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ORIGINAL ARTICLE

Optimizing Thermal Management and Stability in Dental Implant Osteotomy: Comparing Different Irrigation Systems—A Randomized Controlled Trial

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Abstract

Background This study investigates the influence of different irrigation systems on thermal management during implant osteotomy, along with their effects on implant stability and peri-implant tissue health.

Methods The study comprised an initial in vitro phase using freshly sacrificed goat mandibles to compare internal and external irrigation systems versus external irrigation alone. Temperature variations were measured at multiple distances from the osteotomy site. Subsequently, a clinical trial included 26 patients receiving 30 implants, where periodontal pocket depth, crestal bone loss, and implant stability were assessed over a one-year follow-up period.

Results In the in vitro phase, both irrigation methods showed comparable thermal management, with no significant temperature differences observed between groups. Clinical outcomes from the trial demonstrated stable implant integration and negligible peri-implant tissue complications across both irrigation approaches. Periodontal pocket depths and crestal bone loss were similar between groups, indicating no significant difference in long-term outcomes.

Conclusion The findings highlight the effectiveness of both internal and external irrigation systems, as well as external irrigation alone, in minimizing thermal damage during implant osteotomy. These irrigation methods support stable implant integration and preserve peri-implant tissue health over a one-year period. Optimized irrigation techniques are crucial for enhancing implant dentistry practices and ensuring favorable patient outcomes.

Keywords Dental implants · Irrigation systems · Thermal management · Implant stability · Peri-implant tissue

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Introduction

The advent of dental implants has profoundly transformed the field of dentistry [1]. Early literature on osseointegration extensively discussed traditional techniques for treating edentulous patients with implants. With a robust three-decade evidence base supporting their clinical efficacy, dental implants are now widely acknowledged for their predictability and ability to provide patients with durable functional tooth replacements [2].

Branemark and colleagues originally recommended a stress-free, unloaded healing period to ensure the successful osseointegration of endosseous implants [3]. However, it is crucial to consider the impact of heat generation during implant osteotomy on surrounding bone tissue. The heat produced by the drill during osteotomy preparation, influenced by factors such as drill speed and the effectiveness of the cooling system, significantly influences implant success [4].

Research indicates that heat generated during drilling can propagate more than 3 mm from the site and exceed temperatures of 50 °C, even with copious irrigation [5]. Eriksson's studies have highlighted that bone tissue can undergo necrosis at temperatures as low as 40 °C for 7 min or 47 °C for 1 min [6, 7]. Therefore, minimizing thermal and mechanical trauma to adjacent hard tissues is critical.

Effective strategies to mitigate overheating include the use of external and internal cooling agents, continuous saline irrigation, applying intermittent pressure on the drill, employing new drills, and adopting an incremental drilling technique [8]. Given these considerations, the present study aims to assess the impact of two distinct cooling systems on the osseointegration of dental implants. While previous studies have documented the effectiveness of various irrigation systems in reducing bone temperature, our study aims to compare these techniques directly under controlled conditions to assess their impact on both thermal management and clinical outcomes. This direct comparison seeks to fill existing gaps in the literature regarding the practical applications of these systems in clinical settings.

This study uniquely combines an in vitro assessment and a clinical trial to compare the efficacy of internal and external irrigation systems in thermal management during dental implant osteotomy. Unlike previous studies, our dual-phase approach allows for a comprehensive analysis of both temperature control and clinical outcomes, providing valuable insights into optimizing surgical protocols.

Methodology

This study employed a dual-phase design, consisting of an in vitro phase and a clinical trial, to investigate the impact of different irrigation systems on thermal management and implant stability during osteotomy. Ethical approval was obtained from the institutional ethics committee for both phases, ensuring compliance with ethical standards in research. This study was not registered in a clinical trial database, which we acknowledge as a limitation.

In Vitro Phase

Five freshly sacrificed goat mandibles were utilized for the in vitro study. The primary aim was to compare the effects of internal and external irrigation systems on thermal management during implant osteotomy (Fig. 1).

Irrigation Groups:

- Group I: Internal irrigation, where 20 mL of sterile saline was delivered directly through the drill bit during the osteotomy.
- Group II: External irrigation, utilizing a separate system to spray 20 mL of sterile saline around the osteotomy site.

Osteotomy procedures were performed under copious normal saline irrigation at a controlled room temperature of 23 °C. The drilling was executed using a bur speed of 1200 revolutions per minute. Each osteotomy was completed within a maximum of 3.45 min, ensuring no more than 30 s of bone-to-drill contact at any time. Temperature variations were recorded at distances of 3 mm, 5 mm, and 11 mm from the osteotomy site using thermocouples placed in previously drilled holes.

