

Review Article

Determining the feasibility of using the automated market basket analysis method to investigate a cause-and-effect pattern of construction accidents and its safety associations

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Abstract:

Construction sites are complex and dangerous. Over the past decade, construction fatality rates have been high in most countries. Construction accidents cause harm to construction workers and financial loss to construction firms. Smart wearable jackets are among the most effective personal protection equipment (PPE) for India's most recent and future generations. Prevention is better than Cure. To prevent the occurrences of construction accidents and to provide better safety and health to construction workers, the sensor data has to be collected from the IoT environment and has to make it subjected to cloud-based big data analytics to provide better decision support to project managers and doctors. Further, the decision support system can be enhanced by adding semantic capabilities using Ontology, Semantic Web Services, and data mining and artificial intelligence techniques. This study highlights the feasibility of using the automated market basket analysis method to investigate the cause-and-effect pattern of construction accidents, especially when using the Apriori algorithm to extract frequent item set associations. Data File preparation is one of the most essential and significant modules of incorporating automation. Therefore the value of this research effort lies in preparing a sample database and how such a sample database can become helpful in construction safety and health management to prevent accidents, as well as the computations of measures of the Apriori algorithm that support decisions regarding construction safety and health provision to construction supervisors and managers are explained.

Keywords: Apriori Algorithm, Association Rule Mining, Construction Health Management, Construction Safety Management, Frequent Item Set Generation, Investigating cause-and-effect patterns

1. INTRODUCTION

Construction sites are complex and dangerous. Construction fatality rates have been high over the past decade in most countries. [48]. Accidents on the construction sites cause physical harm to construction workers and financial loss to construction firms. One of the most influential personal protection equipment (PPE) in recent times is believed to be wearable jackets. Wearable jackets are cloud-connected devices that detect various hazards in the construction workplace by providing data transfer and information to support managing the impact of such construction-related threats [27].

[55] promoted Bening's Rapid prototyping-based design thinking methodology towards problem-solving and the microcontroller's control process feedback loop in passing. The IoT (Internet of Things) based prototyping has drawn the construction industry's attention to providing worker safety. As a part of the intelligent wearable jacket prototype development, sensors attached to wearable jackets worn by construction workers send the worker's health and safety data using IoT technology to conduct data analysis using cloud computing. If any abnormal conditions are found, the data report will be transferred to the construction manager and on-site or off-site doctor to take appropriate action on the worker's health condition [4] [57].

According to the research work conducted by [57], IoT may be attributed to a micro-controller-based prototyping platform of the author's contribution to developing CRASP methodology. The prototype, connected with a pulse sensor and button sensor, senses various health and safety parameters such as the construction worker's pulse rate, whether the push button of the helmet, which is associated with the belt being pushed properly to make it fasten or not. The status of these parameters is transmitted through Wi-Fi to a central computer at a base station along with the GPS location [3]. By adopting CRASP methodology and adding semantics to big data analytics-based decision support systems, semantic decision-making capability can be realized in the form of creating strategic value for the business [54].

2. LITERATURE REVIEW

The case study-based research work of [55] mentioned that by applying the Apriori algorithm as a part of libraries of Python programming, it is possible to mine the data items of retail purchases to elicit and indicate the patterns of retail purchase items and their associations during the customer visits at a grocery shop. They worked on a use case by accessing the GitHub sources for re-writing an existing Python program for generating output by actually working on the available data file of grocery purchase items that are already available.

Recently, [42] worked on the same kind of problems that mines the essential cause of different types of fatal construction accidents. [9] did similar work use association rules in Chinese construction safety management and decision support? Almost with the same idea, [37] investigated the causality patterns of safety-related incidents using association rules. [50] used association rule mining to evaluate accident investigation records to determine the factors' interrelationships. Authors [45] have worked on the same problem, mining association rules from construction accident data. A research study by [62] identified critical causes of construction accidents in China using a model based on system thinking and case analysis. Analyzed association rules on evidence of fire accidents from Taipei city [22]. Further, [11] worked on an association rule learning algorithm to correlate mining factors by accessing the maritime accidents database. [61] studied analysis of multi-dimensional association rules in marine casualties.

