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Assistive technologies in knee arthroplasty: fashion or evolution? Rate of publications and national registries prove the Scott Parabola wrong

Cécile Batailler¹ · Sébastien Parratte^{2,3}

Abstract

Purpose Most opponents of assistive technologies in orthopedic surgery consider them as a marketing ruse or fashion. Our hypothesis was that many innovations in modern knee arthroplasty are not following the Scott Parabola. This parabola represents the visual curve of a procedure or therapy showing great promise at the beginning, becoming the standard treatment after reports of encouraging results, only to fall into disuse due to adverse outcome reports. This study aimed to assess the interest in these assistive technologies by (1) their number of publications/year and (2) their actual surgical use reported in the National Joint Registries.

Methods The search was performed through PubMed, EMBASE, and MEDLINE databases from 1997 to 2021 inclusive to identify all available literature that described the use and results of assistive technologies or new surgical techniques in knee arthroplasty. In the Australian and Norwegian registries, the number of cases performed with these techniques in knee arthroplasty has been quantified year by year.

Results Following the initial online search, a total of 4085 articles was found. After the assessment mentioned above, 2106 articles were included in the study. The orthopedic techniques assessed in this study are not following the “Scott’s parabola” in the literature. Computer-assisted knee arthroplasty and patient-specific instrumentation have increased quickly to have reached a plateau, with a stable number of publications over the last 6 years. The number of publications concerning robotic surgery, accelerometers and sensors continue to rise. In the Australian registry, the proportion of primary TKA performed by computer-assisted systems increased from 2.4% in 2003 to 32% in 2019. In the Norwegian registry, the proportion of computer-assisted TKA remained between 8 and 12% of primary TKA since 2007.

Conclusion Most of the innovations in modern knee arthroplasty are not following the Scott Parabola. After a fast rise, these techniques do not disappear but continue to evolve. Their evolution is synergistic, and techniques appeared to be linked to each other’s. Despite persisting concerns about the cost-efficiency of assisting technologies in knee arthroplasties, the interest and use do not decrease and seems to be directly linked to an exponential increase in interest for a better understanding of alignment targets and improved functional recovery.

Keywords Knee arthroplasty · Scott parabola · Robotic surgery · Computer-assisted system · Assistive technologies

Introduction

Orthopedic surgery is one of the most dynamic surgical specialties, and knee arthroplasty surgery is one of its fastest-growing sub-segments. In fact, the number of potential candidates for knee arthroplasty is estimated to grow exponentially during the upcoming 20 years [1]. In parallel of this growth, the assistive technologies have been progressively developed to increase the accuracy and the reproducibility of knee arthroplasties [2]. In early 2000, computer-assisted surgery (CAS) started to gain interest. CAS was a logical solution to improve implants position through smaller

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incisions. After a decade of CAS use, new tools arrived in the surgical armamentarium, such as patient-specific instrumentation and accelerometers-based navigation [3, 4]. At the same time, new concepts concerning patient's alignment and more anatomic solutions came-up too. The latest assistive technology that is gaining interest is the robotically assisted surgery in knee arthroplasty [5–7]. Clear advantages and superiority of these innovations or assistive technologies have never been proven [8, 9]. Most of the opponents of these techniques are claiming that these solutions are just trends coming one after another that will fade. Several surgeons state, for example, that robotic surgery as a fashion and a marketing ruse [10, 11]. They often use the Scott Parabola as a reference to describe the phenomenon.

The Scott Parabola describing the rise and the fall of a new surgical technique. This scheme of great craze for innovation then its progressive abandonment has been described by Scott. In 2001, J.W. Scott, a British gynecologist, published in the British Medical Journal a brief paper entitled “Scott’s parabola: the rise and fall of a surgical technique” [12]. This parabola represents a procedure or therapy that shows great promise at the outset, becoming the standard treatment after reports of encouraging results, only to fall into disuse due to adverse outcome reports (Fig. 1). The MIS low-profile tibial component developed for minimally invasive knee arthroplasties is a good example for the Scott Parabola. These implants with a low-profile keel have known a high interest in early 2000, until the publication of disappointing results and early aseptic loosening [13, 14]. The active robotically assisted system ROBODOC presents also a similar evolution in some countries. Recent study did not demonstrate a real benefit of this device [15]. Nevertheless, this device has contributed to the development of current advanced technologies in knee arthroplasties; and the CUREXO system remains commonly used in Korea. If it

is true that some trends in the arthroplasty world are just fashion (such as metal-on-metal bearing surfaces or modular femoral stems for hip arthroplasty) with a real decline, the definition of trend could also be “a general direction in which something is developing or changing”; i–e an evolution.

