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Review

A quantitative and qualitative analysis of Time-Driven Activity Based Costing: the waste side of joint replacement

Andrea Fidanza[1], Irene Schettini[2], Francesco Di Petrillo[1], Michela Saracco[3] Giuseppe Petralia[1], Giandomenico Logroscino[1]

[1]Unit of Orthopaedic Surgery, Department of Life, Health and Environmental Sciences, University of L'Aquila, L'Aquila, Italy; [2]Department of Management and Law, Tor Vergata University of Rome, Via Columbia 2, Roma, Italy; [3]Department of Orthopaedics, "San Giovanni di Dio" Hospital, ASL Napoli 2 Nord, Napoli, Italy

Abstract. *Background and aim:* The Time-Driven Activity Based Costing (TDABC) is a recent and sophisticated analytical accounting systems capable of linking and summarizing the information held by the various stakeholders involved in the provision of health care services. The aim of this review is to quantify the current state of the art of the international TDACB literature in the orthopaedic field, highlighting which orthopaedic topic deriving from the clinical/economic interdisciplinarity is of greater interest. *Methods:* A comprehensive science mapping bibliometric analysis of scientific literature was performed using the Scopus database. Afterwards, the analysis of the 40 most cited articles was carried out to spotlight the area of greatest interest in the orthopaedic field, and from which to extrapolate a qualitative analysis. *Results:* A total of 346 documents resulted eligible for the review. Nine of 40 articles examined TDABC in the prosthetic context. Despite showing a high diversity of methodological application, all 9 articles agree on the two most expensive items of care cycles: operating room consumables followed by length of stay. *Conclusion:* TDABC is a cost calculation methodology that is gaining scientific attention in the orthopaedic world, particularly in the joint replacement area. This tool might be useful for both clinicians and business managers, allowing them to redesign the entire patient care path, making useful changes to reduce waste, while maintaining standards of care. (www.actabiomedica.it)

Key words: TDABC, joint replacement, prosthetic costs, hospital costs, value-based healthcare, cost drivers

Introduction

The Activity Based Costing (ABC) is a sophisticated analytical accounting systems developed in the late 1980s in the United States as an alternative method to increase cost effectiveness without compromising quality of service. It points out a flow of information that helps managers maximize their resources and create new options for improving service quality development (1). A more recent derivation of the ABC, the Time-Driven Activity Based Costing (TDABC), as advocated by Kaplan in 2011 (2), is a valuable tool for linking and summarizing the information held by the various actors involved in the provision of health care services, providing more accurate information about the use of resources, including the "behind-the-scenes" activity. This method is an essential component of the newly defined value-based healthcare (VBHC) agenda (3-5), which strives to analyze the patient's complete usage of resources across healthcare departments and organizations (6,7). Specifically, the value-based approach seeks to develop a new universal language in healthcare administration focused on the patient's value, to balance the interests of all stakeholders (5, 6). The specific application of TDABC plays an important role in this field (8,9). Not surprisingly, the TDABC

requires more local detailed accounting data, which necessitates an increase in the 'bottom-up' micro-costing technique capable of bringing even the slightest waste and consumption out of the shadows. To achieve this goal, the TDABC must be applied following 7 specific steps (2). The main keys to these phases are above all the development of a process map capable of identifying each phase of patient care, with time estimates for each phase. The resources required for each stage of the process (such as personnel and consumables) must be calculated. The computation of the capacity cost rate, which is meant to be a rough estimate of the time and cost per unit of time that each operator needs throughout a care episode, is moreover a distinctive aspect of this methodology. For instance, the cost for interacting with a patient would be United States Dollar (USD) 50 if a staff person spent 30 minutes with them and their time cost was USD 100 per hour.

This strategy will promote insight and, as a result, autonomy and controllability (7,10, 11).

Ultimately, having an accurate cost accounting can implement strategies to bend the cost curve and increase value for patients. Only then it will be possible to truly improve the value of healthcare, defined as health outcomes achieved per dollar spent over the entire care cycle (12).

The purpose of this study is to bring to light the current state of the art of the international TDACB literature in the orthopaedic field. An exhaustive analysis of the scientific mapping can highlight which orthopaedic topic deriving from clinical/economic interdisciplinarity is of greatest interest and to carry out a qualitative review of it.

