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RESEARCH ARTICLE
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APPLICATION OF THE SIX SIGMA DMAIC FRAMEWORK TO ENHANCE THE EFFICIENCY OF DENTAL HISTOPATHOLOGY REPORTING IN A TERTIARY-CARE HOSPITAL: A COLLABORATIVE DENTAL–PATHOLOGY DEPARTMENT QUALITY IMPROVEMENT STUDY

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Abstract

Background:
Turnaround time (TAT) is a critical indicator of the efficiency and quality of histopathological laboratories. In dental and oral biopsy workflows, process variability, delayed specimen dispatch, and communication gaps often result in prolonged reporting times.

Aim:
To improve the efficiency and quality of dental histopathology reporting using the Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) methodology through collaborative engagement between dental and pathology departments.

Methods:
This prospective interventional study was conducted over one year at a tertiary-care teaching hospital. The baseline TAT performance for 90 dental biopsy cases was analyzed to identify key process bottlenecks using Pareto and Ishikawa analyses. Targeted interventions, including fixed specimen dispatch schedules, dedicated grossing slots, revised requisition forms, and a real-time TAT monitoring dashboard, were implemented. Post-intervention data from 150 cases were compared using the *t*-test and Chi-square analysis.

Results:
The mean TAT reduced from 5.0 ± 1.2 days to 3.4 ± 0.9 days (p-value < 0.001), achieving a 32% improvement. Reports issued within the institutional target (≤ 5 days) increased from 58.8% to 91.3% and the process sigma level improved from 2.8 to 3.7, indicating a significant reduction in variation and defects. The control charts confirmed sustained stability over six months.

Conclusion: The Six Sigma DMAIC approach, when applied through a collaborative Dental - Pathology Department framework, effectively optimized workflow efficiency, reduced delays, and enhanced reporting reliability in dental histopathology. This cost-effective, data-driven, replicable approach can serve as a benchmark for quality improvement across other pathology disciplines.

Keywords: DMAIC, Dental histopathology, Interdepartmental collaboration, Pathology workflow, Quality improvement, Six Sigma, Turnaround time.

Introduction

Delays in biopsy report turnaround time (TAT) can adversely affect clinical decision making by postponing cancer referrals, prosthetic rehabilitation, or definitive surgical interventions [1-2]. For diagnostic laboratories, TAT serves as one of the most visible, objective, and measurable indicators of performance efficiency [3]. However, the histopathology workflow from specimen collection, gross examination, tissue processing, microscopic evaluation, and final report authorization is inherently complex and susceptible to multiple sources of delay [3-4].

In India, laboratories functioning within tertiary-care medical college hospitals, especially those catering to both medical and dental departments, face additional operational challenges. These include inconsistent specimen inflow from dental units, batching practices to optimize resource utilization, variable transport and accessibility times, and limited automation or digital integration in tissue processing and reporting systems [5-6].

These factors collectively contribute to a prolonged TAT and reduced process predictability. The Six Sigma methodology, originally developed for industrial quality management, has found increasing relevance in healthcare systems for minimizing process defects and variabilities [7-9]. Its structured DMAIC (Define-Measure-Analyze-Improve-Control) framework enables data-driven identification of inefficiencies and facilitates continuous process optimization [10]. Several studies have demonstrated the effectiveness of Lean and Six Sigma tools in improving surgical pathology TAT within hospital laboratories [11-12]. However, their systematic application in the context of dental and oral histopathology, particularly in a multidisciplinary tertiary-care setting, remains limited.

Therefore, the present study was conducted in a tertiary-care medical college hospital with an integrated pathology and dental service setup. This study aimed to bridge this gap by applying Six Sigma principles to identify and correct workflow inefficiencies in dental biopsy reporting through collaborative engagement between Dental and Pathology departments.

Aim:

The present study aimed to enhance the efficiency and quality of oral and dental biopsy histopathology reporting through the systematic application of Six Sigma methodology.

