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ORIGINAL REPORT: HEALTH SERVICES RESEARCH

Finding Dental Harm to Patients through Electronic Health Record–Based Triggers

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Abstract: ***Background:*** *Patients may be inadvertently harmed while undergoing dental treatments. To improve care, we must first determine the types and frequency of harms that patients experience, but identifying cases of harm is not always straightforward for dental practices. Mining data from electronic health records is a promising means of efficiently detecting possible adverse events (AEs).*

Methods: *We developed 7 electronic triggers (electronic health record based) to flag patient charts that contain distinct events common to AEs. These electronic charts were then manually reviewed to identify AEs.*

Results: *Of the 1,885 charts reviewed, 16.2% contained an AE. The positive predictive value of the triggers ranged from a high of 0.23 for the 2 best-performing triggers (failed implants and postsurgical complications) to 0.09 for the lowest-performing triggers. The most common types of AEs found were pain (27.5%), hard tissue (14.8%), soft tissue (14.8%), and nerve injuries (13.3%). Most AEs were classified as temporary harm (89.2%). Permanent harm was present in 9.6% of the AEs, and 1.2% required transfer to an emergency room.*

Conclusion: *By developing these triggers and a process to identify harm, we can now start measuring AEs, which is the first step to mitigating harm in the future.*

Knowledge Transfer Statement: *A retrospective review of patients' health records is a useful approach for systematically identifying and measuring harm. Rather than random chart reviews, electronic health record–based dental trigger tools are an effective approach for practices to identify patient harm. Measurement is one of the first steps in improving the safety and quality of care delivered.*

Keywords: patient safety, adverse events, trigger tool, dentistry, EHRs, informatics

Introduction

Studies in medicine have demonstrated that health care is one of the least safe industries in the world (Hudson 2003). Medical adverse events (AEs) are one of the leading causes of death in the United States and have gained prominent attention from academic, health care, and government institutions and organizations (Kizer and Blum 2005). But patient safety is largely an uncharted territory for the dental profession. In our prior review of the Food and Drug Administration's MAUDE database (Manufacturer and User Facility Device Experience; Hebballi et al. 2015) and the literature (Obadan et al. 2015), we identified reports of injuries, including aspiration (Weiman et al. 1995), edema due to sodium hypochlorite extrusion (Spencer et al. 2007), sublingual thrombosed vein secondary to dental handpiece laceration during dental treatment (Dhanda et al. 2008), and death (Hebballi et al. 2015). Within this review, we identified 182 publications that contained 270 cases (Obadan et al. 2015) of harm to patients associated with dental treatment. Within the MAUDE database, we found that 28,046 (1.4%) of reports made between January 1, 1996, and December 31, 2011, involved dental

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A supplemental appendix to this article is available online.

devices (Hebballi et al. 2015). Published dental AEs highlight the harms that may occur in the dental office. Although we know that dental harms occur, they are difficult to detect. Despite several calls to action (Ramoni et al. 2012; Yamalik and Perea Perez 2012; Bailey et al. 2014), dental patient safety is still in its infancy.

Identifying harm is the first step to improving the quality and safety of oral health care. A retrospective review of patients' health records is a useful approach for systematically identifying and measuring harm. As it is not time efficient to audit all patient charts, a random sample is often selected for review. Due to the small yield with this approach, the Institute for Healthcare Improvement (IHI) developed the strategy of employing global trigger tools (Resar et al. 2003; Classen et al. 2008) to identify charts that are more likely to contain an AE.

Electronic health record (EHR)–based triggers have been widely used in medicine in both inpatient (Hibbert et al. 2016) and outpatient (Cantor et al. 2007) settings to detect AEs in a variety of areas, including diagnostic errors (Murphy et al. 2019), adverse drug events (Lim et al. 2016), delayed follow-up of abnormal radiology findings (Murphy et al. 2016), and harm in pediatric hospitalized patients (Stockwell et al. 2015). Our pilot studies have also revealed the feasibility of using triggered electronic dental patient charts to detect AEs (Kalenderian et al. 2013; Kalenderian et al. 2018).