Materials and methods

To achieve the aim of the study, a bibliometric analysis of the literature was performed. Bibliometry is a statistical-quantitative tool for analyzing textual and editorial data (13). Bibliometric analysis represents a systematic, transparent, and reproducible literature review process (14), which allows a recognition of the existing literature on a single topic through the definition of an interconnected system of keywords established on the basis of the main contributions deemed relevant. This methodology is suitable for broad aims (e.g., summing up a lot of literature) and was chosen due to the scope of this study and the sample size.

The Figure 1 depicts the steps conducted during the entire investigation. The databases used for the research were Pubmed, Medline, Cinahls and Scopus, and the keywords combination used were: "time driven activity based costing" OR "TDABC" AND "orthopaedic" OR "orthopedic". Initially, the search was conducted across a number of biomedical databases, but Scopus was ultimately chosen since it produced the greatest number of published articles.This search was considered open to all document types and all languages. Since 2011 (the year of the first publication in this topic), all articles published up until December 2022 were taken into consideration.

The program used to analyze and summarize the data was Bibliometrix R-Package. The data were loaded and translated into a R dataframe in Bibliometrix based on the final sample returned by Scopus in bibtex format, to build two primary levels of analysis: bibliometric and qualitative analysis. The bibliometric analysis illustrates the characteristics of the sample and measures its main performances by evaluating the research field identifying the most important actors and analyzing groups of scientific actors and their impact (15, 16).

Within bibliometric analysis a citation analysis and a spatial representation of the relationships between disciplines, fields, specialties, and individual papers or authors (15, 17) were also undertaken. All the data illustrated in the text were generated using "Biblioshiny" (Bibliometix-R software).

Furthermore, an in-depth analysis of the 40 most cited articles was carried out to spotlight the area of greatest interest in the orthopaedic field, and from which to extrapolate a qualitative analysis.

Results

This section, in tandem with the method steps shown in Figure 1, presents the results of the review by first reporting the quantitative findings of the scientific mapping analysis and finally the results of the qualitative analysis on the orthopaedic topics of greatest interest.

