Evaluation of orthodontic micro-implant stability using resonance frequency analysis: An in vivo study

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Aim: This prospective clinical study was undertaken to evaluate micro-implant stability during the various phases of orthodontic treatment following micro-implant insertion.

Settings and Design:

Methods and Material: This study included twenty micro-implants which were inserted in subjects whose treatment plan comprised of a micro-implant placement in the maxillary posterior region between the roots of first molar and premolar. Microimplant stability was evaluated using resonance frequency analysis (RFA) method and Implant stability quotient(ISQ) values was recorded after insertion (T0), during loading (T1), 2 weeks later (T2), 4 weeks later (T3), 6 weeks later (T4) and just before removal of micro-implant (T5) in two directions perpendicular to each other. All ISQ values were tested for statistically significant differences between the different time intervals.

Statistical analysis used: Kolmogorov-Smirnov test, Wilcoxon matched pairs test, Mann-Whitney U test.

Results: From T0 to T5, the overall stability decreased significantly (P < .001) by 5.08 ± 4.02 ISQ values. Highest RFA changes were seen from T1 to T2, were the stability decreased highly significantly (P < .001) by 2.66 ± 2.42 ISQ values.

Conclusions: Longitudinal measurement of micro-implant stability using RFA demonstrated overall significant decrease in stability during the various phases of orthodontic treatment following micro-implant insertion. During 2nd week a significant decrease of the stability was observed compared to other time intervals. Stability of micro-implant was found to be maximum at 1st week after insertion, hence early loading of micro-implant will be appropriate.

Key-words: Resonance Frequency Analysis, Implant Stability Quotient, Micro-Implants, Stability.

Anchorage is an important consideration when planning orthodontic treatment. At the present time micro-implants are turning out to be progressively prevalent in orthodontics because they provide absolute and skeletal anchorage for orthodontic tooth movements.[1] Achievement and maintenance of micro-implant stability are essential for successful clinical outcome of orthodontic treatment. Therefore, greater significance must be emphasised onmeasuring the micro-implant stability for evaluating the success of amicro-implant.

In humans, resonance frequency analysis (RFA) has proven to be an adequate method because of its non-invasiveness and contactless measurement method.[2] Resonance frequency analysis is regarded as the gold standard for clinical stability measurement of dental implants[3]. Micro-implants differ from current dental implants with respect to size, design, surface characteristics, insertion protocol, and insertion sites. To assess micro-implant stability, specially modified SmartPegs are used. Like dental implants, for their reaction to immediate loading, orthodontic micro-implants rely on primary stability, [4] hence the loading time will be dependent upon the stability of micro-implant. Determining primary stability after insertion can help predict success.

Hence, the purpose of this study was to evaluate the micro-implant stability during the various phases of orthodontic treatment following micro-implant insertion using the resonance frequency analysis method, and also to derive a clinical implication regarding which phase following insertion of micro-implant is appropriate for loading. This study also compared the differences among the implant stability values measured among male and female subjects.

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SUBJECTS AND METHODS:

Source of Data:

Twenty micro-implants were selected in total which was inserted in the subjects whose treatment plan comprised of a micro-implant placement in the maxillary posterior region between the roots of first molar and premolar (Figure 1). Subjects were included in this prospective study after getting an approval from the institutional review board and ethical committee, and subjects consent.

Inclusion Criteria:

1. Subjects whose treatment plan comprised of a micro-implant placement.
2. Subjects with healthy periodontium.
3. Subjects with good oral hygiene.
4. Age group above 18 years.

Exclusion Criteria:

1. Subjects having systemic disease affecting bone metabolism/ wound healing.
2. Subjects under any medications, steroids.
3. After insertion, data of subjects who missed examination appointments.

METHOD OF COLLECTION OF DATA

Micro-implant stability was evaluated using RFA method and Implant stability quotient(ISQ) values was recorded after insertion (T0), during loading (T1), 2 weeks later (T2), 4 weeks later (T3), 6 weeks later (T4) and just before removal of micro-implant (T5) in two directions perpendicular to each other. Implant stability quotient (ISQ) value measurement was repeated three times in each direction for each micro-implant.

Fig 1. Intra-oral photograph taken following micro-implant insertion. **2**. The Osstell ISQ device. (Osstell Mentor, Göteborg, Sweden), **3**. Intra-oral photograph taken following mounting of SmartPeg on to the micro-implant. **4**. Activation of the tip of the SmartPeg from the side by the probe tip. **5**. Display of measured ISQ values following measurement.