In this research project, we developed and implemented 7 triggers across 4 large academic dental institutions to determine 1) how well the triggers performed in finding AEs and 2) what characteristics dental AEs had in terms of type and severity.

Methods

Trigger Implementation

In our prior work, we developed and assessed the feasibility of 11 dental triggers (Kalenderian et al. 2018). Given their performance during our feasibility tests, we picked 7 of the best-performing triggers and further adapted them for this study. Appendix 1 shows the description and detailed specifications of the triggers. Each of these triggers was implemented in the axiUm EHR used by all 4 academic dental institutions. The triggers were implemented with structured query language and run against the institutional EHRs. The triggers relied on structured data, such as dental procedure codes (Current Dental Terminology) and medications documented to be taken by the patient. Some triggers also searched for keywords in the clinical notes, such as "paresthesia" to find nerve injuries. For these triggers, clinical team members identified keywords for inclusion. We used an iterative process to run the triggers, review a small sample of the resulting charts, and further refine the triggers. Through this development process, we discovered that sometimes these keywords led to charts being triggered in the wrong context—for example, when these keywords were used to describe possible risks ("risks include paresthesia") or an absence of a finding ("no" paresthesia). To exclude these cases, we included negation phrases in the trigger algorithm. After each trigger was executed, a list of patient charts meeting those criteria over a 1-y period was provided to the chart reviewers for further investigation.

Chart Review Process

In the original IHI global trigger tool (Resar et al. 2003; Classen et al. 2008), a random set of paper charts would first be identified and screened for the presence of triggers by trained nurses. Once triggers were found, physicians would then review those charts to determine if any AEs were present. We adapted the IHI Global Trigger Tool methodology and took advantage of the presence of a searchable EHR. We first used an automated trigger query to identify a set of patient charts that met the designated criteria. Two independent chart reviewers at each site then reviewed a random sample of triggered charts to determine the presence or absence of a dental AE. To estimate the projected number of triggered charts needed to review, we apply the sample size formula for proportions using initial values derived from pilot data. The sample size was calculated with the estimated proportion of triggered AEs, a significance level of $\alpha = 0.05$ with a 2-tailed z value of 1.96, a standard margin for error of $d = 0.05$ for each trigger, and the triggered population.

Reviewers at each site convened to reach a consensus on every AE identified and used a REDCap form (Harris et al. 2009) to input their findings. To confirm our findings, we implemented a second level of review by an expert panel composed of calibrated investigators from each site. They first independently reviewed the AEs found during the individual site review; then, they met as a group and adjudicated every AE to make a final determination.

On the basis of our prior pilot testing (Kalenderian et al. 2018), we developed a definition for AEs and a set of reviewer guidelines to assist in the identification of AEs for the individual site reviewers and the expert panel (see Appendix 2). Once an AE was identified, reviewers categorized it by type (using a list of 12 items) and severity (using a 5-item scale; see Appendix 3).

Data/Statistical Analysis

To determine the performance of each trigger, we calculated the positive predictive value, which measured the likelihood of observed AEs among the triggered population. We reported the results of the positive predictive value to assess the continued validity of the triggers with the corresponding estimates of precision (95% CIs and standard errors). Our primary outcomes of interest were the total number of observed AEs related to each trigger over the total number of patient charts reviewed, the AE type, and the AE severity. We reported the frequency and percentage contribution for each outcome. All statistical analyses were performed with Stata 15 (StataCorp LP).

The study was approved by the institutional review boards of all participating institutions.

Table 1.
Performance of the Triggers to Identify Dental Adverse Events.

Trigger Name	Charts, *n*		Total AEs, *n*		Charts with AE: Phase 2, *n*	PPV
	Triggered	Reviewed	Phase 1	Phase 2		
Failed implants	238	196	86	48	46	0.23
Postsurgery complications	617	363	121	89	83	0.23
Soft tissue injury	1,038	285	63	52	50	0.18
Nerve injury	1,052	477	93	76	70	0.15
Extraction following RCT, crown, filling	264	173	40	23	20	0.12
Allergy, toxicity, foreign body	273	215	24	20	20	0.09
Aspiration/ingestion of foreign body	176	176	63	16	16	0.09
Total	3,658	1,885	490	324	305	

AE, adverse event; PPV, positive predictive value; RCT, root canal treatment.