Moreover, From the perspective of construction safety database formation, research work done by [49] analyzed 157 accident cases based on conducting systematic knowledge engineering method and found that the accident information can consist of six labels such as accident expenses, accident types, accident time, causal factors, worker types, and accident location. Causal factors are the most essential part of case analysis. They further applied the Apriori algorithm to explore the association among these accident factors to recommend more precise safety instructions for workers. In the construction of power transmission and substation projects, many hazards put on workers subjected to numerous accidents such as electrocution, falling from height, and

being hit by objects, causing substantial economic losses to enterprises [34] in passing [33].

Moreover, according to [16], the combination of cognitive and visual analytics engages human-like behavior and produces decision-making capabilities. The harmonious blending of automated visual analysis methods, the quantitative abilities of computers, and the cognitive capabilities of humans, along with human interactive explorations, could lead to the creation of new knowledge in powerful ways. For this purpose, cloud services can be accessed through their corresponding APIs of pattern mining, semantic mining, and visual analytics [16]. It helps prevent hazardous or catastrophic events to construction workers and equipment in the sensing environment in terms of maintaining safe distances from obstacles and responding to stimuli appropriately and on time [12]. Prevention through design is a comprehensive approach to address the issues and problems of construction safety and health. The Prevention through Design (PtD) concept has also been adopted by countries like Malaysia since 2017 to reduce the risk of occurrence of construction accidents during the construction life cycle of a building [43].

3. RESEARCH OBJECTIVE

Although many researchers started working on this problem, this study has put effort into preparing a database that works as a source to prepare a sample data file with about ten records. The database consists of construction safety-based cause-effect related data to match to work on the data frame feature of Pandas library in Anaconda Navigator environment to do Python program to elicit cause-effect based frequently associating items. The result set produces a pattern that can be stored in the pattern database. Pattern mining focuses on identifying rules that describe specific practices within the data. Market basket analysis was one of the first applications of data mining [14]. Associations, Clusters, Correlations, and Frequent patterns fall under the descriptive data mining patterns group, and the other group is predictive data mining patterns [46]. The result sets supports construction administrators in alerting construction workers and supporting construction management personnel in making better decisions toward arranging safety measures to avoid or prevent construction accidents. Prevention is better than curing is a well-known quotation known to the globe. Poor knowledge of accident prevention approaches can become a barrier to informed decision-making and designing workplace policies [13].

4. RESEARCH APPROACH AND METHODOLOGY

4.1 Strategic Rationale

The Balanced Score Card Methodology is a tool for senior management to define their strategy for success. Strategy map diagrams and charts can be developed to translate the successful business organization strategy because strategy map diagrams and charts can include objectives, target markets, value propositions, critical business internal processes, etc. At a higher abstraction level, this map can also illustrate the cause-and-effect linkages between financial and non-financial objectives (e.g., customer loyalty and customer satisfaction) in passing to [2]. Further [5], it attempted to provide the customized strategic

mapping of its adaptability to the electronic enterprise as a part of manifesting the management information principles and its components of delivering what is called 'internal information' and 'external information' to further detailed level abstraction focusing on bringing the outcome of value creation and action generation where e-customer satisfaction becomes the value creation and semantic web service activities become action generation in the context of e-enterprise. While profitability represents the tangible outcome of the organization, e-customer satisfaction becomes an intangible outcome; hence is becoming essential to be considered in the contemporary development of digital society [5].

The National Institute of Health defines Epidemiology as the study of health and disease causes, occurrence, and distribution in a defined population [8]. WHILE DISCUSSING EPIDEMIOLOGY, the UK Faculty of Public Health mentioned the Bradford Hill criteria: "The stronger the association or magnitude of the risk between a risk factor and outcome, the more likely the relationship is thought to be causal."

4.2 Tactical (Analytics) Rationale

Argued that TAMPA (T-Transform, A-Analyze, M-Measure, P-Predict, and A-Act) based analytical approach as an extension to MPA methodology mentioned in the book by Berson, Smith & Threading (2000) for eCRM solution as a close loop methodology provides better solution with its capability of building ontology approach that enables true semantic integration to draw wider inferences and make better conclusion than following a simple ETL based Data Warehousing approach [26]. For example, in the smart cities context, data can be collected directly from various sensors, smartphones, structured data from RDBMS, and unstructured data from crawled online web resources and text files. These kinds of data can be collected directly from a variety of sensors, and smartphones, which are then integrated and linked with smart city data repositories to perform analytical checks and provide reasoning to generate required information as well as new knowledge or inference for having decision making so that better urban governance can be conducted [23]. Aligning internet-based services with the enterprise mission accomplishment will also increase the agency's ability to implement strategic business goals and provides decision-makers with critical web services allocated information. Along with the knowledge-based view, which becomes strategically essential as a service-based resource, the e-enterprise value lies in generating activities related to knowledge-based economic service metamorphosis [5].