Mean values were calculated for each direction and overall ISQ values for each micro-implant at each time.

Measuring micro-implant stability using resonance frequency analysis

The Osstell ISQ device used to measure micro-implant stability in this study is the latest model of the resonance frequency analysis (Figure 2). Osstell ISQ is a portable device that involves the use of the non-invasive technique for measuring micro-implant stability. The device included a metal rod (SmartPeg) which was connected to the micro-implant (Figure 3).

Performing a Measurement

After the SmartPeg was attached on to the micro-implant, the measurement probe washeld in close proximity to the top portion of the SmartPeg without contacting it. The SmartPeg was then energizedby a magnetic pulse from the measurement probe (Figure 4). When the instrument sensed the response signal from the SmartPeg, an audible sound was emitted followed by the display of ISQ value.

Viewing Measurements

Results were displayed on the device as the Implant Stability Quotient (ISQ), whichscaled from 1 to 100 (Figure 5). The higher the number indicated greater thestability.

The stability was measured for each micro-implant at previously determined time intervals to evaluate a change in stability. After each measurement, the ISQ values recorded was used as the baseline for the next measurement performed. Therefore any changes in the ISQ value reflected a change in implant stability. An increase in ISQ values between one measurement time to the next indicated a progression towards better stability and lower ISQ values indicated a loss in stability. A stable ISQ value indicates no change in stability.

Statistical Analysis:

The data obtained were subjected to statistical analysis using the statistical package- SPSS version 20. Not normal distribution was determined by Kolmogorov-Smirnov test. Therefore non-parametric tests were applied. The mean, standard error and standard deviation were tabulated. Significant differences between the ISQ values at T0, T1, T2, T3, T4 and T5 time intervals was tested with Wilcoxon matched pairs test. A comparison between ISQ values measured in two perpendicular directions to each other was performed using the Mann-Whitney U test. A comparison between ISQ values measured among male and female subjects was performed using the Mann-Whitney U test. Statistical significance was tested at $P < 0.05$.

Discussion:

A standout amongst the most essential changes in the way orthodontic treatment is executed occurred with the introduction of micro-implants, by providing superior control of tooth movement. Their relative stability under the use of considerable forces makes it feasible for the orthodontist to eliminate the negative results of the force system being applied. Their advantages and usability are the main reasons that micro-implants have been rapidly and widely acknowledged by the orthodontists. Their summed up utilization has uncovered that one of the real issues associated with micro-implants is the degree to which they fail.[5]Various factors such as gingival inflammation,mobility and placement of micro-implants in areas with non-keratinized mucosa may be responsible for micro-implant failures.

RESULTS:

Table 1: Summary statistics in direction 1, 2 and overall

Directions	Time intervals	Sex	Min	Max	Mean	SD	95% Confidence Interval for Mean	
							Lower Bound	Upper Bound
Direction 1	T0	Male	45.00	60.00	51.30	4.88	47.81	54.79
		Female	45.00	57.00	49.05	3.72	46.39	51.71
		Total	45.00	60.00	50.18	4.37	48.13	52.22
	T1	Male	45.00	60.00	51.37	5.04	47.77	54.97
		Female	44.00	56.00	48.93	3.63	46.33	51.53
		Total	44.00	60.00	50.15	4.45	48.07	52.23
	T2	Male	43.00	53.00	49.06	3.71	46.41	51.71
		Female	41.00	50.00	46.00	2.60	44.14	47.86
		Total	41.00	53.00	47.53	3.49	45.90	49.16
	T3	Male	43.00	53.00	48.50	3.69	45.86	51.14
		Female	41.00	48.30	45.29	2.34	43.62	46.96
		Total	41.00	53.00	46.90	3.43	45.29	48.50
	T4	Male	43.00	52.30	48.03	3.63	45.43	50.63
		Female	40.00	48.00	44.93	2.56	43.10	46.76
		Total	40.00	52.30	46.48	3.45	44.87	48.09
	T5	Male	40.00	54.00	46.80	4.80	43.37	50.23
		Female	40.00	45.00	43.10	1.66	41.91	44.29
		Total	40.00	54.00	44.95	3.98	43.09	46.81
Direction 2	T0	Male	45.00	59.00	51.00	4.69	47.64	54.36
		Female	44.00	57.00	48.87	3.93	46.06	51.68
		Total	44.00	59.00	49.94	4.35	47.90	51.97
	T1	Male	45.30	59.30	51.56	5.02	47.97	55.15
		Female	44.00	56.00	49.04	3.71	46.39	51.69
		Total	44.00	59.30	50.30	4.49	48.20	52.40
	T2	Male	42.70	53.00	49.04	3.67	46.41	51.67
		Female	41.00	50.00	46.17	2.72	44.23	48.11
		Total	41.00	53.00	47.61	3.47	45.98	49.23
	T3	Male	42.00	53.00	48.30	3.77	45.60	51.00
		Female	40.70	48.70	45.44	2.56	43.61	47.27
		Total	40.70	53.00	46.87	3.46	45.25	48.49
	T4	Male	42.00	52.00	47.87	3.85	45.11	50.63
		Female	40.00	48.00	44.99	2.46	43.23	46.75
		Total	40.00	52.00	46.43	3.48	44.80	48.06
	T5	Male	40.00	54.00	46.80	4.78	43.38	50.22
		Female	40.00	45.00	43.20	1.69	41.99	44.41
		Total	40.00	54.00	45.00	3.95	43.15	46.85

