I and Group III, Group II and Group III, Group III and Groups I, II, and IV, as well as between Group IV and Group III. All comparisons were statistically significant with p values below 0.01.

Table 16 compared the A-D distances among the groups, with Group I recording 43.77 ± 0.67, Group II 43.26 ± 1.15, Group III 43.36 ± 0.88, and Group IV 41.93 ± 0.29. The F value was 20.443, and the p value was less than 0.01, indicating significant differences.

Table 17 reinforced these findings at A-D, showing statistically significant pairwise differences between Group I and Group IV, Group II and Group IV, and Group III and Group IV. All p values were below 0.01. The data suggest that Group IV consistently recorded lower mean implant distances at point A-D compared to the other groups, with no significant difference among Groups I, II, and III.

The cast with more angulation in the current study resulted in lower positioning accuracy compared to parallel and less angulated implants. This outcome supports findings by Assunção et al. and Cabral and Guedes, who reported that angulated implants led to less precise impressions, thereby reducing positional accuracy in experimental casts with four or five implants.[20,21]

In this study, six implants were used to simulate a clinical scenario, consistent with Misch's protocol, to enhance reproducibility and clinical relevance. The maximum interimplant distances (A-B, B-C, C-D, B-D, A-C, and A-D) were assessed to capture comprehensive accuracy data.

However, the in vitro nature of this study limits its generalizability to clinical settings. Several factors, such as the design of impression copings and implant geometry, were not addressed. To validate and expand on these findings, future research should involve larger clinical sample sizes, address the need for correction of angulated placements, and consider evaluating additional contributing components.

5. CONCLUSION

Implants placed at higher angulations—such as 25 degrees or more—can lead to significant discrepancies in the positional accuracy of multiple implants on the definitive cast. This deviation often compromises the passive fit of the final prosthesis, especially in full-arch rehabilitations such as All-on-4 and All-on-6. A lack of passive fit can result in mechanical complications, increased stress on the prosthetic components, and reduced long-term success of the restoration.

To achieve an accurate and stable passive fit, implant angulations in All-on-4 and All-on-6 cases should ideally range between 15 and 20 degrees. Positional inaccuracies within this range are generally manageable using standard angled abutments. However, when implant angulation exceeds 25 degrees, corrections become more complex and require custom CAD/CAM abutments or specialized multi-unit abutments.

Although cone-shaped multi-unit abutments offer a solution for correcting angulation and improving parallelism, they present certain limitations. The most notable drawback is the use of a very small prosthetic screw, which can be difficult to handle and tighten securely. In cases of poor alignment, additional manufactured caps and securing screws may be needed to achieve a passive prosthetic bridge fit—adding to both technical complexity and financial costs.

Therefore, to minimize such challenges and ensure optimal prosthetic outcomes, clinicians are recommended to limit implant angulations to below 25 degrees in full-arch restorations. This approach simplifies prosthetic planning, enhances passive fit, and improves overall treatment predictability and patient satisfaction.

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