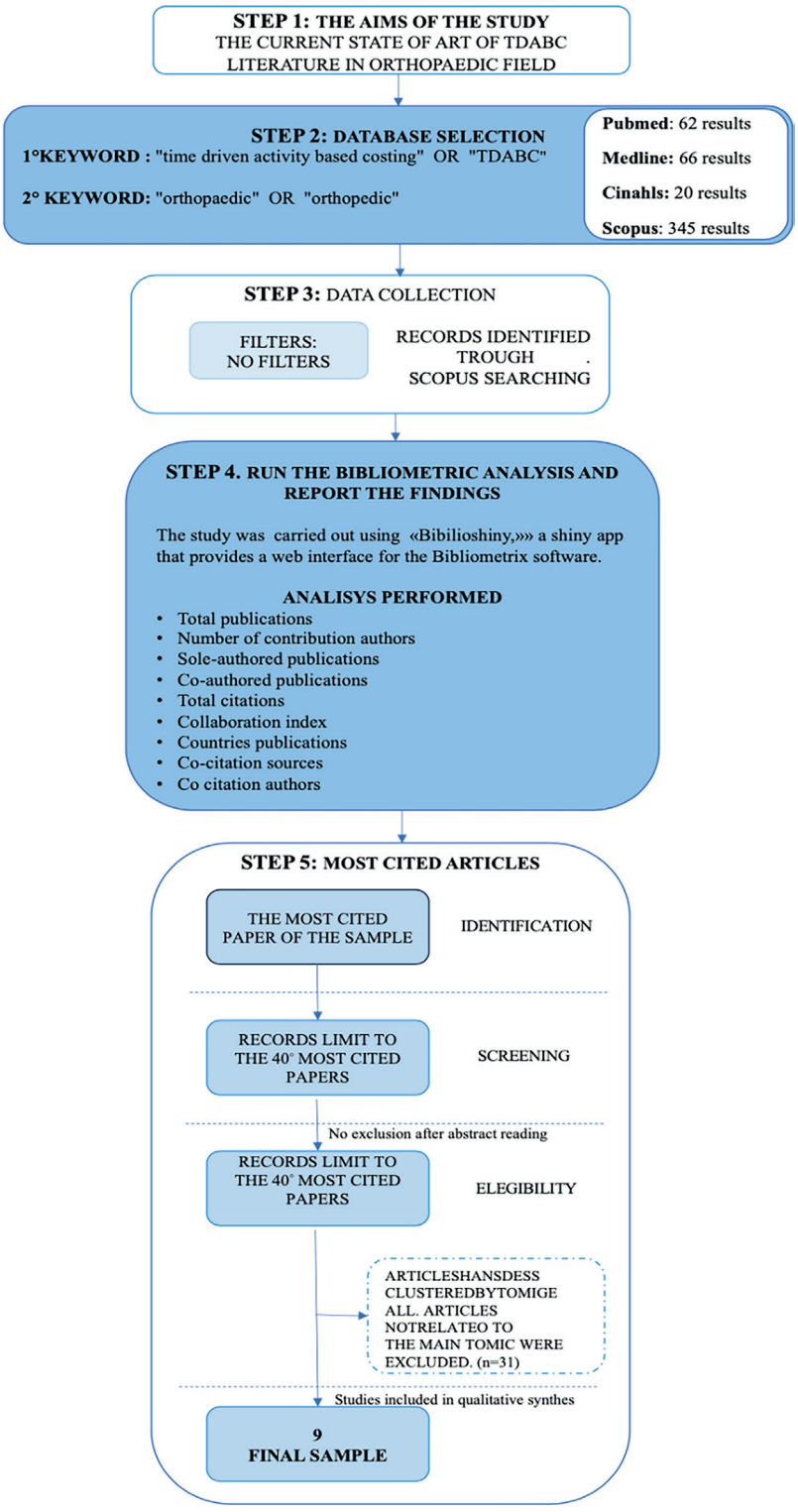

Figure 1. Flowchart of the methodology used for the quantitative and qualitative systematic review.

Quantitative analysis

The entire survey was conducted on the final sample consisting of 346 documents.

In particular, 72% of the documents are articles, 18% reviews and 10% a mix of conference papers, books, editorials. With 1544 authors and a collaboration score of 4.63 (i.e., a Co-authors per Article index calculated just using the multi-authored article set), authorship is highly fragmented. There is an average of 4.46 authors per document, with only a few articles by a single author (15 articles, 4,3%).

The topic has had growing interest in the last five years (going from 30 articles published in 2018, to over 80 documents published in 2022). Based on their publication number, the most relevant authors can be identified (Figure 2).

The documents in the dataset were published in 186 journals. Figure 3 shows the most relevant sources based on the number of articles.

The Figure 4 depicts the top countries in terms of scientific output. Based on all authors' affiliations, the geographical distribution of publications is concentrated in Anglo-Saxon countries (USA, Canada, UK) and other European countries (Italy, Belgium, Germany, Netherlands), more the isolated appearance of Brazil in the Latin area and India.

Finally, the co-occurrence source analysis reveals three major clusters, recognizable in epidemiology, healthcare management, and field of application (Figure 5).

Qualitative analysis

The latest analysis performed is based on the 40 most cited articles extrapolated from the bibliometrics (the list of them is available upon specific request to the corresponding author). The areas of interest are multiple, encompassing various fields of orthopaedics: the studies deal with telemedicine (three articles), robotics and artificial intelligence (three articles), preoperative or non-operative care (three articles), iron therapy (two articles), different costing models (three articles) and intersect other disciplines close to orthopaedics, like neurosurgery, urology, pediatric trauma, geriatric surgery (eight articles). Nine are review articles. The most frequent application of TDABC appears to be in the field of joint replacement (9 out 40 articles, 22.5%), where the cycle of care is often standardized.