Solving national-level economic problems requires understanding the factors that influence the production of MSMEs [40]. MSMEs play a significant role in the growth and development of distributed economy [41]. According to Mohit Jain, Chair of the MSME (Micro, Small, and Medium Enterprises) committee at PHD Chamber of Commerce and Industry (PHDCCI), the MSME (Micro, Small, and Medium Enterprises) sector has faced challenges related to financial liquidity, debt, repayments, meeting fixed expenses like wages and salaries, statutory dues, increase in raw materials, etc., which led to increasing in the product cost, thereby impacting cash flows. Several reasons for this scenario in India are Demonetization, GST implementation, COVID-19 pandemic intervention, and

geopolitical war between Russia and Ukraine. The MSME sector comprises nearly 63 Million enterprises, contributing 30 percent to India's GDP, 45 percent to manufacturing, 40 percent to exports, and employs 113 million-plus people in India as per government data [28]. Now, India urgently needs accelerated growth and development of MSMEs. The effective functioning of MSMEs can be better understood using economic models related to production functions [40].

Cost minimization is one of the most fundamental concepts in the business economy. It is a financial strategy to reduce the cost of products in a firm [30]. The Cobb-Douglas production function is still the most universal form of economic function that provides important theoretical constructs related to growth and productivity such as economic output, technical change, and labor demand [15]. [55] discussed the hypothetical idea of economic module adoption as a part of achieving sustainability, that a general equilibrium-seeking algorithm, based on a Solow model in which Cobb-Douglas economy-based production function (input (cause) and output (effect)) as an instrument represents the sustainable economy in terms of six factors viz., agriculture, materials, energy, industry, services, and technology [11], which when combined with Walrasian trial and error approach will help in bringing in cost minimization. For example, [7] experimented with the combination of Cobb-Douglas economic production function and cost minimization problem and found that when production increases, the minimum cost needed increases non-linear and exponentially. Insurance companies need to come forward and work with construction MSMEs to offer cost-effective smart wearable jackets to construction workers affiliated with MSMEs. It is because society is getting everything delivered to the doorstep by just pushing a button or a click away. But people are still getting hurt or subjected to fatal accidents and getting subjected to death or permanent disabilities or severe injuries, and hence such scenarios are not acceptable. Creating wearable jackets incorporating sensors, artificial intelligence, actuators, BIM, and cloud computing technologies are expected to reduce the worker compensation package under fatal conditions. A wearable jacket captures data and provides feedback about the wearer to reduce injuries and fatalities and improve operational efficiency. Radio Frequency Identification Devices technology also has its value in detecting the presence of wearable transponders and transferring information to a receptor, who can be a construction supervisor, manager, or both. In fact, this kind of technology already exists in the national level authority of sports and games and in defense sector to track their soldiers and employees not only to provide safety but also to improve productivity [25].

5. CONSTRUCTION ACCIDENT PREVENTION THEORETICAL MODELS AS STRATEGIES

Reference 20 described that accident prevention is an integral program involving a series of coordinated activities, which can directly control unsafe conditions and performances based on prior knowledge acquisition, abilities, attitudes, and behaviors. Further, Heinrich developed a five dominoes model having aspects such as ancestry & social environment, unsafe acts and conditions, faults of persons, accident, and injury. This theory highlights that people are the fundamental reason for the cause of accidents,