Overall	T0	Male	45.00	59.50	51.15	4.78	47.73	54.57
		Female	44.50	57.00	48.96	3.82	46.23	51.69
		Total	44.50	59.50	50.06	4.36	48.02	52.09
	T1	Male	45.20	59.70	51.47	5.02	47.88	55.06
		Female	44.00	56.00	48.98	3.65	46.37	51.59
		Total	44.00	59.70	50.23	4.46	48.14	52.31
	T2	Male	42.80	53.00	49.06	3.70	46.42	51.70
		Female	41.00	50.00	46.11	2.65	44.22	48.00
		Total	41.00	53.00	47.59	3.48	45.96	49.21
	T3	Male	42.50	53.00	48.40	3.73	45.74	51.06
		Female	40.80	48.50	45.38	2.45	43.63	47.13
		Total	40.80	53.00	46.89	3.44	45.28	48.50
	T4	Male	42.50	52.20	47.95	3.74	45.27	50.63
		Female	40.00	48.00	44.98	2.50	43.19	46.77
		Total	40.00	52.20	46.47	3.45	44.85	48.08
	T5	Male	40.00	54.00	46.80	4.79	43.37	50.23
		Female	40.00	45.00	43.15	1.67	41.96	44.34
		Total	40.00	54.00	44.98	3.96	43.12	46.83

Table 2. Comparison of T0, T1, T2, T3, T4 and T5 as a whole by Wilcoxon matched pairs test

Time intervals	Mean	Std.Dv.	Mean Diff.	SD Diff.	% of change	Z-value	P-value
T0	50.05	4.36	-0.17	0.72	-0.34	0.8790	0.3794
T1	50.23	4.46					
T0	50.05	4.36	5.08	4.02	10.15	3.7828	0.0002*
T5	44.97	3.96					
T1	50.23	4.46	2.66	2.42	5.29	3.8826	0.0001*
T2	47.57	3.48					
T2	47.57	3.48	0.69	0.75	1.44	3.2010	0.0014*
T3	46.88	3.43					
T3	46.88	3.43	0.43	0.88	0.91	2.1127	0.0346*
T4	46.46	3.45					
T4	46.46	3.45	1.48	1.69	3.19	3.0239	0.0025*
T5	44.97	3.96					