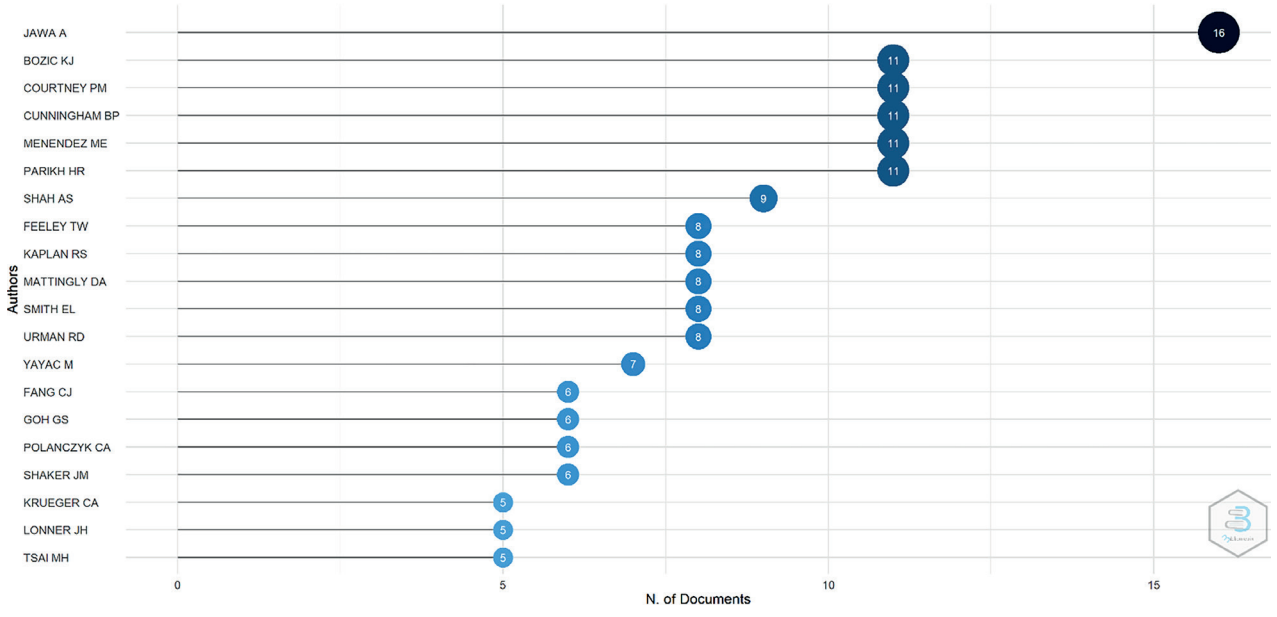

Figure 2. Most relevant authors.

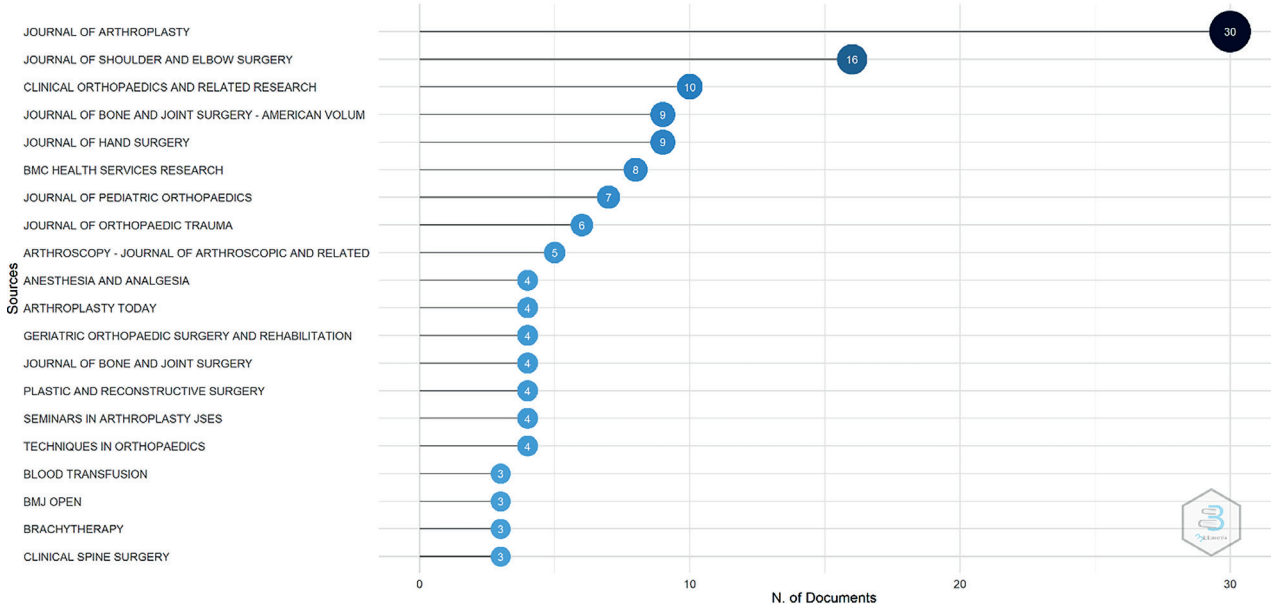

Figure 3. Most relevant sources. The numbers in the circles represent the number of publications.