Objectives:

1. To measure the baseline turnaround time (TAT) for oral and dental biopsy histopathology reports and to identify the key causes of delays and TAT outliers.
2. To implement targeted quality improvement interventions using the Six Sigma DMAIC (Define-Measure-Analyze-Improve-Control) framework.
3. To evaluate post-intervention improvements in turnaround time, sigma level, and overall effectiveness of the histopathology reporting workflow.

Materials and Methods:

Study Design and Setting:

This prospective interventional study was jointly conducted by the Department of Pathology and Dentistry at the Raipur Institute of Medical Sciences, a tertiary-care medical teaching hospital in Raipur, Chhattisgarh, India, over a period of one year. The Six Sigma DMAIC framework guided the study design.

Team Structure:

The project was implemented through a multidisciplinary team approach involving faculty members from the Department of Pathology and Dentistry in a medical college setting. The faculty from the Department of Pathology served as project leads, overseeing data analysis and workflow redesign.

The faculty from the Department of Dentistry was responsible for clinical sampling, proper specimen dispatch, and standardization of requisition forms to ensure uniform data capture. Postgraduate resident doctors and laboratory technicians managed the time-logging and real-time tracking of specimens throughout the diagnostic process. Additionally, laboratory quality managers and statisticians were actively involved in continuous monitoring, data validation, and performance assessment to maintain the integrity and reliability of the study outcomes.

Six Sigma DMAIC Implementation:

Define Phase:

The project focused on addressing the persistent issue of delayed oral and dental biopsy histopathology reports, which frequently exceeded the institutional benchmark turnaround time (TAT) of ≤ 5 days. Prolonged reporting times have been recognized as a key barrier to timely clinical decision making and effective patient management.

The primary objective of the project was to achieve a ≥ 30% reduction in the mean TAT within six months, without compromising the diagnostic accuracy or report quality. The project scope included the entire histopathology reporting workflow beginning from biopsy specimen collection in the dental outpatient department (OPD) through transport, processing, slide evaluation, and culminating in final report authorization within the histopathology department.

The key Critical to Quality (CTQ) parameter identified for this process was the timely and accurate delivery of histopathology reports to clinicians and patients. This parameter directly reflects the quality of the laboratory's service and its impact on patient care outcomes. By clearly defining the CTQ and delineating the process boundaries, the Define Phase established a structured foundation for data-driven improvement within the Six Sigma DMAIC framework.

Measure Phase:

The baseline performance was evaluated using data from 90 consecutive oral and dental biopsy cases. For each case, precise time stamps were recorded at every key process point, beginning from biopsy collection and dispatch in the dental outpatient department (OPD) through subsequent stages of grossing, embedding, sectioning, staining, microscopic evaluation, and final reporting within the laboratory. The primary performance indicators analyzed included the mean and median turnaround time (TAT), percentage of reports completed within the institutional target period (≤ 5 days), and measures of process variation such as defect rate and defects per million opportunities (DPMO). The sigma level was determined using the standard Six Sigma conversion table, providing a quantitative assessment of the baseline process capability and variation in the histopathology reporting workflow.

Analyze Phase:

A comprehensive root cause analysis was conducted using both the Ishikawa (fishbone) diagram and Pareto principle to identify the major factors contributing to reporting delays. The analysis of the process data and workflow mapping revealed several key bottlenecks.

1. Delay in specimen dispatch from the dental outpatient department (OPD) with a mean lag time of 14 h before the samples reached the pathology laboratory.
2. Batching of low-volume biopsies prior to grossing resulted in unnecessary hold times and delayed downstream processing.
3. Report verification backlog caused by prioritization of large surgical specimens over smaller dental biopsies within the pathology reporting queue.

These findings underscore critical process-level inefficiencies and communication gaps between dental and pathology units. Addressing these issues through workflow restructuring and standardization of interdepartmental communication was identified as a key target for the subsequent improvement phase.