and also, the management is responsible for preventing accidents when happening by providing safety facilities to workers to avoid workers' accidents from happening in hazardous environments, as cited in [39] [1] [18]. According to the research conducted by [29], accident causation models best describe the factors influencing accidents and help develop strategies for accident prevention. [32] in master thesis mentioned the use of a fishbone diagram as a tool that represents the cause-and-effect relationship to help identify and display the causes and effects of a problem in general and construction accidents in specific. McClay identified hazards, human actions, and functional limitations as three critical elements of accidents with the "universal framework." Hinze's distraction theory (1996) [21] argued that production pressure might distract construction workers from hazards and cause construction accidents. [48] the constraints-response model argues that management decisions and project conditions can lead to inappropriate actions and become the cause of actions as cited in passing to [29]. The Construction Accident causality model (ConAC) model is a holistic model of accident causation developed from the investigations of 100 construction accidents prepared by both Loughborough University and the University of Manchester Institute of Science and Technology. This model recognizes the accident causation process produced by various complex integrating factors. It enhances construction safety by considering different parties involved (e.g., contractors and sub-contractors apart from clients and others), as cited in [19].

Construction management is where heavy data is expected to be increased, generated, and collected. Association rule mining is a widely used data mining technique that can be made applicable to the field of construction safety management. Association rules can be used to deduce possible correlations between attribute data item labels such as Construction Accident, Cause of Accident, Effect of Accident, and Safety Measures [60]. Association Rules as a data mining technique refers to the most frequently utilized algorithms like Apriori, FP-growth, and Dynamic item-set counting, others being RARM-Rapid Association Rule Mining, ECLAT-Equivalence Class Clustering, and Bottom-Up Lattice Traversal algorithm and ASPMS-Associated Sensor Pattern Mining of Data Streams [38]. Association rules are determined in the form of $A \rightarrow C$ where A is called Antecedent, and C is called Consequence, which are disjointed item sets. Association rules can help identify undiscovered relationships for forecasting and decision-making [52] in passing to [42].

Secondary data is formed by gathering labels and data on different construction scenarios, causes of accidents, the effect of accidents, and safety measures from different results produced by performing Google Search using phrases "cause and effect relationship," "association analysis," "construction safety." According to CII (1988), the major causes of accidents are related to the poor safety management, difficult work-site conditions, unique nature of the industry, human behavior and unsafe work methods and procedures as cited in passing to [6] and [31]. Hence prevention of construction accidents is to be more critical.

5.1 Developing Construction Safety & Health Management Sample Database

The sample data is construction for ten (10) construction accident types as following Table 1.

Table 1. Qualitatively Correlated Data based on Systematic Knowledge Base

Sl. No.	Construction Accidents Type	Unsafe Site Conditions	Cause of Accident	Effect of Accident	Safety Measure
1	Slips	Materials, tools, and debris	Slippery surfaces, extra materials, tools, and debris	Sprains, fractures, head injuries	Helmets, shoes, jackets, Gloves
2	Workers Falling from Height	Scaffolding or Ladders	Unguarded scaffolding Loose and Incorrect placement	Fractures of Bones, Spines, Head Death (e.g., falling from the highest story)	Guarded scaffolding Firmly fixing and placing a ladder Wearing a helmet, wearable jacket,
3	Things Falling from height	Sharp and Solid objects used at an elevation	Sharp and Solid objects used at elevation Fall from height.	Cuts, head bruises, death	Cleaned workspace and well-organized equipment and handling.
4	Being hit by vehicles	Highway projects	Speed driving, distracted driving	Non-fatal accident, fatal-accident	Slow driving, cautious driving Supported barriers to pedestrians
5	Electrocution	Wiring and welding	Exposed wires, unfinished electric system Downed power lines	Electric shocks, electric firing	Hard-duty gloves, shoes, helmets, wearable jackets
6	Trench collapse or Getting struck by moving or falling materials	Raft Foundation	Fall of loose soil, land sliding	Head injuries, Red Eye	Helmet, wearing belted eyeglasses, wearable jackets
7	Fire or explosions Injuries	Gas welding Surrounded by Unwanted debris Chemical explosion	Explosions, Gas leaks	Burns, Deaths	Fireproof jackets, wearing nose masks
8	Heavy Equipment-crane	Crane operation	Lack of communication between drivers, safety staff, and pedestrians, strikes & crashes	Cuts, head bruises, death	Maintain distance from Crane heavy equipment.