Results

In total, 3,658 patient charts were identified by the 7 triggers (see Table 1). A random sample of 1,885 charts were reviewed, and 305 charts (16.2%) contained an AE. In some cases, multiple AEs were found in the same chart, yielding a total of 324 AEs. The individual site reviewers initially identified 490 AEs. The expert panel that further reviewed each of these events determined that 66% (n = 324) were actually AEs.

As shown in Table 1, the performance of the triggers (measured by positive predictive value) ranged from a high of 0.23 for our 2 best-performing triggers (failed implants and postsurgical complications) to 0.09 for our lowest-performing triggers (allergy/toxicity and aspiration/ingestion).

The most common types of AEs found were pain (27.5%), hard tissue (14.8%), soft tissue (14.8%), and nerve injuries (13.3%; Table 2). The least common AEs detected were those relating to wrong site, wrong patient, or wrong procedure (0.6%).

Table 3 shows the severity of the AEs. Most were classified as temporary harm (89.2%). Permanent harm was present in 9.6% of the AEs, and 1.2% required transfer to an emergency room.

There was also wide variation in the types of AEs detected by each trigger (see Table 4). The AE type *pain* was detected by multiple triggers, including postsurgical complications and nerve injury, while *nerve injuries* were detected mainly through the nerve injury trigger.

Discussion

We developed, implemented, and assessed 7 EHR-based triggers to identify dental AEs documented in EHRs at 4 dental institutions. After manually reviewing 1,885 charts, we found that 324 contained a dental AE. Taken individually, these triggers had success rates ranging from 23% to 9% in detecting AEs. Our triggers therefore have a relatively low predictive value, which means that many triggered charts did not contain an AE. A low positive predictive value may result in alarm/alert fatigue and is burdensome to chart reviewers (Call et al. 2014; Musy et al. 2018). While the performance of these triggers is lower than those developed in medicine (Musy et al. 2018), they are still far superior to random chart reviews, where we estimate that only 1.5% contain AEs (unpublished data). Triggers are opportunities or clues in a patient's EHR that may indicate harm to a patient. Triggers themselves do not represent an AE but are designed to detect different types of AEs. For example, the postsurgical complications trigger flagged patients who either came back for an unscheduled visit or were prescribed medications after going home but within a week of a surgery. This trigger detected 10 types of AEs, including pain, infections, and nerve injuries. Other triggers were designed for specific purposes. For example, the soft tissue injury trigger searched patients notes for keywords such as "burn," "canker sore," "hematoma," "laceration," and "ulcer" and predictably found soft tissue injuries and associated AEs, such as pain and bleeding.

The current research extends our prior pilot work (Kalenderian et al. 2013; Kalenderian et al. 2018). In this study we updated the trigger logic, selected 7 of the better-performing triggers, and reviewed a larger and statistically appropriate sample of charts to better estimate the performance of each trigger. Our findings showed the reproducibility of the approach. We did, however, find differences in the distribution of the

Table 2.
Categorization of the Dental Adverse Events.