It was our hypothesis that most of the assistive technologies in modern knee arthroplasties are not following the Scott Parabola. To demonstrate our hypothesis, we aimed in this study to evaluate (1) the interest for the technique as measured by the number of publication/year on each of these assistive techniques and (2) the actual surgical use as measured by the number of cases performed with these techniques reported in the National Joint registries.

Materials and methods

Article identification and selection process

A search in February 2021 was performed to identify all available literature that described the use and results of assistive technologies or new surgical techniques in knee arthroplasty. The search was performed through PubMed, EMBASE, and MEDLINE databases from 1997 to 2021 inclusive.

Inclusion criteria for the search strategy were all English studies reporting information regarding the use and results of assistive technologies or new surgical techniques in knee arthroplasty. The included articles were randomized controlled studies, cohort studies, case-controlled studies, cadaveric studies, systematic reviews, and meta-analyses. The following terms were used: “knee arthroplasty” or “knee replacement” associated with each following groups “PSI” or “patient-specific instruments” or “patient-specific

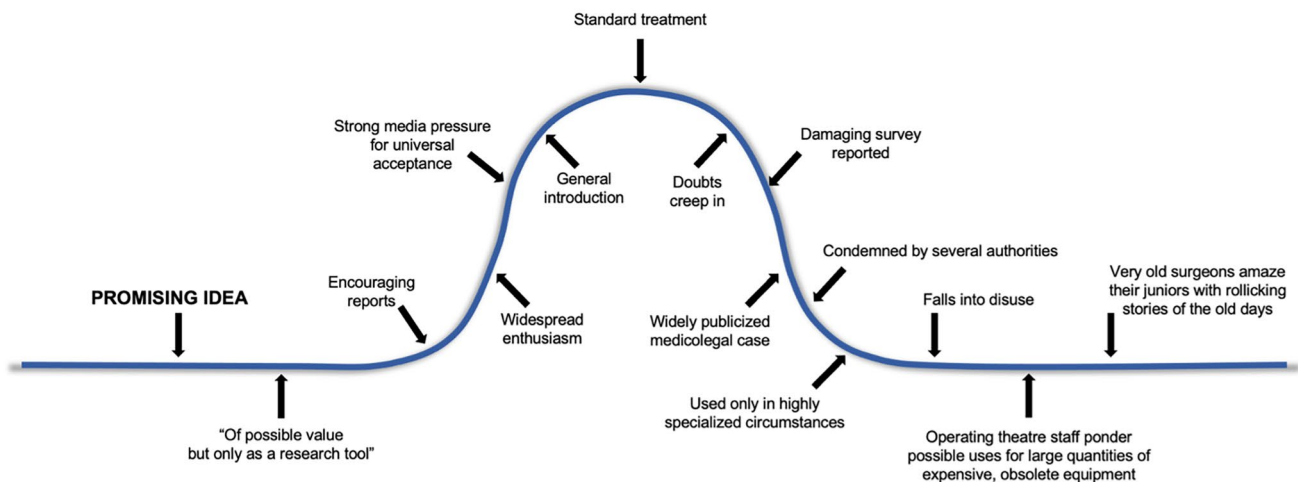


Fig. 1 Scott’s parabola

instrumentation” or “patient-specific guide”; “navigation” or “navigated” or “computer-assisted”; “robotic” or “robotically assisted”; “accelerometer”; “sensor” or “sensing technology”. Exclusion criteria consisted of (1) comments on previous articles, (2) articles evaluating joints other than the knee. The abstracts from all identified articles were independently reviewed by two senior orthopedic surgeons. Articles were excluded based on the title and abstract. The number of included articles describing each technique was assessed year by year.

