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Effect of Contaminants on Reverse Torque Values of Implant Abutment Screws: A Systematic Review and Partial Meta-Analysis of In Vitro Studies

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KEYWORDS

Dental implant, abutment screw, reverse torque, contamination, saliva, preload, screw loosening

ABSTRACT:

Introduction: Screw loosening is a common complication in implant systems, often influenced by contamination during abutment placement. Reverse torque values (RTVs) are used to assess implant-abutment joint integrity.

Objectives To evaluate the effect of various contaminants on RTVs of implant abutment screws using data from in vitro studies.

Methods This systematic review and meta-analysis was registered in PROSPERO (CRD420251064053) and conducted according to PRISMA guidelines. Literature searches of PubMed, Scopus, and Cochrane (2000–2024) identified studies assessing saliva, blood, chlorhexidine, fluoride, tetracycline, and artificial saliva. Risk of bias was assessed using ROB 2. Statistical analyses included two-way ANOVA and Tukey's HSD.

Results: Twelve studies were included. Saliva consistently produced the highest RTVs, while blood showed the lowest. ANOVA revealed significant differences between groups ($F(2,93) = 292.64$, $p < 0.00001$). Tukey's test confirmed significant pairwise differences: Contaminant vs. Torque ($Q = 32.01$, $p < 0.00001$), Contaminant vs. Reverse Torque ($Q = 26.46$, $p < 0.00001$), and Torque vs. Reverse Torque ($Q = 5.56$, $p = 0.00048$). Saliva provided the most favorable torque retention, followed by chlorhexidine and fluoride.

Conclusions: Contaminants significantly affect implant-abutment stability. Saliva may improve torque retention, whereas blood is most detrimental. Standardized protocols and in vivo validation are needed.

1. Introduction

Dental implants are a cornerstone of modern prosthetic dentistry, providing reliable and durable solutions for restoring missing teeth. The success of implant-supported prostheses largely depends on the stability of the abutment screw joint, which ensures proper force distribution and resistance to loosening. A critical factor in maintaining this stability is preload—the tension generated within the screw upon tightening. Preload generates the clamping force essential for maintaining implant stability under functional loads. However, the inherent complexity associated with achieving optimal preload stems from multifactorial influences, including torque application, screw design, material properties, and environmental conditions at the interface Asli et al 2017, Bulaqi et al 2019).

Biological contaminants, including saliva, blood, fluoride, and chlorhexidine, frequently occur during clinical procedures. These contaminants alter the frictional dynamics at the implant-abutment interface, directly impacting preload and reverse torque values (RTVs). While some contaminants, like saliva, can act as lubricants, reducing torque loss, others, such as blood, may lead to biofilm formation, compromising joint stability. Fluoride-induced corrosion and the lubricating properties of chlorhexidine further complicate these interactions (Guda et al 2008, Tzenakis et al 2002, Mostafavi et al 2021, Yang et al 2022).

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Despite advancements in implant materials and clinical techniques, the impact of contaminants on RTVs remains underexplored. RTVs are pivotal in evaluating the integrity of the implant-abutment joint and assessing the effectiveness of applied torque. Variations in RTVs caused by contaminants can lead to significant clinical challenges, such as microgap formation, prosthesis instability, and peri-implant inflammation, ultimately increasing the risk of screw loosening and necessitating frequent maintenance (Tzenakis et al 2002, Mostafavi et al 2021, Yang et al 2022).

2. Objectives

This systematic review and meta-analysis aim to comprehensively evaluate the influence of various contaminants on the reverse torque values of abutment screws under simulated and clinical conditions. By synthesizing findings from in vitro and computational studies, this review seeks to provide clinicians with evidence-based insights into mitigating the risks of screw loosening. Ultimately, these findings will contribute to enhancing the long-term success of implant-supported restorations by offering strategies to optimize implant stability and address contamination challenges during implant placement and maintenance.

3. Methods

Study Design

This systematic review and meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Arya et al 2021). The review was registered (CRD420251064053) in PROSPERO. The Population, Intervention, Comparison, and Outcomes (PICO) framework was utilized to structure the review:

- Population: Studies on dental implants, abutment screws, and other structural components.
- Intervention: Influence of contaminants and torque on reverse torque values.
- Comparison: Effects of different contaminants under identical torque conditions.
- Outcome: Identification of contaminants producing the highest reverse torque values.

