

Methods for measuring temperature generated by implant drills

Abstract

This study aimed to identify, categorize, and analyze the main methods used to measure the temperature generated by implant drills during osteotomies, emphasizing their advantages, limitations, and clinical implications. A scoping review with integrative characteristics was conducted in accordance with the PRISMA-ScR guidelines. The search strategy included descriptors related to temperature, implant drills, and measurement techniques, applied across PubMed, Scopus, Web of Science, and SciELO databases. Studies published between 2000 and 2025 were considered, and 20 articles met the eligibility criteria. The identified measurement methods included thermocouples, infrared thermography, fiber optic sensors, digital pyrometry, and finite element analysis. Thermocouples remain the most widely used technique due to their low cost and high precision, although they are limited by reduced spatial resolution. Infrared thermography offers the advantage of being non-invasive but requires controlled environments and specialized equipment. Finite element models provide valuable theoretical predictions of thermal behavior but are highly dependent on material properties and boundary conditions. There is still no consensus regarding the most accurate method for assessing temperature during osteotomies, and methodological heterogeneity continues to hinder the establishment of clinical thresholds for thermal damage. Future studies should aim for methodological standardization and the development of real-time, non-invasive measurement technologies.

Keywords: temperature measurement, implant drills, infrared thermography, thermocouple, osteotomy

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Introduction

The clinical success of osseointegration in implant dentistry is directly associated with the preservation of bone vitality during osteotomy. One of the major risk factors for implant integration failure is the excessive increase in temperature during bone bed preparation. Classic studies have demonstrated that temperatures above 47 °C sustained for more than one minute can induce thermal necrosis of bone, thereby compromising primary stability and subsequent osseointegration.¹

Several variables influence heat generation during bone drilling, including drill design, number of reuses, rotational speed, applied pressure, irrigation, and bone density.^{2,3} To define critical thresholds and optimize operative conditions, it is essential to employ temperature measurement methods that are accurate, reproducible, and compatible with both surgical and experimental settings. Currently, the main methods used to assess temperature during osteotomy include thermocouples, infrared thermography, pyrometers, fiber optic sensors, and finite element analysis.⁴⁻⁶

Each technique presents distinct advantages and limitations in terms of accuracy, invasiveness, response time, and cost, and the choice of method can directly affect study outcomes and comparability. Thermocouples remain the most widely employed technique due to their reliability, low cost, and straightforward integration with experimental systems. However, they present limitations regarding spatial resolution and precise probe positioning at the bone-drill interface.⁷ Infrared thermography, in contrast, provides dynamic and non-invasive visualization, but it is strongly influenced by environmental conditions and requires a direct line of sight to the surface under evaluation.^{8,9}

Computational modeling approaches, such as finite element analysis, have been applied to simulate thermal distribution during drilling. Although valuable for predicting theoretical risk zones, these models depend on complex biomechanical parameters and require experimental validation to ensure clinical applicability.⁹ Furthermore, emerging methods such as fiber optic sensors and digital pyrometers are being explored for their potential in real-time measurements with high thermal sensitivity.¹⁰

Given the methodological diversity and the lack of standardization among studies, it is necessary to critically map and categorize the methods used to measure the temperature generated by implant drills. Therefore, this scoping review aims to identify the main methods employed, their applications, limitations, and clinical implications in contemporary implant dentistry.

Methodology

This study is a scoping review with integrative and qualitative characteristics, aiming to map, classify, and critically analyze the methods used to measure the temperature generated by implant drills during osteotomy procedures. The protocol followed the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) recommendations.

Data sources and search strategy

The search strategy was conducted in the PubMed, Scopus, Web of Science, and SciELO databases, covering the period from January 2000 to July 2025. The following descriptors and Boolean operators were applied: ("implant drill" OR "implant osteotomy" OR "implant site preparation") AND ("temperature measurement" OR "thermal analysis" OR "thermocouple" OR "infrared thermography" OR

“pyrometer” OR “finite element analysis”). All terms were adapted for each database using MeSH and DeCS, when available. In addition, the reference lists of the included studies were manually screened to identify further relevant articles (snowballing technique).

Eligibility criteria

Inclusion criteria

- Original studies (*in vitro*, *ex vivo*, or *in vivo*) that evaluated the temperature generated during implant osteotomy procedures using any measurement technique.
- Articles published in English, Portuguese, or Spanish.
- Full-text availability.

Exclusion criteria

- Reviews, editorials, conference abstracts, and letters to the editor.
- Studies not involving dental implant drills.
- Studies not addressing temperature measurement methods or lacking methodological details.
- Duplicate publications.

Information sources and search strategy

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Selection process

The selection process followed four stages: (1) identification of records through database searches, (2) title and abstract screening, (3) full-text eligibility assessment, and (4) final inclusion of studies meeting all criteria. Two independent reviewers conducted the selection process. Discrepancies were resolved by consensus or, when necessary, by consultation with a third reviewer.

Data collection process and data items

Data extraction was performed independently by two reviewers using a standardized form. Extracted information included: author(s), year of publication, study design, measurement method, experimental setting, implant system, variables evaluated, and main findings.

Study selection flow

A total of 134 records were identified. After screening and eligibility assessment, 20 studies met the inclusion criteria and were included in the final analysis. The study selection process is presented in a PRISMA 2020 flow diagram.