Graph 1. Comparison of T0, T1, T2, T3, T4 and T5 as a whole

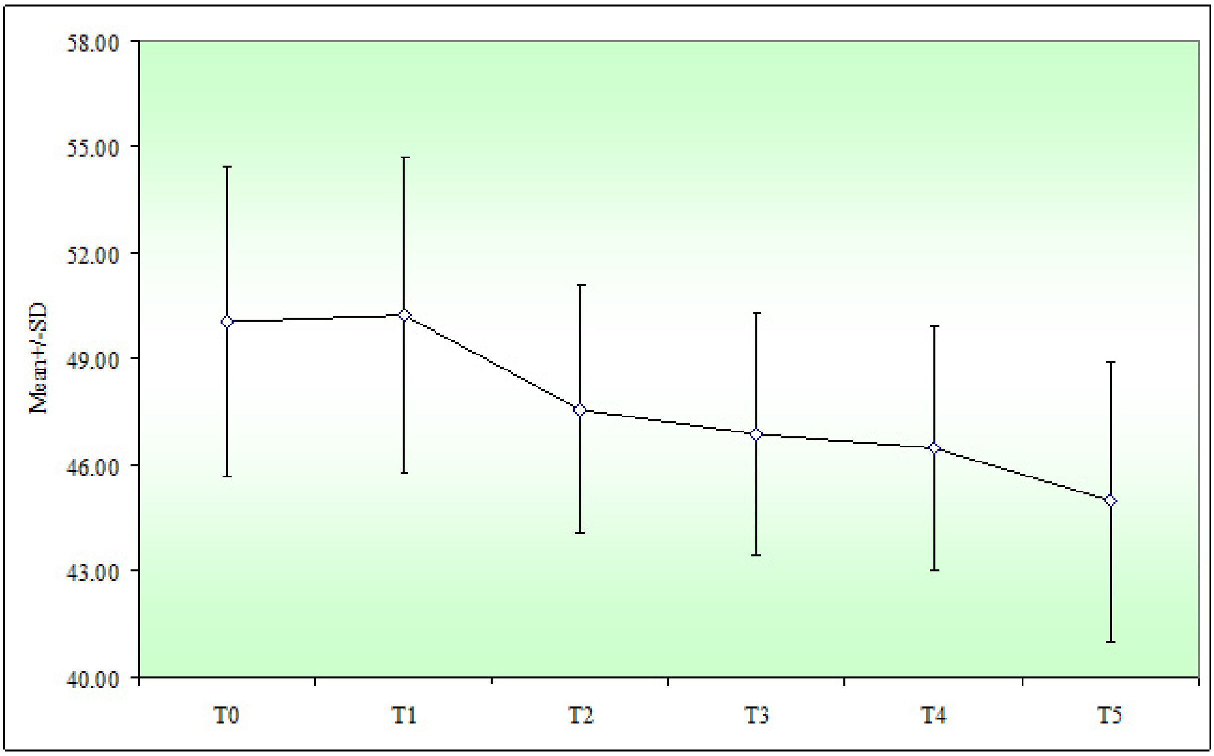


Table 3. Comparison of direction 1 and direction 2 at different time intervals by Mann-Whitney U test (total subjects)

Time intervals	Direction 1			Direction 2			U-value	Z-value	P-value
	Mean	SD	Sum of ranks	Mean	SD	Sum of ranks			
T0	50.18	4.37	417.00	49.93	4.35	403.00	193.00	-0.1894	0.8498
T1	50.15	4.45	407.50	50.30	4.49	412.50	197.50	-0.0676	0.9461
T2	47.54	3.49	409.00	47.61	3.47	411.00	199.00	-0.0271	0.9784
T3	46.90	3.43	410.50	46.87	3.47	409.50	199.50	-0.0135	0.9892
T4	46.48	3.45	411.00	46.43	3.48	409.00	199.00	-0.0271	0.9784
T5	44.95	3.98	405.50	45.00	3.95	414.50	195.50	-0.1217	0.9031

Primary stability is determined immediately after implant insertion. Because of osseointegration, an implant gains secondary stability, which can be determined after the recuperating phase or at the end of its utilization period. There is clinical proof from dental implantology that it is an implant's primary stability, beyond the factors such as bone quality and oral cleanliness that for the most part determines its survival rate and reliability.[6,7]Studies have demonstrated the significance of adequate primary stability for orthodontic loading, lack of primary stability causes insufficient healing and premature failure of the micro-implant.[8,9] Therefore, the primary stability observed during implantation assumes an imperative part in the success rates of the micro-implants.

Quantification of micro-implant stability at various time intervals gives a noteworthy data about individual healing times.[10]And also a technique that can estimate the physical properties of the peri-implant bone will allow us to time loading in a like manner and avoid loading when the quality of the bone around the implant is not optimum.