For the articles on CAS, articles have been allocated into two groups. The first one included all articles assessing CAS in knee arthroplasty (comparative studies, cadaveric studies, and reviews or meta-analysis on the outcomes of CAS). The second group included all comparatives in vivo studies in which CAS was used during the surgery, but was not the main topic assessed in the study. The aim of this second group was to assess if this device was always used in current practice.

National registries

In each National Joint Registry available via Internet, the number of cases performed with these techniques in knee arthroplasty has been quantified year by year. The searched techniques included: CAS, PSI, robotically assisted systems, sensors, accelerometers-based navigation in total knee arthroplasty (TKA) or unicompartmental knee arthroplasty (UKA). The assessed national joint registries were: American Joint Replacement Registry, Australian Orthopaedic Association National Joint Replacement Registry, National Joint Registry for England Wales Northern Ireland, and the Isle of Man, New Zealand Joint Registry, Canadian Joint Replacement Registry, Swedish Knee Arthroplasty Register, Norwegian Arthroplasty Register.

Results

Evolution of surgical techniques in knee arthroplasty in the literature

Following the initial online search, a total of 4085 articles were found. After the assessment mentioned above, 2106 articles were included in our study. In the literature, the publications progression evolves in two different ways: growth and plateau phase or continuous growth. The assistive technologies where a plateau phase was observed were: CAS and PSI; and the ones with a continuous growth: accelerometers, sensor technologies, and robotically assisted knee arthroplasties.

The first group comprises: computer-assisted knee arthroplasty and PSI have increased quickly during 5–8 years to

then reach a plateau, with a stable number of publications/year over the last six years (Fig. 2a and b). Articles on “computer-assisted knee arthroplasty” represent the highest proportion of articles on assistive technologies in knee arthroplasty. Concerning the articles on CAS, 2 phases can be observed: from early 2000 until 2013–2014, the articles mainly reported studies on the assessment of the efficiency of CAS with publications reporting randomized or non-randomized comparative studies (with or without CAS). The second phase after 2013 until today shows a persistent interest with more than 60 new publications by year (Fig. 3) quoting CAS. The content of these publications, however, has changed as CAS is not the main topic evaluated in the study, but just the tool used to perform the operation.

The second group with a continuous increase of the number of publications/year comprises: accelerometers, sensor technologies, and robotically assisted knee arthroplasties. For the first two technologies, the number of publications continuously increased over the last 10 years (Fig. 2b) with more than 20 articles reporting their results by year currently. The number of publications concerning robotically assisted knee arthroplasty is also rising quickly since 2000, with a rapid increase since 2012 and more than 80 publications in 2020. Nevertheless, currently we did not find the same transition between the papers assessing these devices and the papers quoting them, as for CAS.

Evolution of surgical techniques in knee arthroplasty in national registries

Only two registries have detailed the surgical techniques in knee arthroplasty: the Australian and Norwegian registries. They reported similar results than in the literature, with the lack of decrease in new techniques.

In the Australian registry, the proportion of primary TKA performed by computer-assisted systems increased from 2% in 2003 to 32% in 2019 [16] (Fig. 4). In 2019, a computer-assisted system was used in 32% of all primary TKA. The robotically assisted system follows the same increase for the UKA. The proportion of UKA using robotic assistance had risen from 7% in 2015 to 30% in 2019 [16]. In 2019, 30% of UKA used robotic assistance.

In the Norwegian registry, the proportion of computer-assisted TKA remained between 8 and 12% of primary TKA since 2007 [17]. In 2019, computer navigation was used in 8% of all primary TKA [17]. The number of cases operated with a computer-assisted system remains steady, even if there are some fluctuations from year to year.