Adverse Events		Examples
Category	***n* (%)**	
Pain	89 (27.5)	PT had RCT on No. 18 and reported pain lasting all day since RCT started. PT takes 5 Advils per day and claims that he feels pain *all* the time.
Hard tissue injury	48 (14.8)	Furcation perforation of tooth No. 3 during pulpectomy procedure; tooth was nonrestorable, and pulpectomy was completed to alleviate an infection. Tooth is going to be extracted.
Soft tissue injury	48 (14.8)	Gingival flap surgery was completed on Nos. 4 to 6 region. Postoperative visit reveals that PT lost sutures 3 d in the surgical areas of Nos. 4 to 6 and tenderness to palpation. Visual examination reveals a 15-mm-diameter exposure of connective tissue and a 3-mm exposure of palatal bone near No. 4. Slight tissue necrosis was noted. Preoperative radiograph reveals vertical bone loss of Nos. 5 and 6 with No. 4 missing. No. 5 has a bone loss of about 3 mm on distal side and about 5.5 mm on medial side. No radiograph was taken after surgery or at postoperative visit.
Nerve injury	43 (13.3)	No. 18 was determined to be a nonrestorable carious tooth and was extracted. During follow-up visit, PT complained of numbness and tingling of her lower lip region and numbness in the posterior left mandibular region. At second-week follow-up visit, PT reported occasional aching sensation to lower left lip.
Infection	36 (11.1)	Implant on No. 21 was placed, with infection and pus noticed in that area. Antibiotics prescribed and No. 21 was healing well.
Other orofacial harm	17 (5.2)	Implant failed Nos. 2 to 4. Implant removed. Implant caused granulation tissue and maxillary sinus communication and bony defect.
Bleeding	14 (4.3)	PT had tooth No. 3 extracted in morning by outside clinic. PT presented to our emergency clinic in the afternoon complaining that area is profusely bleeding. On examination, area No. 3 shows torn gingival tissue and is actively oozing blood.
Allergy, toxicity, foreign body response	13 (4.0)	Extraction of Nos. 18, 20, 22, 29, and 31 was performed and prescriptions for penicillin VK and hydrocodone 5/325 were written. PT called emergency line stating that he had woken up in the morning feeling itchy and noticed that he was bright red all over his body. Postoperative day 2 status post multiple dental extractions. PT stated that he had been given Vicodin and penicillin VK, with no history of prior allergy. Provider told PT that he should take over-the-counter antihistamine and observe if rash resolves. If he does not improve, he should present to the emergency room or primary care physician for evaluation. If at any point he develops difficulty breathing or swallowing, he should report to ED immediately. A prescription was phoned in for erythromycin and later changed to clindamycin due to cost.
Other systemic harm	9 (2.8)	Under general anesthesia, PT had undergone extraction of Nos. 1, 16, 17, and 32. PT then underwent surgical exposure of Nos. 30 and 31. PT's mother called to report that PT's right arm was slightly swollen and face was swollen, and she thought that she heard some wheezing. PT had vomited 4 times since surgery. Due to concern about possible allergic reaction to Lortab and dehydration, provider asked PT to go to ED.
Aspiration/ ingestion of foreign body	5 (1.5)	During oral prophylaxis, ultrasonic scaler tip fractured, and PT may have swallowed or aspirated the scaler tip. PT was immediately rushed to ED. KUB radiograph revealed a radiopaque foreign object in the area of the duodenum, measuring approximately 1 cm. PT was informed that her airways were clear and that she will pass the foreign body.
Wrong-site, wrong-procedure, wrong-patient errors	2 (0.6)	Root canal cavity preparation was completed on No. 18 instead of No. 19. No. 18 now needs RCT and postoperative buildup and crown
Other harm	0	—
Total	324	

ED, emergency department; KUB, kidney, ureter, and bladder; PT, patient; RCT, root canal treatment.

Table 3.
Severity of the Dental Adverse Events.

Severity	*n* (%)
Temporary minimal harm (E1)	176 (54.3)
Temporary moderate to severe harm (E2)	113 (34.9)
Requires transfer to an emergency room (F)	4 (1.2)
Permanent minimal harm (G1)	24 (7.4)
Permanent moderate to severe harm (G2)	7 (2.2)
Total	324

types of AEs. For example, in prior work, 57% of the AEs found were classified as pain, as opposed to 28% in our current work. The discrepancy may be explained by the fact that we reviewed a larger number of charts in this study, and our chart reviewers also included AEs with severity ratings of temporary minimal and permanent minimal harm. In prior work, we focused on events that were moderate to severe.

A limitation of our study is that we did not identify why charts were falsely triggered. Although this is an improvement over the current practice of conducting random chart audits or relying solely on reported events, improving the predictive value will have many benefits, including the better use of human resources. In future work, we expect to improve the performance of the triggers by first conducting an error analysis on those charts that are falsely triggered. After systematically understanding why these charts are triggered, we expect to be able to identify additional criteria that can be used to improve the predictive value. We also plan to improve trigger performance by exploring the use of natural language processing approaches (Patel et al. 2018). For example, we may reduce the number of false-positive charts triggered by using existing and validated negation algorithms, such as NegEx (Chapman et al. 2001). Once we have collected

Table 4.
Types of Adverse Events Detected by Each Trigger.