Graph 2. Comparison of direction 1 and direction 2 at different time intervals (total subjects)

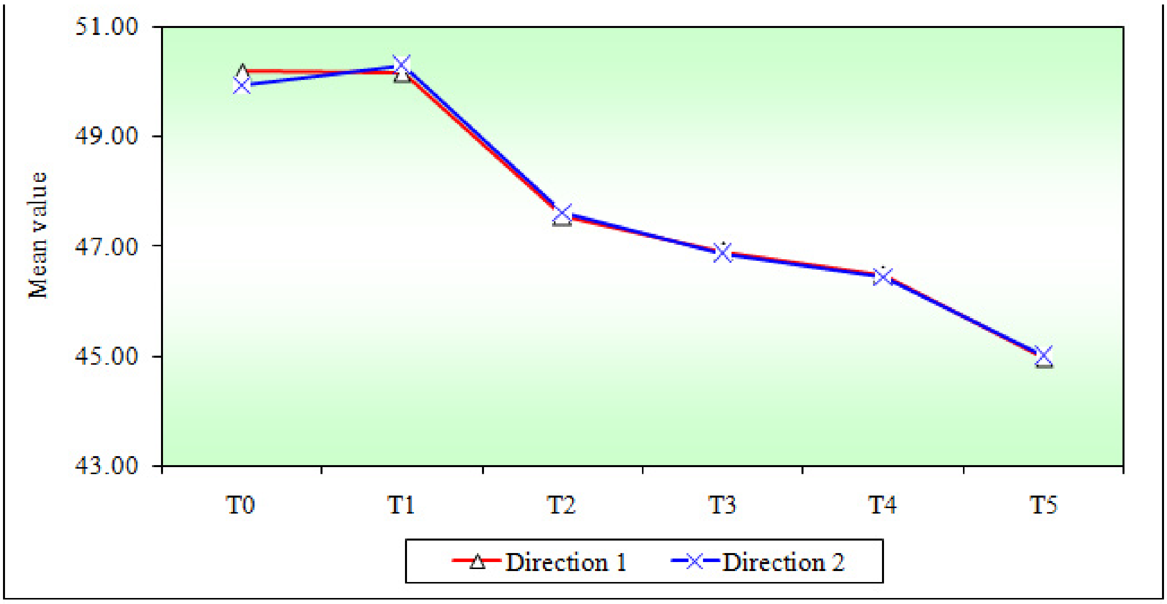


Table 4. Comparison of male and females with respect to overall scores at different time intervals by Mann-Whitney U test

Time intervals	Male			Female			U-value	Z-value	P-value
	Mean	SD	Sum of ranks	Mean	SD	Sum of ranks			
T0	51.15	4.78	121.50	48.96	3.82	88.50	33.50	-1.2473	0.2123
T1	51.47	5.02	119.50	48.98	3.65	90.50	35.50	-1.0961	0.2730
T2	49.05	3.70	128.50	46.09	2.64	81.50	26.50	-1.7764	0.0757
T3	48.40	3.73	130.00	45.37	2.43	80.00	25.00	-1.8898	0.0588
T4	47.95	3.74	125.50	44.96	2.50	84.50	29.50	-1.5497	0.1212
T5	46.80	4.79	125.00	43.15	1.67	85.00	30.00	-1.5119	0.1306

Methods for studying micro-implant stability

The available methods for studying implant stability can be divided into invasive, which meddle with the osseointegration process of the implant, and non-invasive, which don't. Invasive methods include cutting torque resistance analysis, histologic and histomorphometric evaluations, pull out and insertion torque tests. Since the procedure is invasive, the implant site is annihilated after the test has been performed, making it difficult to assess the implant–bone interface intermittently. The non-invasive methods include finite element analysis, impact hammer tests, radiographic evaluations of the implant, pulsed oscillation waveforms, percussion tests and resonance frequency analyses.