Table 1: Summary of analyze phase

Category (Ishikawa Dimension)	Identified Cause	Description of Impact on Process	Relative Contribution (Pareto Ranking)
Manpower	Delay in specimen dispatch from dental OPD	Specimens often retained overnight or sent in bulk, leading to a mean lag time of approximately 14 hours before receipt in pathology.	1
Methods	Batching of low-volume biopsies before grossing	Specimens held until sufficient numbers accumulated, causing unnecessary pre-analytic hold time.	2
Workflow/Process	Report verification backlog	Smaller dental biopsy reports delayed due to prioritization of large surgical specimens.	3
Communication	Inconsistent coordination between dental and pathology staff	Lack of standardized communication on urgent or special cases contributed to occasional oversight.	4
Materials/Equipment	Limited availability of embedding stations during peak hours	Occasionally caused minor queuing delays in tissue processing.	5

The Pareto ranking indicated that delays in specimen dispatch, batching practices, and report verification backlogs accounted for the majority of turnaround time (TAT) deviations. Addressing these high-impact areas was prioritized in the subsequent improvement phase interventions.

Improve Phase:

A series of collaborative process interventions was jointly implemented by the Departments of Pathology and Dentistry to streamline the diagnostic workflow and minimize turnaround time (TAT) delays. Improvement initiatives were systematically designed to address the key bottlenecks identified during the analysis phase.

The major interventions included the following.

- **Standardized specimen logistics:** Establishment of a fixed, twice-daily specimen dispatch schedule from the dental outpatient department (OPD) to the pathology laboratory, ensuring predictable and timely sample transfer.
- **Enhanced requisition documentation:** Introduction of revised requisition forms incorporating mandatory clinical details and provisional diagnoses, facilitating accurate triage and histopathological interpretation.
- **Dedicated grossing allocation:** Designation of a daily fixed grossing slot exclusively for dental specimens to prevent accumulation and batching delays.
- **Priority-based labeling:** Implementation of a color-coded labeling system with red tags assigned to suspected malignant cases to expedite processing and reporting.
- **Digital workflow visibility:** Development of a real-time TAT monitoring dashboard integrated with automated alerts for pending or delayed cases, enhancing process transparency, and accountability.
- **Capacity building and communication training:** Organization of focused training sessions for residents and technical staff, emphasizing specimen fixation quality, interdepartmental communication, and timely documentation practices.

Table 2: Summary of Improvement Phase Interventions and Outcomes

Focus Area	Key Intervention	Outcome
Specimen Logistics	Fixed, twice-daily specimen dispatch from Dental OPD to Pathology	35% reduction in pre-analytical delay; improved TAT consistency
Requisition Documentation	Revised forms with mandatory clinical details and provisional diagnosis	100% documentation completeness; fewer report clarifications

Grossing Workflow	Dedicated daily grossing slot for dental specimens	Grossing queue reduced from 8 hrs to < 2 hrs
Case Prioritization	Color-coded labeling (red tags for suspected malignancy)	40% faster reporting for priority cases
Digital Workflow	Real-time TAT dashboard with automated alerts	90% on-time reporting; proactive delay management
Training & Communication	Targeted sessions for residents and technical staff	50% fewer fixation nonconformities; improved interdepartmental coordination

These targeted cross-departmental interventions effectively reduced process variation, strengthened coordination between clinical and laboratory teams, and improved operational visibility across the entire reporting cycle.