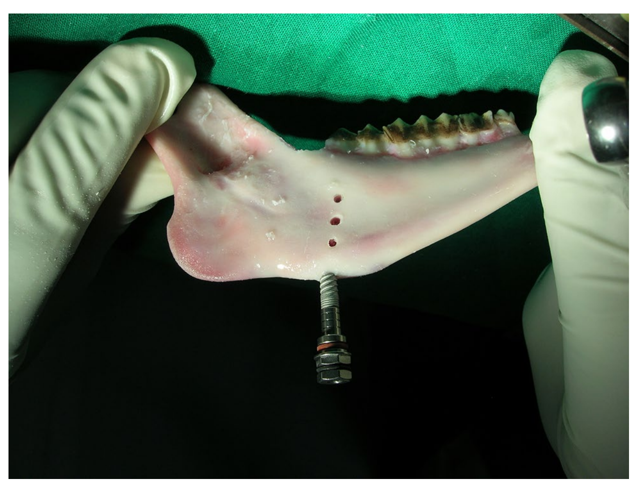

Fig. 1 Osteotomy marking and implant placement in Goat Mandible

Clinical Trial

Following the in vitro phase, an open, prospective clinical trial was conducted involving 26 patients who required the placement of 30 dental implants. Patients were recruited from the out-patient department of the dental college from January 2019 to December 2023.

Inclusion Criteria:

- Patients aged 18 years and older
- Sufficient bone density and volume at the implant site

Exclusion Criteria:

- History of systemic diseases affecting bone healing
- Ongoing periodontal disease
- Chronic Smokers

Patients were randomly assigned to one of two groups using a computer-generated randomization method to ensure unbiased distribution:

- Group I: Osteotomy with internal and external irrigation.
- Group II: Osteotomy with external irrigation only.

Sample Size Calculation

The sample size for this randomized clinical trial was calculated based on the primary outcome measure: difference in temperature rise during osteotomy preparation between the two irrigation techniques.

Assuming an alpha error (Type I error) of 0.05 (5%) and a beta error (Type II error) of 0.20 (20%), corresponding to a study power of 80%, and anticipating a moderate effect size (Cohen's $d = 0.6$) based on previous literature and pilot observations, the required minimum sample size was determined to be 12 osteotomies per group (total of 24 osteotomies).

To account for possible dropouts or missing data (~ 10%), the sample size was increased to 15 osteotomies per group, resulting in a final target sample of 30 osteotomy sites across both groups.

Sample size estimation was performed using G*Power software version 3.1 (Heinrich-Heine-University Düsseldorf, Germany), employing a two-tailed independent samples t-test for comparing means between two groups.

Preoperative Assessment

All patients underwent diagnostic orthopantomography and intraoral periapical radiographs to assess bone density, bone loss, periapical pathology, and the involvement of surrounding teeth. Study models were obtained to evaluate the dimensions and morphology of the edentulous ridge.

Before implant site preparation, the bone quality at each surgical site was assessed using preoperative radiographs. Bone density was classified according to the Lekholm and Zarb classification system, based on the trabecular pattern and cortical thickness observed in panoramic and periapical radiographs.

This classification system categorizes bone into four types:

- Type 1: Homogenous, dense cortical bone
- Type 2: Thick cortical bone with dense trabecular bone
- Type 3: Thin cortical bone with dense trabecular bone
- Type 4: Very thin cortical bone with low-density trabecular bone

Bone quality assessment was performed by an experienced clinician prior to osteotomy preparation to assist in planning the drilling protocol and to account for potential variations in heat generation during the procedure.

Surgical Protocol

Osteotomy preparation for all implants was conducted using the Adin Surgical Drilling Kit (Adin Dental Implant Systems Ltd., Afula, Israel), following the sequential drilling protocol recommended by the manufacturer. All drills were used under continuous external irrigation to minimize heat generation. The implants placed in this study were Adin Dental Implants (Adin Dental Implant Systems Ltd., Afula, Israel), characterized by a sandblasted, large-grit, acid-etched (SLA) surface, specifically treated with aluminum oxide particle blasting to enhance micro-roughness and promote early osseointegration.

Implant dimensions varied according to clinical indications, with diameters ranging from [3.3 to 4.2 mm] and lengths from [8 to 13 mm]. Placement was performed sub-crestally 0.5–1 mm, ensuring primary stability while respecting the biological width and peri-implant tissue health.

All surgeries were performed by a single experienced oral and maxillofacial surgeon to ensure consistency across all cases.