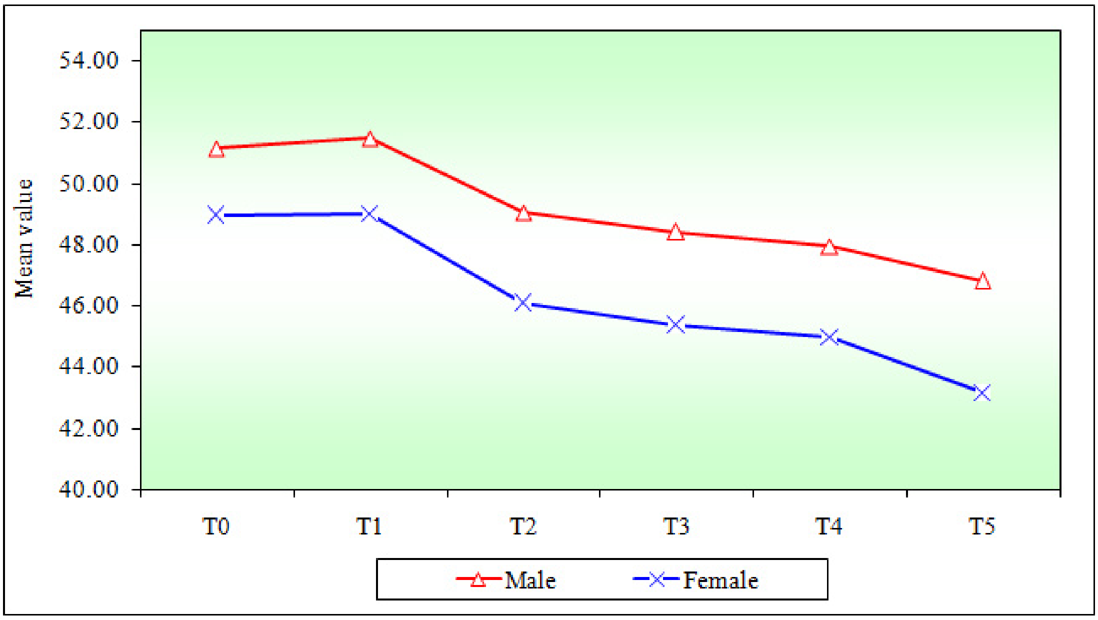
As of now there is no method accessible that permits assessment of a micro-implant's stability after insertion and before removal. However, non-invasive methods for measuring dental implant stability have been available for nearly a decade.[11]The two methods most commonly used are dampening capacity assessment (Periotest, Modautal, Germany) and resonance frequency analysis (Osstell Mentor, Göteborg, Sweden).

Various studies have demonstrated that resonance frequency analysis with the Osstell device is the best method evaluating implant stability.[3]The Periotest instrument demonstrates a more noteworthy measurement error in clinical application (intraclass correlation 0.88), in this manner making the Osstell a more reliable option to be utilized clinically(intraclass correlation 0.99).[12]

The Osstell ISQ device utilized as a part of this study is the latest model of the resonance frequency analysis, where a metal rod (SmartPeg) is connected to the implant by a screw connection. The Osstell ISQ meter invigorates a SmartPeg mounted on the implant, by emitting magnetic pulses. These cause the SmartPeg to resonate with certain frequencies depending of the stability of the implant. The resonance is picked up by the Osstell ISQ meter. The results are displayed as the implant stability quotient (ISQ). ISQ depends on the underlying resonance frequency and ranges from 1 (lowest stability) to 100 (highest stability).

This method has demonstrated valuable for dental implants in research and clinical applications.[13, 14]

Graph 3. Comparison of male and females with respect to overall scores at different time intervals



Despite of the fact that the Osstell device has been used extensively with dental implants, it has not yet been utilized with micro-implants has it was not possible to mount a smart peg on micro-implants. In this study a custom made abutment was used to mount the smart peg on micro-implant (Figure 3). This novel, non-invasive, measurement technique could demonstrate valuable in helping orthodontists better comprehend the healing procedures of bone around micro-implants.

Interpretation of Results

I. Table 1: Summary statistics in direction 1, 2 and overall.

The table shows mean ISQ value of twenty micro-implants at each time intervals in direction 1, 2 and overall.

II. Table 2 and Graph 1: Comparison of T0, T1, T2, T3, T4 and T5 as a whole by Wilcoxon matched pairs test.

Table shows the comparison of overall mean ISQ values at different time intervals in total subjects. Non-significant increase in ISQ values was observed from T0 to T1. Significant decrease in ISQ values ($p < 0.05$) was observed from T1 to T5, with highest decrease in ISQ value seen from T1 to T2 ($p < 0.01$).

III. Table 3 and Graph 2: Comparison of direction 1 and direction 2 at different time intervals by Mann-Whitney U test (total subjects)*

IV. Table 4 and Graph 3: Comparison of male and females with respect to overall scores at different time intervals by Mann-Whitney U test *

*In table 3 and 4: No significant changes in ISQ values was observed.