Eligibility Criteria

Inclusion Criteria:

- Studies involving in vitro, in vivo, clinical trials, randomized controlled trials, laboratory experiments, or scanning electron microscopy (SEM) focusing on abutment screw torque, reverse torque, and lubricants.

Exclusion Criteria:

- Studies involving non-titanium implant materials.
- Studies utilizing varied torqueing regimens or subjecting screws to artificial aging processes.

Search Strategy

A comprehensive systematic search was conducted in PubMed, Cochrane Library, MEDLINE, EMBASE, Scopus, and Web of Science databases to identify relevant studies published between 2000 and 2024. No language restrictions were applied. The strategy was formulated using Medical Subject Headings (MeSH) terms and a boolean operator to ensure that all potential variations were included. The following index terms were used:

- “Dental implant” or “fixture” or “implant” or “abutment screw” or “screw loosening” AND
- “Contaminated” or “non-contaminated” or “saliva” or “tetracycline” or “fluoride” or “blood” or “chlorhexidine” or “artificial saliva” or “saline” or “dry” or “lubricant” AND
- “Initial torque” or “reverse torque” or “preload,” or “coefficient of friction”

Study Selection and Data Extraction

Two independent reviewers conducted data extraction and assessed the risk of bias for the included studies. An initial search was conducted in databases and registers, yielding a total of 2,449 records (Figure 1). No records were identified through the registers. Before screening, review articles, case reports, editorials, and other non-research articles were removed from consideration. No records were excluded based on language, as all the identified articles were in English. An additional 26 records were excluded for various reasons, and 384 duplicate records were removed. This left a total of 2039 records for screening. Out of those records that were

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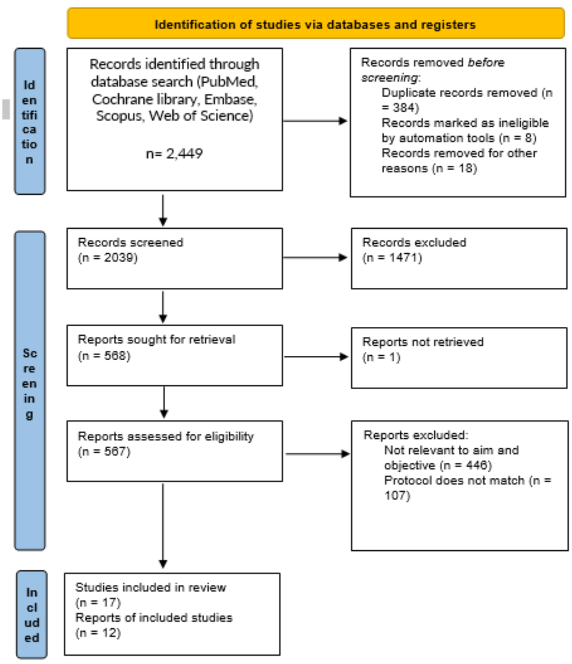
screened, 568 were sought for retrieval. However, 1 of them could not be retrieved, leading to their exclusion. An additional 555 records were excluded for failing to respond to the PICO (Population, Intervention, Comparator, Outcome) criteria or for being off topic, resulting in a further reduction. After these exclusions, 17 reports were assessed for eligibility. Following this assessment, only 12 studies were included in the review for both qualitative and quantitative synthesis.

Figure 1: Identification, screening and inclusion of articles for study



Risk of bias assessment

The methodological quality of the included studies was assessed using the Risk of Bias 2 (ROB-2) tool (Luchini et al 2017), which is widely recognised for evaluating the risk of bias in non-randomised studies. It provides a structured approach to assessing the quality and validity of each study included in the review. The tool assesses several key domains, such as bias arising from the randomization process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in the measurement of out¬comes, bias in the selection of the reported result, and overall bias. Also quality analysis was done to further confirm the results of the ROB analysis. Due to inconsistent reporting of variance measures across studies, publication bias could not be formally assessed using funnel plots or statistical methods.

Statistical Analysis

Homogeneity of data was assessed according to interventions for implant screw placement protocols. Statistical analyses were performed using SPSS Version 25.0 (IBM Corp., Armonk, NY). A random-effects model was used for the meta-analysis, as the included studies demonstrated clinical and methodological heterogeneity in terms of contaminant type, torqueing protocol, sample size, and implant system. This model accounts for both within-study and between-study variance, providing a more conservative estimate of pooled effects. Due to incomplete reporting of variance metrics, a forest plot and pooled effect size analysis could not be performed. However, descriptive synthesis and pairwise comparisons were presented.