Outcome Measures

Primary Variables: Implant stability, temperature variation during drilling, and bone-to-implant contact (measured on standardized intraoral periapical radiographs taken at the 3rd, 6th, and 12th months using a grid method from a fixed reference point at the highest point on the implant).

Secondary Variables: Crestal bone loss, periodontal pocket depth, and the presence of any peri-implant complications.

A type K thermocouple (Omega Engineering, Inc., USA) was used to measure temperature at the osteotomy site. The thermocouple was calibrated using a certified temperature calibration bath before each session. The probe was placed 2 mm from the drilling site in the buccal bone, following validated methodologies. Continuous temperature readings were recorded at 1 s intervals using a digital data logger (Omega Data Logger). This approach ensures accurate monitoring of thermal changes during the drilling procedure.

Clinical assessments were conducted at follow-up visits to evaluate, Implant mobility, Presence of erythematous gingiva, Tenderness on percussion and Radiographic assessment of peri-implant periodontium status.

Statistical Analysis

Statistical analyses were performed using SPSS Software, with p-values calculated to determine significance. The Chi-square test was used for categorical variables (gender, implant site, and bone density), and independent samples t-tests were used for continuous variables (age, implant length, and diameter). The test performed were ANOVA for comparisons between groups and post hoc tests wherever necessary.

Results

The study evaluated heat generation during osteotomy in an in vitro model, revealing no significant differences across various irrigation methods, as shown in Table 1 ($p = 0.06$). Similarly, it also evaluated the heat generation clinically in patients. The Table 2 includes age, gender, implant site, bone density, and implant specifications (length, diameter), which help ensure that participants are distributed evenly across the two groups. The p-values indicate no significant differences between groups for each variable, suggesting that both groups are comparable at baseline.

Table 3 presents comparable crestal bone loss among different osteotomy techniques at the one-year mark, with no significant differences between groups ($p = 0.20$). Table 4 indicates consistent probing depths around implants after one year, further supporting the lack of significant differences based on irrigation methods ($p = 0.14$). Table 5 shows no significant differences in temperature changes between Group I (Internal + External Irrigation) and Group II (External Irrigation Only) were observed at any distance from the osteotomy site ($p > 0.05$ for all comparisons).

Insights from the in vitro phase informed the in vivo study, which yielded several important conclusions. Notably, all implants placed in both groups exhibited stability throughout the one-year follow-up period, illustrated in Figs. 2 and 3. This finding underscores the efficacy of both

Table 1 Temperature difference observed by in vitro study:

	Serial Number	Baseline temperature in °C	Temp in °C at 3 mm	Temp in °C at 5 mm	Temp in °C at 11 mm	Mean Temp in °C
Left side. Osteotomy prepared using external irrigation. Group I	1	23	38.5	42.5	44	41.6
	2	23	39	42.5	43	41.5
	3	23	38.5	41	43.5	41
	4	23	38	42	44	41.3
	5	23	38.5	42.5	44.5	41.5
			38.50 ± 0.35	42.10 ± 0.65	43.80 ± 0.57	41.38 ± 0.24
Right side. Osteotomy prepared using internal & external irrigation. Groups II	Serial Number					
	1	23	38.5	40.5	42.5	40.5
	2	23	38.5	41	43	40.8
	3	23	38.5	40	42	40.2
	4	23	38	39	43	40
	5	23	39	40.5	42.5	40.6
			38.50 ± 0.35	40.20 ± 0.76	42.60 ± 0.42	40.42 ± 0.32
			$t = 0.0$; $P = 0.06$	$t = 7.36$; $p = 0.0001$	$t = 6.57$; $p = 0.0001$	

Table 2 Distribution of demographic data and study variables

Variable	Group I (Internal & External Irrigation)	Group II (External Irrigation Only)	p-value
Age (mean ± SD, years)	51.2 ± 6.8	52.4 ± 7.1	0.42
Gender			
Male	12 (48%)	11 (44%)	0.76
Female	13 (52%)	14 (56%)	
Implant Site			
Mandible	16 (64%)	17 (68%)	0.81
Maxilla	9 (36%)	8 (32%)	
Bone Density (Lekholm & Zarb Classification)			
Type I (high density)	6 (24%)	7 (28%)	0.83
Type II (medium density)	11 (44%)	10 (40%)	
Type III (low density)	8 (32%)	8 (32%)	
Implant Length (mean ± SD, mm)	10.5 ± 1.2	10.7 ± 1.3	0.64
Implant Diameter (mean ± SD, mm)	4.2 ± 0.4	4.3 ± 0.5	0.56

Table 3 Comparison of bone loss on consecutive follow-ups in studied type of irrigation