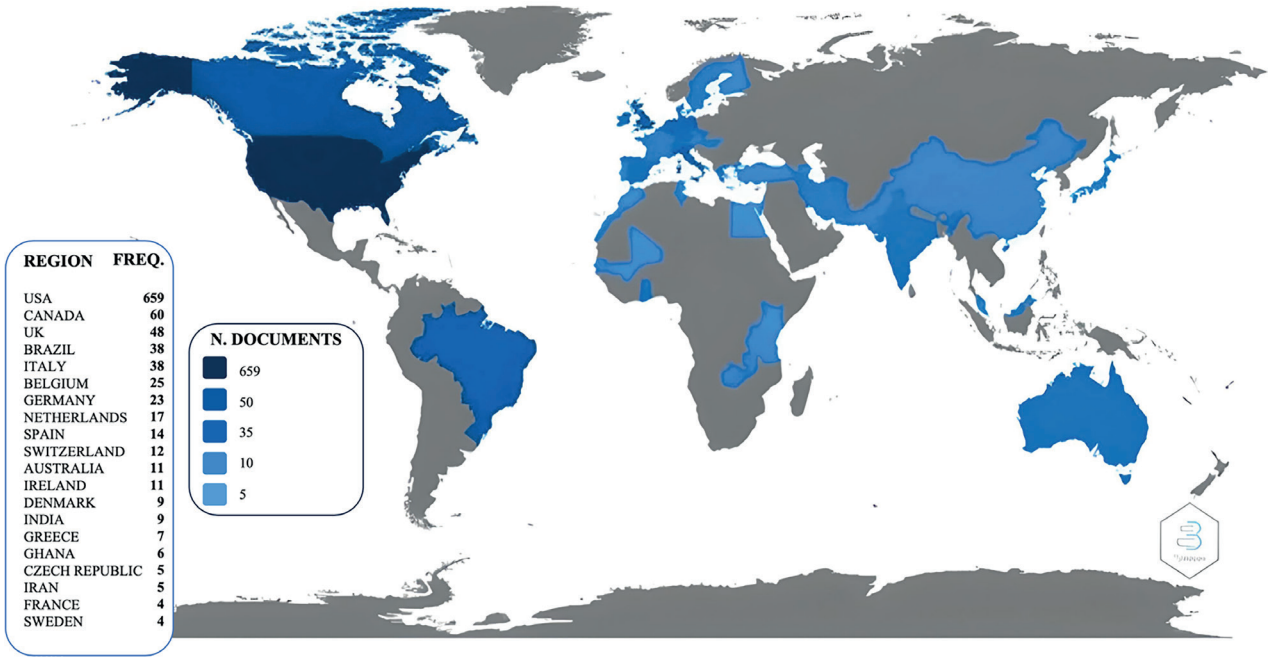

Figure 4. Country scientific production.

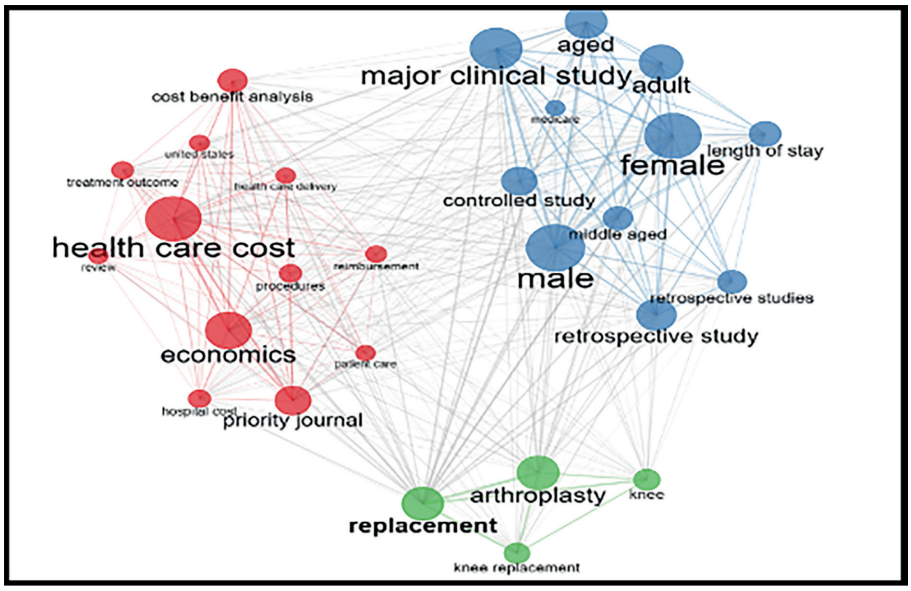

Figure 5. Co-occurence analysis of sources identifies different areas of interest: epidemiology (blue), healthcare management (red), and field of application (green).