Category	Trigger, *n*							
	Failed Implants	Post-surgery Compli-cations	Soft Tissue Injury	Nerve Injury	Extraction Following RCT, Crown, Filling	Allergy, Toxicity, Foreign Body	Aspiration / Ingestion of Foreign Body	Total
Pain	2	40	6	22	12	3	4	89
Hard tissue injury	32	4	2	4	5	0	1	48
Soft tissue injury	0	9	27	5	0	2	5	48
Nerve injury	2	7	2	31	0	1	0	43
Infection	9	15	3	6	2		1	36
Other orofacial harm	2	5	4	2	2	1	1	17
Bleeding	0	5	5	3	0	0	1	14
Allergy, toxicity, FB response	0	1	2	1	0	9	0	13
Other systemic harm	1	2	1	2	0	2	1	9
Aspiration/ingestion of FB	0	0	0	0	2	1	2	5
Wrong-site, wrong-procedure, wrong-patient errors	0	1	0	0	0	1	0	2
Other harm	0	0	0	0	0	0	0	0
Total	48	89	52	76	23	20	16	324

FB, foreign body; RCT, root canal treatment.

a large-enough data set, we expect to explore the use of machine learning algorithms to better detect AEs from dental health records (Wei et al. 2019).

Dental trigger tools can be used by practices interested in measuring their AE rates. Consistent measurement is the first step toward improvement. While the trigger tools may be used individually, we recommend that all 7 triggers be deployed at once to increase the number of AEs detected. While the triggers were developed for the axiUm EHR, we are confident that the logic provided (see Appendix 1) can be adapted for use in other EHRs. We also expect that the number and type of AEs detected will be more meaningful when the triggers are consistently run over time. While finding a few AEs might be informative, when we study them longitudinally, we gain the opportunity to discover the patterns and "hot issues." That is when we think about the underlying systems that could be ripe for improvement.

As our study was multi-institutional, we found the use of a 2-step process—in which local reviewers first identified AEs, which were then adjudicated by reviewers from all sites—a valuable approach to calibrate reviewers and ensure that the same standard and perspective were applied across all sites. Through this process, 66% of the AEs found by the local reviewers were upheld. We recognize that the use of an external expert panel may not be feasible for some individual practices seeking to use the dental trigger tools. In these cases, the phase 1 review would be sufficient, especially if the intent is not to compare the AE rate with that of other institutions. In addition, it is important that the individual chart reviewers are well calibrated in detecting AEs consistently over time. We have developed online training material that can be used to help train chart reviewers (https://uth.instructure.com/courses/16371).

Our results of deploying the dental trigger tool across the 4 institutions suggest that patients do suffer harm in the dental setting. We found that pain, soft tissue, hard tissue, and nerve injuries were the most common. Pain has been described in the medical literature as a "neglected" AE. Although pain is difficult to measure and sometimes expected after many dental procedures, we determined it to be an important AE type to capture. Our reviewers were provided specific guidelines to include pain as an AE when it met a specific threshold. In future work, we are further analyzing the pain AE to its sequelae and management.

While measurement is important, it is only one of the first steps in improving the safety and quality of care delivered. Now that we know the types of harm that can occur and we have a mechanism to measure them, the next step is to determine why they occur. Root cause analysis is a promising tool to use (Wu et al. 2008). Once we have identified the contributing factors, we can then develop interventions to prevent them in the future.

Conclusion

Identifying harm is the first step to improving the quality and safety of oral health care. By developing 7 specific triggers and a process to identify harm, we were able to measure AEs in dental EHRs, which is one of the first steps to mitigating harm in our dental patients.

Author Contributions

M.F. Walji, contributed to conception, design, data acquisition, analysis, and interpretation, drafted the manuscript; A. Yansane, J. White, contributed to conception, design, data analysis, critically revised the manuscript; N.B. Hebballi, A.M. Ibarra-Noriega, K.K. Kookal, S. Tungare, K. Kent, R. McPharlin, V. Delattre, E. Obadan-Udoh, O. Tokede, contributed to data analysis, critically revised the manuscript; E. Kalenderian, contributed to conception, design, and data analysis, drafted the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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