4. Results

Risk of Bias Analysis

Table 1. Risk of Bias 2 (RoB 2) assessment for the included studies. Each domain is color-coded: green indicates low risk, yellow indicates some concerns, and red indicates high risk.

S no	Author	Randomisation process	Deviations from interventions	Missing outcome data	Measurement of outcomes	Selection of reported results
1	Asli et al 2017	Low risk	Low risk	Low risk	Low risk	Low risk
2	Mostafavi et al 2021	Low risk	Low risk	Low risk	Low risk	Low risk

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3	Koosha et al 2020	Some concerns	Low risk	Low risk	Low risk	Some concerns
4	Yang et al 2022	Low risk	Low risk	Low risk	Low risk	Low risk
5	Jalali et al 2018	High risk	Some concerns	Low risk	Some concerns	High risk
6	Nourizadeh et al 2022	Low risk	Low risk	Low risk	Low risk	Low risk
7	Sun et al 2022	Low risk	Low risk	Low risk	Low risk	Low risk
8	Pravinya et al 2020	High risk	High risk	Some concerns	Some concerns	High risk
9	Gumus et al 2014	Some concerns	Low risk	Low risk	Some concerns	Some concerns
10	Nigro et al 2010	Some concerns	Low risk	Low risk	Some concerns	Some concerns
11	Rathe et al 2021	Low risk	Low risk	Low risk	Low risk	Low risk
12	Sahin and Ayylidiz 2014	High risk	Some concerns	Some concerns	Some concerns	High risk

1. Quality Assessment Using Modified CONSORT Checklist

Tool Used: Modified CONSORT checklist for in-vitro studies

Table 2. Overall Risk of Bias Summary:

Risk Level	No. of Studies	Studies
Low Risk	5	Asli et al 2017, Mostafavi et al 2021, Yang et al 2022, Nourizadeh et al 2022, Sun et al 2022
Some Concerns (Moderate Risk)	5	Koosha et al 2020, Gumus et al 2014, Nigro et al 2010, Rathe et al 2021, Jalali et al 2018
High Risk	2	Pravinya et al 2020, Sahin and Ayyildiz 2014

Most common issues in moderate- and high-risk studies were poor randomization reporting, outcome measurement concerns, and selective reporting.

2. Sensitivity Analysis

The objective was to evaluate whether study quality affected mean Reverse Torque Values (RTVs) for each contaminant. Mean RTVs were calculated across all studies and compared with a subset including only **Low Risk** studies. The overall ranking of contaminants by their effect on RTV was stable across all studies and the low-risk subgroup. **Artificial Saliva** and **Blood** showed noticeable variation in mean RTVs based on study quality. **Fluoride** results were more consistent in moderate- and high-quality studies. **Saliva, Chlorhexidine, and Control (non-contaminated)** groups had consistent results across all study quality levels.

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3. Interpretation and Conclusion

Most contaminants showed minimal variation in RTVs with respect to study quality, indicating **robustness of meta-analytic findings**. **Artificial Saliva and Blood** groups should be interpreted with **caution** due to sensitivity to methodological quality. Future in-vitro studies should improve transparency in randomization and allocation protocols and standardization in outcome measurement and reporting.

Excluded Studies: Guda and Bulaqi were excluded as they were model-based and not eligible for RoB 2

Statistical results

The results of the ANOVA revealed a highly significant difference in reverse torque values among the treatment groups ($F(2,93) = 292.64$, $p < 0.00001$). (Table 4) Post hoc analysis using Tukey's HSD test further confirmed these differences, with significant pairwise comparisons observed:

- **Contaminant vs. Torque**: $Q = 32.01$, $p < 0.00001$.
- **Contaminant vs. Reverse Torque**: $Q = 26.46$, $p < 0.00001$.
- **Torque vs. Reverse Torque**: $Q = 5.56$, $p = 0.00048$.