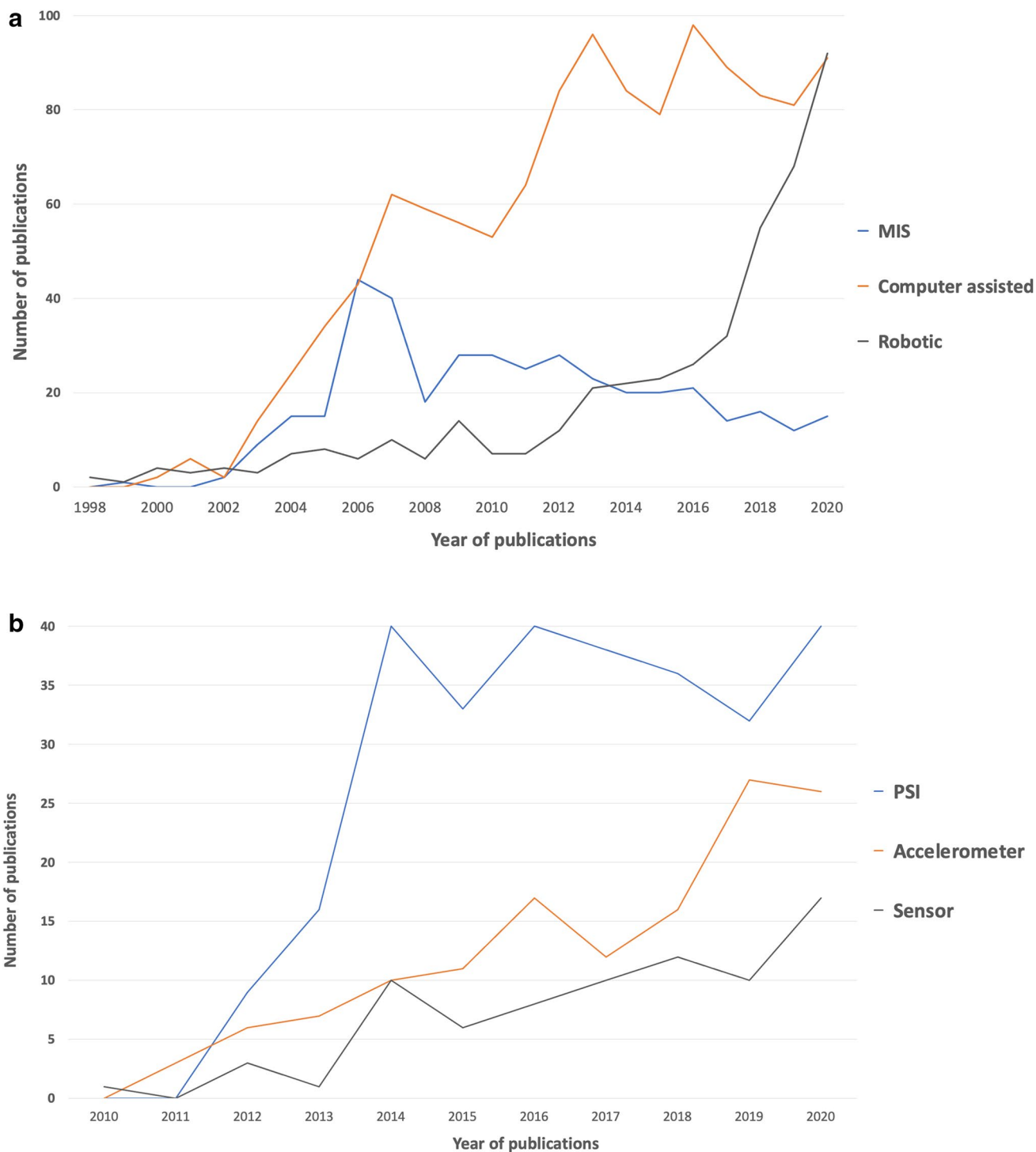


Fig. 2 **a** Evolution of the publications number by year on the orthopedic techniques over the last 20 years, including MIS, computer-assisted system and robotically assisted system. **b** Evolution of the publications number by year on the orthopedic techniques over the last 10 years, including PSI, accelerometer, sensor and machine learning