Five are prospective studies, and the study period varies from 2012 to 2018. Five of these were set in teaching hospitals (24, 25, 27, 28, 31), where most surgeries were performed by trainee/fellow orthopaedic surgeons. The Table 1 collects the main information extrapolated from the topics covered, maintaining the focus on the keys of the cost methodology, including study design and investigations, implanted prostheses, creation of the process maps, hospitalization and main results.

Discussion

Recently, great interest in Value-Based Health Care has turned to the development of a standard costing method to enable healthcare providers to understand the cost of providing care for conditions and control. The main finding of this study is that TDABC is a cost calculation methodology that is gaining scientific attention in the orthopaedic world, particularly in the prosthetic context. Probably, the reason why the annual scientific growth rate exceeds 49% with publication peaks in the last five years (2017-2022), is because the TDABC is an innovative tool based mostly on two cornerstones: the capacity cost rate and the time required to perform activities in service delivery - hence the name "time-driven" ABC (6, 8). Additionally, using this model enables you to redesign the procedure to cut costs, add new activities to the care cycle, make adjustments, and, most importantly, compare the best pathway and give the patient the best option possible by spotting areas for development in terms of time, goods used, and activities performed (2, 6). We found a drop in production and citations on this topic in the two-year period 2020-21, probably linked to the main concentration on the COVID19 pandemic in that period, while the recovery of scientific attention on this focus occurred in 2022.

The current analysis covers the entire time span from the first publication on the topic (2011) to December 2022. The orthopaedic-related field remains highly fragmented. The 346 collected articles are distributed among 186 sources. Concerning the most cited articles (Figure 2, Table 1), the one that received the most citations was published in 2018 (18) and aimed to show the average cost of the operating room (OR) using financial data from California in the fiscal year 2014. In terms of geographic distribution of author's affiliations (Figure 4), the United States has the most

Table 1. A qualitative overview of joint replacement TDABC-related articles.

	Investigation	Sample	Process map	Lenght of stay	Main findings
Akhavan S [22] 2016	Retrospective Monocentric TA vs TDABC	700 THA and TKA	TJAs from the operating day	NA	Cost categories with the greatest variability between TA and TDABC: 1 Operating room services 2 Room and board.
Palsis JA [24] 2018	Retrospective Monocentric TA vs TDABC	124 THA 148 TKA	From the day surgery was scheduled to 90 days post-discharge	THA: 3 days TKA: 2 days	Costs calculated using TDABC were 59% (THA) and 58% (TKA) of costs calculated using the TA. Costs of equipment and consumables were equivalent between the 2 methods, but in percentage terms represent: TDABC/TA 55%/32% (THA) and 65%/37% (TKA).
Haas DA [25] 2016	Retrospective Monocentric TDABC	200 TKA per Hospital	NA	NA	The largest cost drivers was the length of the operation. Implants and personnel costs varied greatly between hospitals, with no difference in clinical outcomes.
Andreasen SE [26] 2017	Retroscpective Fast-track double center TDABC	249 THA and 216 TKA	From preoperative visit to inpatient stay to follow-up	2 days (100% discharged home)	The most costly aspects of the carecycles are surgery and inpatient stay (51.1% and 31.2% respectively at Hospital 1 and 59.3% and 24.5% respectively at Hospital 2). Implant cost not included.
Chen A [27] 2015	Prospective Monocentric TDABC	20 TKA	From the decision to admit the patient to discharge from the ward	5 days (4-7)	The largest cost drivers were operating room consumables and implant (34.35%), company overheads (30.46%) and ward costs (16.79%).
Menendez ME [28] 2018	Prospective Monocentric TDABC	415 TSA	Preoperative, intraoperative and postoperative	2.2 days	Implant purchase price was the main driver (57%) of total inpatient costs, followed by personnel costs from patient check-in through the time in the operating room (20%).
Husted H [29] 2018	Prospective Outpatient. Double Center TDABC	1 TKA 1 uncemented THA. 1 cemented THA (in each institute)	From the first visit to 90 days post-discharge	11h (ward) 7h (ambulatory)	Compared to the cost associated with fast-track, outpatient procedures are approximately 2/3 cheaper. Implant and indirect cost not included.