Bone Loss	Group I (n = 15)	Group II (n = 15)	Significance
At 3rd month	0.81 ± 0.512	1.13 ± 0.535	$t = 1.174$; $p = 0.15$
At 6th month	1.69 ± 0.359	1.92 ± 0.783	$t = 1.096$; $p = 0.20$
At 12th month	2.069 ± 0.4936	2.375 ± 1.2760	$t = 0.905$; $p = 0.20$
Significance 3/6 3/12	$t = 7.00$; $P < 0.0001$ $t = 9.30$; $P < 0.0001$	$t = 7.31$; $P < 0.0001$ $t = 5.55$; $P < 0.0001$	

Table 4 Comparison of Probing Depth on consecutive follow-ups in studied type of irrigation

Probing Depth	Group I (n = 15)	Group II (n = 15)	Significance
At 3rd month	2.4856 ± 0.34827	2.7125 ± 0.58644	$t = 1.365$; $p = 0.19$
At 6th month	2.55 ± 0.518	3.01 ± 1.015	$t = 1.667$; $p = 0.11$
At 12th month	2.86 ± 0.758	3.29 ± 0.904	$t = 1.514$; $p = 0.14$
Significance 3/6 3/12	$t = 0.469$; $P > 0.05$ $t = 191$; $P > 0.05$	$t = 2.12$; $P < 0.05$ $t = 4.19$; $P < 0.001$	

internal and external irrigation systems in promoting secure implant integration.

The study also found no statistically significant difference in the increase of periodontal pocket depth after one year between the two groups ($p = 0.20$), suggesting that both irrigation methods effectively maintained peri-implant tissue health over the study duration.

Regarding bone health, the increase in crestal or marginal bone loss after 1 year postoperatively was measured at 2.06 ± 0.49 mm in Group I (internal and external irrigation) and 2.37 ± 1.27 mm in Group II (external irrigation alone). These results indicate non-significant differences between the groups ($p = 0.15$), suggesting that both

Table 5 Comparison of Temperature Changes between Groups for All Patients

Distance from Osteotomy Site (mm)	Group I: Internal + External Irrigation (Mean ± SD)	Group II: External Irrigation Only (Mean ± SD)	p value
3 mm	43.80 ± 0.57	42.60 ± 0.42	0.06
5 mm	44.20 ± 0.53	43.10 ± 0.49	0.08
11 mm	43.50 ± 0.54	42.80 ± 0.51	0.10

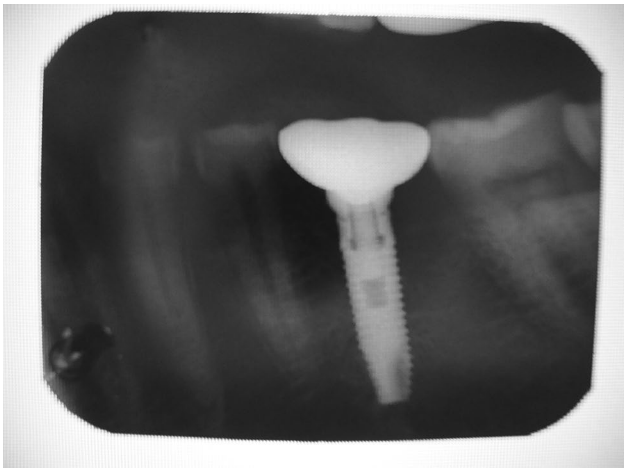

Fig. 2 One year postoperative radiograph showing successful implant in group 1

Fig. 3 One year postoperative radiograph showing successful implant in group 2

irrigation methods similarly contribute to preserving marginal bone levels around implants.

In summary, the study's findings support that both internal and external irrigation systems, as well as external irrigation alone, are effective in ensuring stable implant outcomes and maintaining periodontal health over a 1 year period. These results provide valuable insights into optimizing surgical protocols for dental implant procedures, emphasizing the importance of careful irrigation techniques in minimizing heat generation and promoting long-term implant success.

Discussion

To mitigate thermal bone injury during osteotomy for dental implants, various techniques have been advocated, including controlling bur speed [9], and employing copious irrigation with different irrigants and irrigation systems, such as internal and external irrigation [10]. In our in-vitro study, the maximum temperature recorded was 44.5 °C with a mean of 43.80 ± 0.57 °C in Group I, and 43 °C with a mean of 42.60 ± 0.42 °C in Group II. Notably, the temperature differences between the two groups were found to be statistically insignificant. The lack of significant differences in temperature rise between the irrigation methods may be attributed to consistent bur speed and the effective cooling provided by both irrigation systems, suggesting that both techniques are equally capable of managing thermal effects during osteotomy. These findings differ from those reported by Dabag ANA et al. [11], who examined temperature variations in bovine femur cortical bone using cooled and room temperature irrigants at a depth of 15 mm.