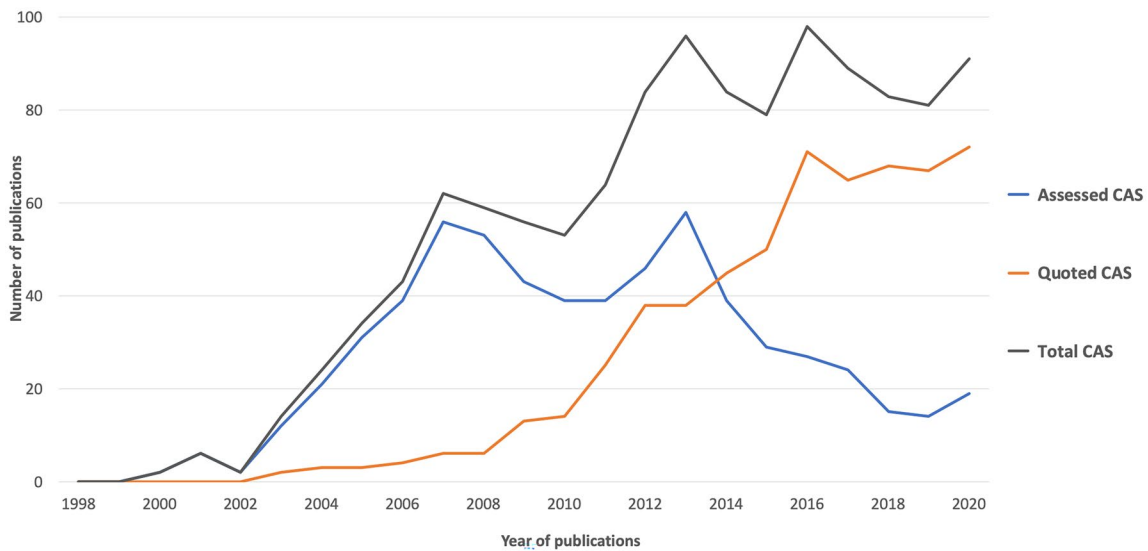


Fig. 3 Evolution of the publications number by year on computer-assisted knee arthroplasties over the last 20 years, with the articles assessing the computer-assisted system (assessed) and the articles where this system was used usually (quoted)

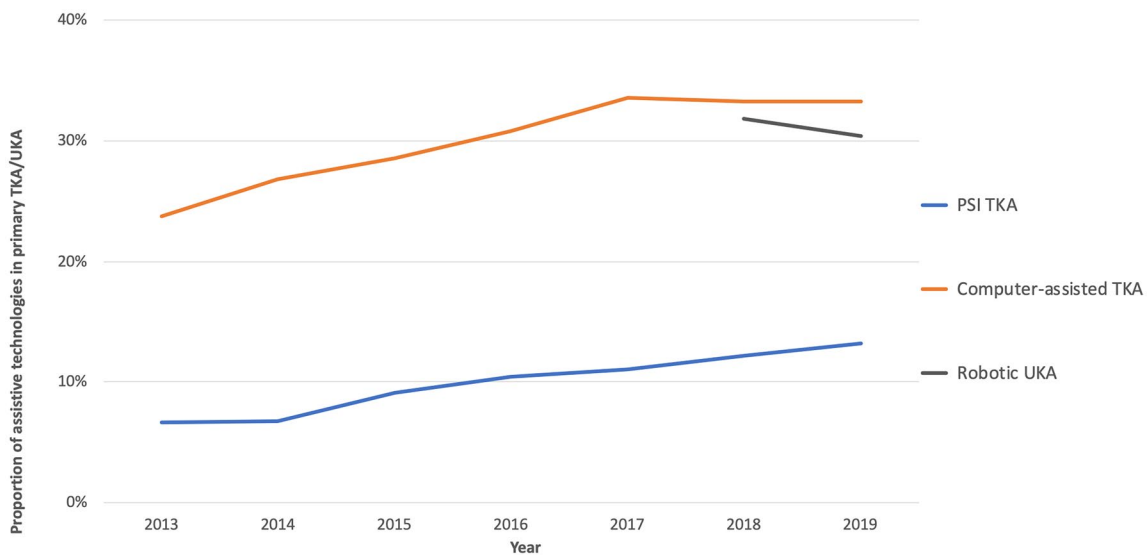


Fig. 4 Proportion of primary TKA performed by computer-assisted system or PSI, and proportion of primary UKA performed by robotically assisted system in the Australian registry between 2013 and 2019

Discussion

The main findings of this study were first that publications concerning these assistive technologies experienced a high rise during their development phase and maintained an important interest year by year. Second, the usage as described in the joint registries remains stable without observing any real decline.