Table1 continues

Table 1. A qualitative overview of joint replacement TDABC-related articles. *(continued)*

	Investigation	Sample	Process map	Lenght of stay	Main findings
Carducci MP [30] 2020	Prospective Monocentric TDABC	10979 TKA 10067 THA 688 RSA 392 TSA 75 TAA 14 TEA	Mentioned, but NA	3.14 TKA 2.29 THA 2.27 RSA 1.92 TSA 1.87 TAA 2.35 TEA	The cost of the implant represented 53,8% and is related to the higher total costs for a cycle of hospital treatment. Length of stay was correlated with the increase in personnel costs, without significant effect on total cost.
Hamid KS [31] 2017	Prospective Monocentric comparing two techniques TDABC	87 TAA	Mentioned, but NA	NA	Shorter OR time for patient-specific instrumentation results in cost-savings threshold over standard referencing.

TA: Traditional Accounting; TDABC: Time-Driven Activity Based Costing; TJA: total joint arthroplasty; THA: total hip arthroplasty; TKA: total knee arthroplasty; TSA total shoulder arthroplasty; RSA: reverse shoulder arthroplasty; TAA: total ankle arthroplasty; TEA: total elbow arthroplasty; NR: not reported

productive researchers with a total of 659 published papers (46%), followed by Canada (4%), the United Kingdom (3%), and Brazil and Italy tied at 2.5%. Followed by other European countries and Australia and India. These findings are expected; in fact, the research is far more thorough and accurate in nations where healthcare reforms are projected to move the business away from fee-for-service reimbursement and toward bundled or pay-for-performance models. The objective is to find novel approaches to restructure the delivery of healthcare, shifting from quantity-based to value-based efficiency.

Science mapping is a tool that can return the connections across topics, authors, and countries.

The keywords co-occurrence in this context identify three clusters: general epidemiology area, healthcare management, and specific orthopaedic field of application (Figure 5). Because of the connections between these nodes, the most closely matched nodes - relating to the economic evaluation - demonstrate the importance of interdisciplinarity between the economic and medical fields. This finding is consistent with economic studies related to organizational management, which therefore involve all dimensions, including the clinical/medical ones and then employ these sources. It is crucial to note that building a process benchmark in the clinical area and conducting cost-effectiveness assessments are cornerstones of the value-based agenda (19, 20), which recognizes these methodologies as particularly proper for cost and value analysis (3-6). Furthermore, Kaplan and Porter highlighted the TDABC as a strategy to "solve the cost crisis" in healthcare organizations in the first of TDABC study (2). Unfortunately, this utopian result has not yet been achieved (21).

However, this methodology has proven to be able to identify redundancies and curative disservices, the economic impact of which was previously undetectable due to the lack of a detailed analysis of the processes obtained with traditional accounting methods. Properly, there is a particular focus on joint replacement which support the most relevant sources: due to the structure of the sample, it is not surprising that the most active journals are OR-based (Figure 3) and that the most relevant topic is arthroplasty (Table 1). Indeed, being the TDABC developed on the analysis of the time taken to perform an action, it is more suitable to be applied when this action is methodologically repeated (6, 22, 23). As a result, the scientific maturity of activity-based costing as applied to non-standardized or non-surgical healthcare is quite low. On the contrary, according to the most cited papers, the TDABC approach is the most used in the field of surgery. Based on this evidence, it has been reported that one third of

these (14 out of 40 papers, including review articles) come from joint replacement, which is a specific and frequently performed surgery.