Similarly, Sharawy M et al. [9] conducted a study on porcine jaws evaluating external and internal irrigation systems and the effect of drilling speed. They concluded that at an 8 mm depth, the mean maximum temperature rise in the internal and external irrigation group was significantly lower than in the group using only external irrigation at 1650 rpm. This discrepancy can be attributed to the direct relationship between frictional heat generation and the amount of cortical bone engaged during drilling.

Benington IC et al. [10], in their study on sheep mandibles, found no significant advantage of internal cooling when used alongside external irrigation during osteotomy preparation for dental implants. Similarly, Noger M et al. [12] reported no significant difference in temperature rise between external and internal irrigation systems in their study on human hip bones, corroborating our findings.

Thermal injury to bone leading to fibro-osseointegration can compromise implant stability [6]. Such compromised stability can lead to increased sulcular depth around implants, fostering bacterial colonization and potentially resulting in periodontal pocket formation [13]. While inadvertent periosteal handling during the initial surgical stage is a common cause of crestal bone loss post-implant insertion, progressive deepening of the periodontal pocket further exacerbates bone loss [14]. Unchecked, these factors can significantly impact implant success outcomes.

In our study, periodontal pocket depth was measured at three-month intervals postoperatively using William's graduated probe, revealing no significant differences based on irrigation method. Similar findings were reported by

Heydenrijk K et al. [15], who compared outcomes between single-stage and two-stage implant procedures. According to Blanes RJ et al. [16], a critical periodontal pocket depth at one year post-implantation is ≤ 3 mm; however, both our study and long-term evaluations show a progressive increase in periodontal pocket depth around implants, consistent with previous research.

Common causes of crestal bone loss in implant therapy include overloading, microgaps at the implant-abutment interface, polished implant necks, infections, inflammation, and surgical trauma [17]. Horwitz J [18], in a study on non-loaded implants, observed comparable bone loss after one year to our findings. Overall, bone loss in our study remained within normal limits and was insignificant after 12 months of follow-up.

Vidyasagar L [4] observed that implant stability correlates with bone loss, initial implant stability, and bone density at the implant site, findings that align with our study population. Corinaldesi G et al. [19] similarly reported stable implant outcomes following bone augmentation procedures.

While some advocate against irrigation during osteotomy, citing potential complications, including Flanagan D [20], the consensus supports the prudent use of irrigation to cool the osteotomy site and minimize thermal damage. Given the safety and potential benefits, irrigation remains a recommended practice during osteotomy preparation to optimize clinical and surgical outcomes.

This study acknowledge several limitations including the small sample size of 26 patients and 30 implants limits generalizability, and the single-center design may introduce site-specific biases. Operator bias could arise from assessments conducted by a single clinician, and subjective measures may vary in interpretation. The 1 year follow-up may not capture long-term stability or complications. While randomization was attempted, it may not fully eliminate selection bias. Additionally, using goat mandibles may not accurately reflect human bone behavior, and factors like patient age and bone quality were not strictly controlled.

One of the limitations of this study is the lack of use of cone beam computed tomography (CBCT) for measuring crestal bone loss and implant-to-bone contact. While periapical and panoramic radiographs were used to assess bone levels, CBCT imaging offers higher precision and three-dimensional visualization of the peri-implant bone, which could have provided more accurate measurements of bone loss and implant stability. The absence of CBCT imaging may have impacted the precision of our bone measurements and limited the ability to detect subtle changes in bone morphology over time.

Addressing these limitations is essential for future research on irrigation techniques in dental implant procedures. Future research should also explore the implications of heat generation after multiple uses of drill systems, specifically examining how temperature variations correlate with changes in drill sharpness and metal wear. Such studies could provide empirical guidelines for optimizing the longevity and performance of implant tools, ensuring better clinical outcomes.

Conclusion

In conclusion, our study shows that both internal and external irrigation systems, as well as external irrigation alone, effectively mitigate thermal effects during implant osteotomy. With consistent outcomes observed over one year, these methods promote stable implant integration and maintain peri-implant tissue health. These findings highlight the importance of meticulous surgical techniques and optimized irrigation practices for achieving successful implant outcomes. Further research to refine these protocols for diverse clinical contexts will advance standards in implant dentistry, ensuring better patient outcomes and long-term implant stability.

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Declarations

Conflict of interest Authors declare that there is no conflict of interests with publication of this paper.

Ethical Approval Obtained from institution ethics committee for both the phases.

Informed Consent No patient identifying photographs included.

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