Sl. No.	Construction Accidents Type	Unsafe Site Conditions	Cause of Accident	Effect of Accident	Safety Measure
9	Heavy equipment-Noise	Bull Dozers and others	Loud, Non-audible sounds	Deafness & numbness	Maintain distance from Noisy, heavy equipment
10	Hand-held power tools	Drilling operation	Operating vibratory power tools	Hand Arm Vibration Syndrome	Appropriate PPE equipment

Three measuring factors play a significant role in determining the strength of the association rule. They are (i) Support, Confidence, and Lift. Based on the set level of support, the frequent item set is filtered iteratively, and the confidence determines the strength of the association rule and lift, as mentioned in passing to [33]. When the Apriori algorithm is used to perform association rule mining, i.e., to generate frequent item sets from a given location of a large number of transactions file, which works in two stages, they are (i) Support and (ii) Confidence. Transaction file consists of transaction data, which is a set of fact data related to occurrences of construction accidents and preventive measures [24]. The transaction record combines antecedents and consequences with an implicit meaning of the conditional expression, i.e., IF antecedent THEN consequence form.

5.2 Terminology related to Association Rule Mining and Apriori Algorithm

(a) Item set: An Item Set is a set of items placed together. If any item set has n-items, it is called n-item set. An item set consists of two or more things.

(b) Frequent Item Set: If any item set occurs frequently, it is called a frequent item set. Apriori Algorithm follows an iterative approach in identifying the regular item sets and extracts the most frequent ones.

(c) Measures of Apriori Algorithm

The example calculations on measures of the Apriori algorithm, viz., Support, Confidence, Lift, and convictions, are performed based on the customizing efforts made by Zamil et al. (2020) [59] to the present context of construction accident causes, effects and prevention or safety measures.

Table 2. Sample Transactional data for realizing the computations of Support, Confidence, Lift, and Conviction while using the Apriori Algorithm

Transaction ID	Type of Accident (Cause)	Health Issue (Effect)	Safety
Tran-1	Slip	Head Injury	No Helmet
Tran-2	Slip	Head Injury	No Helmet
Tran-3	Slip	Head Injury	No Helmet

Transaction ID	Type of Accident (Cause)	Health Issue (Effect)	Safety
Tran-4	Slip	Death	
Tran-5	Fall From Height	Head Injury	No Helmet
Tran-6	Fall From Height	Head Injury	No Helmet
Tran-7	Fall From Height	Head Injury	No Helmet
Tran-8	Fall From Height	Death	

The steps followed in the Apriori data mining algorithm are shown in Figure 1.

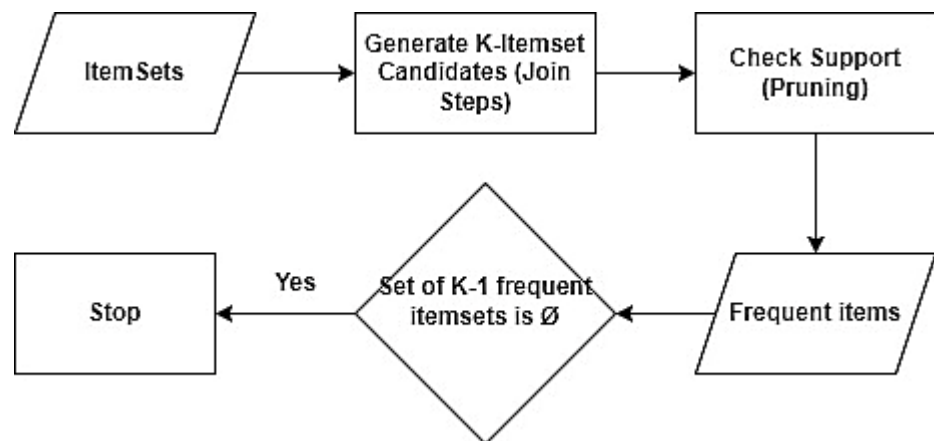


Fig. 1. Flowchart of Apriori Algorithm (Redrawn Source: [47])

(i) Support: It is the percentage of transactions that contain all the items in an item set (e.g., in the context of preventing construction accidents as a part of construction safety management, can be expressed in terms of a stereotype of item set as follows: << Construction Accident Type, Unsafe Conditions, Worker Unsafe Behavior, Cause of Accidents, Effect of Accident, Safety Measure>>—the more the item set's occurrence frequency, the higher the support. High support item sets are more likely acceptable to many future transactions [35].