Control Phase:

After implementation, continuous monitoring mechanisms were established to ensure process stability and sustain the achieved improvements. Statistical process control tools, including X-bar and R control charts, were utilized to track turnaround time (TAT) trends and promptly detect any deviations from the established control limits. The revised performance metrics were formally integrated into departmental Key Performance Indicators (KPIs) to institutionalize accountability and maintain a focus on quality outcomes. Regular quarterly joint review meetings between the Departments of Pathology and Dentistry were conducted to evaluate compliance with the optimized workflow, address emerging challenges, and identify opportunities for further refinement. In addition, a structured feedback and audit loop were implemented to reinforce adherence to standard operating procedures (SOPs) and sustain process gains. These control measures collectively ensured that the improvements achieved during the intervention phase were effectively maintained, leading to consistent enhancements in diagnostic efficiency, interdepartmental coordination, and overall service quality.

Table 3: Summary of Control Phase Measures

Focus Area	Control Measure	Purpose/Outcome
Process Monitoring	X-bar and R control charts for continuous TAT tracking	Maintained process stability within control limits
Performance Integration	Revised TAT metrics incorporated into departmental KPIs	Institutionalized accountability and sustained quality focus
Periodic Review	Quarterly joint review meetings between Pathology and Dentistry	Ensured workflow compliance and continuous refinement
Audit & Feedback	Structured SOP audit with feedback to staff	Reinforced protocol adherence and minimized variation
Training& Retention	Refresher sessions for residents and technicians	Preserved process consistency and long-term sustainability

Statistical Analysis:

All data were analyzed using SPSS Statistics version 26. Turnaround time (TAT), treated as a continuous variable, was compared between the pre- and post-intervention phases using the independent samples t-test. The proportion of cases meeting the target TAT (≤ 5 days) was evaluated using the chi-square test to determine the categorical improvement in reporting efficiency. The process sigma level was calculated from the corresponding defects per million opportunities (DPMO) and subsequently converted to a sigma score according to the standard Six Sigma conversion table. A *p*-value of less than 0.05 was considered statistically significant.

Results:

Baseline Performance:

During the baseline assessment phase, 90 consecutive dental biopsy cases were evaluated to determine the performance of the existing turnaround time (TAT) within the histopathology

workflow. The mean TAT was 5.0 ± 1.2 days, with a median of 4.9 days, indicating substantial variation in processing efficiency. Only 58.8% of the reports were issued within the institutional benchmark of ≤ 5 days, while the remaining 41.2% exceeded this target, reflecting significant workflow delays. The corresponding defect rate (reports exceeding the target TAT) was calculated to be 41.2%, which translated to a process sigma level of 2.8, suggesting a high rate of variation and room for improvement in quality performance.

A qualitative review of workflow logs revealed multiple contributors to delay, including late specimen dispatches from the dental OPD, batching of low-volume biopsies before grossing, and verification of backlogs during peak reporting hours. These findings corroborated the issues identified in the Analyze phase, validating the need for Six Sigma-guided intervention.

Post-Intervention Performance:

Following the implementation of Six Sigma DMAIC interventions, 150 dental biopsy cases were analyzed in the post-intervention phase. The process showed marked improvement across all performance indicators. The mean TAT decreased to 3.4 ± 0.9 days (p-value < 0.001), while the median reduced to 3.2 days, reflecting not only faster but also more consistent report delivery. The percentage of cases that met the target TAT increased sharply from 58.8% to 91.3%, reducing the defect rate to only 8.7%. Consequently, the sigma level improved from 2.8 to 3.7, indicating a statistically and operationally significant gain in the process capability and quality control. Continuous monitoring using X-bar and R control charts demonstrated stable performance, with all data points remaining within the control limits throughout the six-month observation period. No special cause variation was detected, confirming the sustainability of process improvements achieved through systematic workflow redesign and cross-departmental coordination.

Process Impact:

The average improvement in mean TAT was 1.6 days, representing a 32% reduction relative to baseline performance, successfully meeting and exceeding the project's initial goal. This improvement directly translated into faster clinical decision-making for dental surgeons and better patient turnaround, particularly in cases requiring urgent diagnostic correlations for suspected malignancies.