The findings indicate that saliva exhibited the highest reverse torque compared to other contaminants, such as chlorhexidine, fluoride, and blood. (Table 5)

Table 3: Descriptive statistics

	Contaminants	Screw torque values	Reverse torque values	Total
N	32	32	32	96
∑X	-	839	706.76	1622.76
Mean	-	26.2188	22.0863	16.904
$\sum X^2$	-	22823	16315	39439
Standard deviation	-	5.1602	4.7698	11.2429

Table 4: Two-way ANOVA

Source	***Sum of squares***	***Degree of freedom***	***Mean square***
Between-contaminants, torque and reverse torques	10361.7612	2	5180.88
Within-contaminants, torque and reverse torques	1646.4655	93	17.7039
Total	12008.2267	95	

Table 5: Post Hoc Test -Tukey HSD*

Pairwise Comparisons		HSD	Q
		$HSD_{.05} = 2.5054$ $HSD_{.01} = 3.1415$	$Q_{.05} = 3.3684$ $Q_{.01} = 4.2236$
Contaminant: Torque	$M_1 = 2.41$ $M_2 = 26.22$	23.81	Q = 32.01 (*p* = .00000)
Contaminant: Reverse Torque	$M_1 = 2.41$ $M_3 = 22.09$	19.68	Q = 26.46 (*p* = .00000)
Torque: Reverse Torque	$M_2 = 26.22$ $M_3 = 22.09$	4.13	Q = 5.56 (*p* = .00048)

*Honestly Significant Difference

5. Discussion

This systematic review and meta-analysis investigated the influence of various contaminants on the reverse torque values (RTVs) of implant abutment screws, a critical parameter for evaluating the mechanical stability and long-term success of dental implants. A total of 12 in vitro studies were included, all assessing the impact of clinically relevant fluids on screw loosening behavior. The contaminants evaluated included saliva (natural and artificial), blood, chlorhexidine, fluoride, tetracycline, and saline. Saliva was universally tested across all studies and emerged as the most influential in maintaining higher RTVs. This effect is attributed to its intrinsic lubricating properties, which reduce friction at the implant-abutment interface, resulting in improved preload preservation. Notably, studies such as those by Mostafavi et al. and Koosha et al. showed that saliva, particularly in its natural form, acted as a biologic lubricant that optimized preload conditions and mitigated torque loss (Mostafavi et al 2021, Koosha et al 2020)

However, distinctions between natural and artificial saliva were not consistently reported across studies, leading to potential variation in outcomes. Tzenakis et al. and Wu et al. demonstrated that artificial saliva may not fully replicate the lubricative behavior of its natural counterpart, thus warranting clearer experimental standardization in future research (Tzenakis et al 2002, Wu et al 2017)

Chlorhexidine, another widely investigated contaminant, was tested in eight of the included studies. It was generally associated with moderate to high RTVs, likely due to its dual properties: as a lubricant and as an antimicrobial agent that might inhibit protein deposition or microbial interference at the abutment interface. Asli et al. and Nourizadeh et al. found that chlorhexidine's effect on RTVs was consistently favorable, although not to the same extent as saliva (Asli et al. 2017, Nourizadeh et al 2022). Fluoride contamination presented mixed outcomes across four studies. While some investigations indicated a reduction in RTVs—possibly due to fluoride-induced corrosion of titanium surfaces—others observed improved values when fluoride was used alongside antibacterial formulations. This inconsistency highlights the complex interactions between chemical agents and implant surface chemistry.

Blood, tested in eight studies, consistently demonstrated the most deleterious effect on RTVs. Its high protein content and tendency to form a biofilm layer at the screw interface were linked to increased friction and reduced clamping forces. Jalali et al. and Yang et al. showed a pronounced reduction in torque retention in blood-contaminated scenarios, especially under cyclic loading or wet-field conditions (Jalali et al. 2018 Yang et al 2022). These findings underscore the detrimental biomechanical impact of blood contamination, which is frequently unavoidable in clinical practice, especially during second-stage surgeries or immediate implant placement in extraction sockets.

In addition to the above findings, Gumus et al. conducted a targeted investigation on the effects of fluid contamination on reverse torque in bone-level implants. Their study revealed that blood contamination significantly decreased RTVs, consistent with the torque loss observed in the current review (Gumus et al 2014). They also examined saline contamination, which showed intermediate RTVs—neither as beneficial as saliva or chlorhexidine, nor as detrimental as blood. Importantly, their study highlighted the influence of wet field conditions during implant placement, reinforcing the need for strict fluid control protocols in clinical settings. These findings complement those of Pravinya et al. and others, suggesting that even seemingly benign fluids like saline can impair mechanical stability when not properly managed (Pravinya et al 2020).