The present study showed high ISQ value from micro-implant insertion to the time of first loading and then a significant decrease in ISQ values during second week and thereafter by the time of micro-implant removal there was overall decrease in stability.

The results obtained are discussed as follows-

A. A comparison between the ISQ values at T0, T1, T2, T3, T4 and T5.

B. A comparison between ISQ values measured in two perpendicular directions to each other.

C. A comparison between ISQ values measured among male and female subjects.

A. A comparison between the ISQ values at T0, T1, T2, T3, T4 and T5.

Non-significant increase in ISQ values was observed from T0 to T1.

The mean ISQ value from insertion to the time of first loading was high because of the primary mechanical stability.

Significant decrease in ISQ values ($P < 0.05$) was observed from T1 to T5.

In studies related to dental implants, within the first weeks, stability decreased. The lowest stability was reported after three [15]or four [16] weeks. In this study, the highest decrease in stability was seen during second week after insertion i.e., from T1 to T2 ($P<0.01$). A possible explanation for this phenomenon is a diminishing of the mechanical stability of the micro-implants due to the encompassing hard tissue relaxation explained by bone resorption due to osteoclast activity in the initial healing phase.[17]

This supports the idea that primary stability is highest immediately after micro-implant placement, and then decreases over time, as previously demonstrated for dental implants.Since the stability of micro-implant was found to be maximum at T0-T1 time intervals, from this study findings, early loading of micro-implant will be appropriate.

Overall from T0 to T5 significant decrease in ISQ values ($P< 0.01$) was observed.

The decrease in stability of micro-implants during the first three weeks can be explained by the physiological processes occurring around the implant. Within two hours of implant placement, erythrocytes, neutrophils, and macrophages coalesce in a fibrin network; osteoclasts and mesenchymal cells, which appear by day four, begin removal of bone damaged during micro-implant placement.[17] This leads to the decreases in primary stability observed in the present study and holds important implications forthe formation remain, which could account for the apparent lower stability observed at the sixth week.

However loading of micro-implant after second week would not be appropriate, since the stability of micro-implant was found to be decrease from T1 to T5 time intervals.

B. A comparison between ISQ values measured in two perpendicular directions to each other.

In the current investigation, there were no differences between the different measurement directions of RFA. These results are in line with those of Park et al., [18] who found no differences between the ISQs of dental implants when measuring from different directions, buccolingual and mesiodistal. Simet al.[19] also reported no significant effect of different positioning of the RFA device.

C. A comparison between ISQ values measured among male and female subjects.

No significant decrease in stability changes was observed between male and femalesubjects with respect to overall scores at different time intervals.

With regard to the micro-implants indications in orthodontic treatment, this sort of healing seems to be satisfactory. Micro-implants are utilized as temporary anchorage devices and are easily removed after achieving the orthodontic aims. Whereas the osseointegrated dental or palatal implants have to be removed by a trepan drill, leaving a bony deformity. In addition, the smaller diameter of micro-implants bears the risk of an implant fracture when ISQ values turns out to be too high.[20]

Clinical implications

1. Micro-implant stability is subject to changes during the healing process.
2. Longitudinal measurement of micro-implant stability using RFA demonstrated overall significant decrease in stability.
3. During 2nd week i.e., from T1 to T2 a significant decrease of the stability was observed compared to other time intervals.
4. Stability reduced with subsequent loading, which in turn questions the development of secondary stability.
5. Since the stability of micro-implant was found to be maximum at T0-T1 time intervals, early loading of micro-implant will be appropriate.

Limitations of the study

1. Although the study was prospective in nature, it had a sample size of 20 microimplants.Hence the results obtained from current study have to be confirmed with larger sample size.
2. From this study it was seen stability reduced with subsequent loading, a study can be performed to evaluate the micro-implant stability during healing phase without loading the micro-implant and compare the findings to this study so has to evaluate to what extent loading of micro-implant affects the development of secondary stability.

Scope for further studies

1. Further clinical investigation using resonance frequency analysis can be performed regarding the factors that may affect healing and stability changes such as different micro-implant dimensions and insertion sites.
2. A prospective study could be planned with increased sample size.
3. Further research based on a new design of micro-implant with an inner thread that will enable direct mounting of Smart peg on the micro-implant can be performed elucidating the influence of micro-implant design, insertion site and loading protocols on stability changes during healing.

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