Support (Fall From Height) = Transaction Containing Fall From Height /Total Number of Transactions

Support (Fall From Height) = $4/8 * 100 = 50\%$

Support (Fall From Height → Head Injury) = $3/8 * 100 = 37.5\%$

Support (Fall From Height, Head Injury → No Helmet) = $3/8 * 100 = 37.5\%$

Support (Head Injury) = $6/8 * 100 = 75\%$

Support (Head Injury, No Helmet) = $6/8 * 100 = 75\%$

(ii) Confidence: Confidence refers to the likelihood occurrence of a Head Injury when a Slip Occurs; Expressed as (Fall From Height→Head Injury)

Confidence (Fall From Height→Head Injury) = Support (Fall From Height→ Head Injury)/Support (Fall From Height)

Confidence (Fall From Height $\rightarrow$ Head Injury) = $37.5\%/50\% * 100 = 75\%$

Confidence (Head Injury, No Helmet) = $75\%/75\% * 100 = 100\%$

Almost similar to Naïve Bayes Algorithm result (in passing to stakebuse.com)

(iii) Lift: Lift (Fall From Height $\rightarrow$ Head Injuries) refers to the increase in the ratio of occurrence of Fall From Height leading to Head Injuries

Lift (Fall From Height $\rightarrow$ Head Injury) = Confidence (Slip $\rightarrow$ Head Injury) / Support (Slip) = $75\%/50\% = 1.5 > 1$

Inference: Lift > 1 - There is a positive correlation between Fall from Height and Head Injury

Inferences for Lift Values:

- (i) Lift ($X \rightarrow Y$) = 1 means – There is no correlation within item set
- ii) Lift ($X \rightarrow Y$) > 1 means – There is a positive correlation within item set
- (iii) Lift ($X \rightarrow Y$) < 1 means – There is no correlation within item set

(iv) Conviction: Conviction ($X \rightarrow Y$) = $(1 - \text{Support}(Y)) / (1 - \text{Confidence}(X \rightarrow Y))$

Conviction (Fall From Height, Head Injury) = $(1 - 0.75) / (1 - 0.75) = 1$.

Inferences for Conviction Values:

- (i) Conv ($X \rightarrow Y$) = 1 means – There is no correlation within item set
- ii) Lift ($X \rightarrow Y$) > 1 means – There is higher interest in the rule

6. CONCLUSION

The literature review developed theoretical frameworks from various research efforts. Further, some Github implementations [44] revealed that it is feasible to work on AI-based intelligent helmet detection, Wearable jacket detection that workers are wearing as a part of PPE or not. Regarding frequent item set generation using the Apriori algorithm of Association Rule Mining: [17], they cited that 88% of all industrial accidents were caused primarily by unsafe acts of the workers. Based on their case study of workers' hazardous behavior, their research built a rule mining database and applied the Apriori algorithm to extract frequent item sets concerning worker unsafe behaviors of different worker types in different construction phases. So, most IoT and AI-based application programming provide better results only when their case accesses the relevant database in a specific format. Therefore an effort is made to build a sample database. It is a secondary data-based sample database pertinent to apply the Apriori algorithm. It is then attempted, prepared, and explained how to compute measures on support, confidence, lift, and conviction values to understand the accuracy of semantics. Regarding construction safety data: Structured OSHA accident and injury data for the period between 2015 and 2017 can be found on the Kaggle.com website. [67] revealed the .csv formatted data files related to construction site parameters for predictive analysis on the kaggle.com website. For better accuracy, one has to put effort into collecting and preparing the real-time

scenario data in a format accessible by data mining algorithms such as the Apriori algorithm and machine learning libraries containing these kinds of algorithms. Python programming language helps in working on these kinds of libraries of algorithms by accessing data files and producing the required output with visualization and information accuracy levels better to interpret the model results and their corresponding accuracies. When the data is properly formatted, the research by [53] shows how Association Rule mining using the Apriori algorithm can extract antecedents with corresponding lift values grouped or classified by various incident types, such as First Aid and Damaged Property. Similarly, it is possible to provide such data categorized by Construction Fatalities too.

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AUTHOR CONTRIBUTIONS

All authors contribute to Conceptualization, Methodology, validation, formal analysis, investigation, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision project administration, funding acquisition, and have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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