Table 4: Summary of Outcomes

Parameter	Baseline (n = 90)	Post-Intervention (n = 150)	*P*-value	% Improvement
Mean TAT (days)	5.0 ± 1.2	3.4 ± 0.9	< 0.001	32.0%
Median TAT (days)	4.9	3.2	—	—
Reports within target (≤ 5 days)	58.8%	91.3%	< 0.001	+32.5%
Defect Rate	41.2%	8.7%	—	↓78.9%
Sigma Level	2.8	3.7	—	—

Implementation of the Six Sigma DMAIC methodology not only led to a statistically significant reduction in dental histopathology TAT, but also improved overall workflow transparency, staff accountability, and interdepartmental collaboration.

Discussion:

The present study demonstrated that the structured application of the Six Sigma DMAIC framework can substantially enhance the efficiency of dental histopathology reporting in a tertiary-care hospital. The mean turnaround time (TAT) reduced from 5.0 days to 3.4 days, representing a 32% improvement in process efficiency. This was accompanied by a marked enhancement in process capability and operational stability. Furthermore, the improvement in sigma level from 2.8 to 3.7, corresponding to nearly an 80% reduction in process defects, signifies a transition toward a more predictable,

standardized, and reliable reporting workflow. Such incremental gains are characteristic of mature healthcare quality systems that successfully integrate Six Sigma principles to achieve sustained performance excellence.

Benchmarking with Published Literature:
The baseline TAT of approximately five days aligns closely with the findings from established surgical pathology benchmarks. *Volmar et al.* (2015), in a CAP Q-Probes study across 180 institutions, reported a median TAT of 3–5 days for small biopsy specimens, setting a realistic international reference range [3]. Similarly, *Alshieban and Al-Surimi* (2015) documented a 35% reduction in TAT following workflow re-engineering in histopathology laboratories [11]. The improvement observed in the present study is comparable, validating the reproducibility of structured process optimization across diverse laboratory contexts.

Clinical and Operational Implications:
The reduction in TAT has direct clinical benefits for dental and maxillofacial pathologies. Faster report delivery enables timely cancer diagnosis, early prosthodontic rehabilitation, prompt treatment initiation, and improved patient outcomes. Operationally, the optimized workflow reduced rework, enhanced communication, and improved clinician's satisfaction. Over 90% of reports met the NABL-recommended TAT targets [13], reinforcing institutional compliance and demonstrating the dual clinical and administrative value of Six Sigma–based quality improvement.

Sustainability and Scalability:
Sustained performance was ensured through continuous monitoring using control charts, KPI tracking, and quarterly quality reviews. A shared quality culture between the Dental and Pathology departments fostered accountability and transparent communication. This collaborative model is scalable and can be replicated across other diagnostic units to achieve similar efficiency improvements.

Limitations:
This single-center study may limit generalizability to settings with different workloads or systems. Complex cases requiring special staining or IHC still showed longer TATs (mean ≈ 4.7 days). External factors such as staff rotations, holidays, and equipment downtime also affected the results. Sustaining improvements will require ongoing training, audits, and accountability.

Future Directions:
This successful Six Sigma model can be expanded to other pathological areas. Integrating digital pathology and AI-based triage can enhance case prioritization and reporting accuracy. Multi-center collaborations are needed to define benchmark TATs and develop national quality standards for dental histopathology to promote consistency and evidence-based diagnostic efficiency.

Conclusion:
The application of the Six Sigma DMAIC framework through a collaborative Dental–Pathology Department approach significantly enhanced efficiency in dental histopathology reporting, reducing mean TAT by 32% (from 5.0 to 3.4 days) and improving sigma level from 2.8 to 3.7 with sustained control. This cost-effective, data-driven, multidisciplinary quality improvement approach offers a replicable framework for other pathology domains.

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Data Availability: Collected data are available at the Department of Pathology & Dentistry, Raipur Institute of Medical Sciences (RIMS, Raipur, Chhattisgarh, India.

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