The 9 articles that underwent the qualitative review include more than 20000 patients with total hip and knee replacement (only one author (25) did not report the exact number); 1495 shoulder, 162 ankle and 14 elbow arthroplasty. The use of the TDABC provides for the rigorous consequential introduction of the seven steps defined in the literature (2) for the use of this tool. The 7 steps are discussed individually below and divided with the letters a-g. (a) The first step is to select the medical condition, defined as an "interrelated set of patient circumstances that are best addressed in a coordinated way and should be broadly defined to include common complications and comorbidities" (2). None of the articles matched the description of a medical condition as the authors did not include comorbidities or complications associated, which could lead to a loss of granularity in the cost analysis. Only two articles (30, 31) mentioned the inclusion of complications, but this was not evident in the subsequent cost analysis. The reason may be that studying highly standardized care is easier to compare than studying patients with many comorbidities who need individualized treatments. (b) The second step is to define the care delivery value chain, which is to track the activities that occur and their locations throughout the entire care cycle. This step is directly related to the following ones, consisting of (c) developing process maps for each activity in patient care delivery and (d) obtaining time estimates for each process. Six studies published process maps or more simply chronologically listed the phases of the process from preoperative, intraoperative and to discharge and follow-up (24, 26-29). In one case (22) the process map concerns only the day of the intervention, while in 3 works it is not available (25, 30, 31). (e) The fifth step is to estimate the cost of providing patient care resources, replaced by the cost of all primary resources (direct care costs) (32), and then estimate the cost of the resources needed to deliver them (indirect care costs), e.g., overhead and support center costs. (f) At this point, the capacity cost rate (CCR), which is the cost of the capacity providing the resources divided by the practical capacity of those resources, is calculated. In each article, the CCR was calculated by comparing the average monthly salary of each type of staff with the time spent providing the health service. This method was used for all the employees considering the different salaries. However, deriving from different Health Systems, it is not possible to compare if an operator is rightly paid more. Finally, all the calculated costs were added up, thus defining the total cost of patient care in the structure examined (g). In this way, through the TDABC it is possible to find out which items cost more, ignoring the patients' reporting outcomes. The most expensive items of care cycles were found to be those related to the operating room (including surgical time, personnel, consumables, and implant) (22, 25-28, 30, 31) followed by length of stay (22, 26, 27, 29, 30). In articles comparing TDABC to traditional costing methodologies, equipment and consumable costs were equivalent between the 2 methods, but in percentage terms there was large variability in favor of TDABC (22, 24). The purchase price of the implant was not included in the sum of costs by 3 authors: Andreasen et al. compared the fast track in two hospitals (26), Husted et al. compared the costs of fast-track VS outpatient surgery (29), and Hamid et al. compared the same procedure using a navigation system VS a traditional operation (31). Only for Chen et al. high administration overheads (30.46%) are among the major costs incurred during hospitalization (27).

Limits

This study has some limitations that must be addressed. Firstly, although the bibliometric analysis is based on a statistic procedure, that is objective and replicable, the chosen keywords, as well as the use of a single database, could be insufficient. Second, the objective of the qualitative review was to explore in which orthopaedic settings TDABC was most widely used. In light of this, we limited our investigation to the 40 most mentioned publications, only 9 of which have been finally examined through qualitative analysis. However, the scientific quality of the studies was not assessed, and it is possible that articles with methodological deficiencies or misreported results were included. In addition, the literature presents some clear limitations of TDABC that need to acknowledge.

TDABC is still a new technique in the field of healthcare and one of the major barriers shown is the lack of understanding or appreciation of its possible impact. Indeed, many of the conclusions are likely limited to their respective fields and institutions. Finally, a major limitation of TDABC in orthopaedic surgery is that there is little field experience with this cost-effective approach (6). The topics analysed, while involving heterogeneous contexts, all concern well-standardized procedures without including more demanding conditions in determining the real value of a procedure, which can also have complications.

Regardless, these findings are helpful for all healthcare systems since they highlight the need to accurately estimate the costs of a particular treatment, excluding overhead, before implementing a fixed payment system to reimburse a service. Little research has been conducted on how healthcare organizations should change or adapt to implement the TDABC in the design, monitoring, delivery, and evaluation of a healthcare delivery process in order to improve it and assist managers and clinicians in meet all the necessary decisions on the steps taken by the patients. Although narrative reviews have been carried out on the use of TDABC in the orthopaedic field, to the best of our knowledge this is the first critical quantitative and qualitative bibliometric review.

Conclusion

TDABC appears as a decision-making tool that can be used by all actors in a healthcare institution, whether they are clinicians or administrators, in order to illuminate the shady information regarding investments and waste in orthopaedic surgery, and more precisely in the field of prosthetics, delivering care with similar, or even improved, outcome. The findings help in the identification of future study directions.

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Correspondence:
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Giuseppe Petralia, MD
Unit of Orthopaedic Surgery, Department of Life, Health and Environmental Sciences
University of L'Aquila,
Piazzale Salvatore Tommasi 1, 67100 L'Aquila, Italy
Phone: +39 3277756906
giuseppe.petralia@graduate.univaq.it
ORCID: 0009-0003-9521-9098