Study outcome of literature

Thermocouples: gold standard in experimental models

Thermocouples remain the most frequently used method for temperature assessment in implant osteotomy research, primarily due to their low cost, high precision, and rapid response time. In most studies, a Type K thermocouple is positioned near the implant bed to monitor real-time temperature changes. However, accurate positioning is critical, as even minor displacements can compromise measurement accuracy.^{1,2} The invasive nature of this method and its

inability to capture temperature gradients across different regions are considered major limitations.³

Infrared thermography: non-invasive visualization

Infrared thermography (IRT) has gained popularity as a non-contact method for surface temperature monitoring. It enables visualization of heat distribution over wide areas, which is useful for comparing drill designs, irrigation protocols, and drill reuse.⁴ Despite its advantages, IRT is sensitive to environmental interference, emissivity variations, and requires a clear line of sight to the target surface.⁵ Nevertheless, the ability to generate real-time thermographic images represents a valuable advantage in both experimental and clinical contexts.⁶

Digital pyrometry and fiber optic sensors

Digital pyrometers allow contactless temperature assessment by detecting emitted radiation. Although effective in high-temperature applications, their utility in dental osteotomies is limited due to small measurement areas and susceptibility to motion artifacts.⁷ Fiber optic sensors, on the other hand, are emerging as highly sensitive tools for temperature monitoring, offering compact size and suitability for placement near implant beds. However, their fragility and high cost remain barriers to broader application.^{8,9}

Finite element analysis (FEA): simulated thermal prediction

Finite element analysis enables virtual modeling of heat distribution within cortical and trabecular bone under varying drilling conditions. Studies indicate that parameters such as drill speed, bone density, and irrigation rate significantly influence peak temperatures.^{10,11} While FEA provides valuable theoretical insights and reduces experimental dependency, its reliability is highly dependent on accurate input parameters and robust validation.¹² Moreover, notable discrepancies persist between simulated outcomes and *in vivo* findings.

Comparative studies between measurement methods

Comparative studies evaluating thermocouples and infrared thermography in parallel have demonstrated strong correlations in peak temperature detection, particularly when both techniques are properly calibrated.¹³ However, IRT tends to underestimate maximum temperatures compared to intrabony thermocouples.¹⁴ Hybrid approaches, such as combining thermography with FEA or thermocouples with optical sensors, have been proposed to enhance data accuracy and reproducibility.¹⁵

Clinical applications and methodological limitations

Measuring temperature in clinical scenarios remains challenging due to ethical and technical constraints. Consequently, most available data are derived from *in vitro* or animal models, which, although informative, are not fully translatable to human physiology.¹⁶ Additionally, significant heterogeneity exists among experimental setups such as bone type, irrigation systems, drill design, and applied forces compromising comparability across studies.¹⁷ These limitations underscore the importance of standardized protocols and the validation of non-invasive, real-time measurement technologies.^{18,19}

Discussion

Analysis of the 20 included studies demonstrates a consistent concern in implantology regarding the risk of thermal damage during osteotomy. The literature confirms that temperatures exceeding 47 °C for more than one minute may compromise osseointegration and result in early implant failure.¹ Nonetheless, marked heterogeneity

in protocols, measurement techniques, and drill designs prevents direct comparisons and hinders the establishment of universal clinical guidelines.^{2,3}

Thermocouples remain the most reliable and commonly used method in *in vitro* and *ex vivo* experiments due to their accuracy and real-time response.⁴ However, their invasive nature and limited spatial resolution may lead to underestimation of critical thermal peaks.⁵ Infrared thermography presents an appealing non-contact alternative but is subject to calibration issues, ambient interference, and restricted surgical applicability.^{6,7} Furthermore, surface measurements obtained by IRT may not reflect intrabony temperatures, where thermal damage is most clinically relevant.

Emerging technologies, such as fiber optic sensors and digital pyrometry, offer high sensitivity and the potential for real-time monitoring. Despite their promise, limitations such as cost, fragility, and lack of clinical integration continue to restrict their widespread adoption.⁸ Finite element analysis (FEA) provides valuable predictive modeling, enabling the evaluation of multiple variables under controlled conditions.⁹ Yet, its dependence on accurate material properties and model validation raises concerns about external validity.¹⁰

A major gap identified in this review is the lack of methodological standardization. Variables including irrigation protocols, drill geometry, diameter, drilling depth, bone density, and drill reuse significantly influence heat generation.^{11–13} This inconsistency compromises reproducibility and weakens the clinical applicability of results.

Moreover, the scarcity of *in vivo* studies represents a significant limitation. Ethical concerns, patient variability, and technical difficulties restrict the real-time application of temperature sensors during surgery.¹⁴ Consequently, much of the current evidence is based on simplified models that may not adequately replicate clinical conditions. Translational research bridging *in vitro* findings with clinical practice is therefore urgently needed.¹⁵

Final considerations

This scoping review demonstrates the diversity of methods for assessing heat generation during implant osteotomy and the lack of consensus on the most accurate approach. Thermocouples remain the experimental gold standard, while infrared thermography and computational modeling provide valuable complementary insights. There is a clear need for methodological standardization regarding experimental protocols, drilling parameters, and critical thermal thresholds. Future research should prioritize non-invasive, real-time methods with clinical applicability and validate hybrid approaches to enhance reliability. A deeper understanding of the thermal behavior of implant drills is essential to improve surgical safety, clinical predictability, and long-term implant success.

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Data availability

All data analyzed during this study are available from the corresponding author upon reasonable request.

Disclaimer of liability and disclosure

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None.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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