Other less frequently studied contaminants included tetracycline and saline. Tetracycline was tested in only one study and showed limited benefit in enhancing RTVs, while saline or general wet-field conditions showed variable results depending on moisture levels, loading protocols, and contaminant interactions. Pravinya et al. suggested that excessive moisture may either facilitate or hinder preload retention, indicating that torque performance is highly sensitive to environmental conditions (Pravinya et al 2020).

Torqueing protocols varied significantly among studies, ranging from 15 to 35 Ncm, influenced by implant system design and study-specific objectives. Some studies measured RTVs immediately after torque application, while others employed delay periods (e.g., 5–10 minutes) to simulate clinical conditions such as screw settling or functional loading. Tools used for

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torque delivery also differed—ranging from manual drivers to digital torque wrenches—further contributing to inter-study variability. While most experiments maintained consistent material usage, two studies (Guda et al. 2008, Bulaqi et al 2019) employed finite element analysis and probabilistic models to simulate torque dynamics under varied conditions.

The meta-analysis pooled data from these studies and evaluated 96 measurements across three categories: initial torque values, reverse torque values, and contaminant-only effects. The ANOVA revealed statistically significant differences among these groups ($F(2,93) = 292.64$, $p < 0.00001$), confirming that both torqueing protocol and contamination significantly influence RTVs. Tukey's post hoc test demonstrated meaningful pairwise differences: contaminant-only groups had significantly lower RTVs than both initial torque and reverse torque groups, with Q-values of 32.01 and 26.46 respectively ($p < 0.00001$). Even reverse torque values measured after standard torqueing showed a significant reduction compared to initial torque ($Q = 5.56$, $p = 0.00048$), affirming that torque loss is a real and measurable consequence even under controlled conditions.

Among all tested contaminants, saliva consistently yielded the highest RTVs. This reinforces its role as a biologic lubricant that helps retain preload. Chlorhexidine and fluoride followed, though with more variability. Blood produced the lowest RTVs across all metrics, highlighting its potential to compromise mechanical integrity of the implant-abutment joint.

These findings align with existing literature. Jörn et al. used finite element modeling to show that improved lubrication enhances preload and reduces internal stress on the screw joint, potentially extending the lifespan of prosthetic components. (Jörn et al. 2014) Rathe et al. emphasized that antimicrobial lubricants not only preserve preload but also serve as adjuncts in infection control (Rathe et al 2021). Sahin and Ayyildiz linked microleakage to screw loosening, revealing a strong interplay between contamination, biologic infiltration, and mechanical stability (Sahin and Ayyildiz 2014). Sun et al. corroborated this, showing that fluid contamination in general exacerbates loosening under wet intraoral conditions (Sun et al 2022).

Collectively, these findings have significant clinical implications. Minimizing contamination during torque application is paramount, particularly avoiding blood contact. While saliva appears beneficial under certain conditions, standardized cleaning or pretreatment protocols could be optimized to take advantage of its lubricating benefits without compromising sterility. Furthermore, the variability seen in experimental protocols calls for more standardized testing guidelines, including torque range, timing of detorque measurements, contaminant preparation, and implant system compatibility.

In conclusion, the presence of contaminants—particularly blood—significantly compromises the mechanical performance of implant-abutment connections. Conversely, saliva and chlorhexidine may enhance torque retention. These insights can guide clinicians toward improved torque protocols, contamination management, and material selection in implant dentistry.

6. Clinical Implication

These findings underscore the importance of minimizing contamination during implant placement and leveraging saliva's lubricative properties. However, the choice of lubricant or surface treatment must be tailored to optimize implant stability while mitigating adverse effects from other contaminants. Standardized protocols and rigorous clinical practices can further reduce complications associated with torque loss.

7. Limitations

This meta-analysis is limited by the heterogeneity in torqueing protocols, types and concentrations of contaminants, and measurement timing across studies. Some studies lacked detailed reporting of standard deviations, reducing the ability to perform certain analyses such as publication bias testing. The inclusion of only in vitro data limits generalizability to clinical settings. Despite these limitations, this review provides a comprehensive comparison of contaminant effects on reverse torque values.

8. Conclusion

This review highlights the substantial influence of contaminants on RTVs, with saliva demonstrating the highest torque-retaining capacity among all tested

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conditions. These findings emphasize the critical need for meticulous clinical protocols to control contamination and optimize implant stability. Future research should focus on long-term in vivo studies and the development of advanced surface treatments to mitigate the adverse effects of specific contaminants.

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