Based on the literature screening and the analysis of publications per year, the assistive techniques assessed in

this study are not following the “Scott’s parabola”. For earlier innovations, such as CAS, the publications number remained high, but the type of publications has evolved. The articles assessing the efficiency of these techniques have decreased drastically. Only few articles have been published to evaluate these techniques with a strong study design or a long follow-up [18, 19]. Most current publications, quoting CAS use it as a tool now within the study, where CAS is no longer the objective of that study. This “consolidation phase” can be interpreted as a form of maturity of the technique. It’s also interesting to consider

the synergy between different techniques and concepts in the literature linked to each other like the pieces of a puzzle. Indeed, the real need for CAS has exponentially grown as a tool to improve the position of the implants when surgeons started to reduce the length of their incisions [20]. Then, CAS was considered accurate, but time consuming and cumbersome. Furthermore, it asked for a capital investment from surgeons and hospitals. Therefore, PSI and accelerometers have been developed to answer these needs. Thanks to the use of PSI, surgeons discovered the interest of limiting the number of surgical tools to improve surgical efficiency. The concept of optimizing OR efficiency increased. In parallel, interest for new alignment concepts started to gain interest and this interest never declined. Bone cuts were improved but surgeons realized that the analysis of the ligament tension was an important factor to integrate, aiming for less releases. That is when the interest for the sensors started to grow. Modern robotic platforms are integrating all these parameters and will probably continue to evolve integrating augmented reality to be able to visualize 3D and to use intra-operatively a 3D planning without having to look at a screen while operating. AI tools will also probably become a part of the platforms as most of these systems are giving direct feedbacks on a significant number of intricate surgical parameters such as component position, bone resections, femoral rotation [21], ligament balancing [22], and global alignment [23].

The registries' data are limited, but they confirmed the persistent use of some surgical technique or technology, such as computer-assisted. Contrary to the publications, the registries report the practice of all surgeons in a country and not only in highly specialized surgical centers. Boylan et al. confirmed this evolution for the robotic and computer navigation technology in the New York State [24]. They reported that the proportion of cases using technological assistance grew each year in the New York State, increasing from 4.3% in 2008 to 11.6% in 2015. The proportion of hospitals and surgeons using robotic assistance also increased from 16.2% of hospitals and 6.2% of surgeons in 2008 to 29.2% of hospitals and 17.1% of surgeons in 2015. Similar results have been reported in the Nationwide Inpatient Sample database from 2005 through 2014, corresponding to the largest nationwide all-payer hospital inpatient care database in the United States (approximately 20% sampling of all hospital discharges) [25]. The proportion of technology-assisted TKAs steadily increased in this database from 1.2% in 2005 to 7.0% in 2014. Even if these studies were on a smaller scale, they confirmed the persistence, and even the growth, of the use of these surgical techniques.

The opponents of assistive technology in orthopedic surgery present these innovations as a fashion, sometimes dangerous due to unknown complications. Indeed, some

innovations in recent years have known this decline, such as metal-on-metal bearing surfaces [26], modular femoral stems for hip arthroplasty [27], or MIS low-profile tibial component [13]. Nevertheless, these devices or innovations did not represent the majority of new surgical technologies in orthopedic surgery. Scott's parabola, described for the metal-on-metal bearing surfaces [27], does not represent the evolution of all surgical techniques. The "consolidation phase" described for CAS is not yet reported for other assistive technologies. Some could also decrease, as for example the PSI described by several authors as disappointing [28, 29]. However, the PSI conserves a high interest for other reasons than the surgical accuracy. The PSI is recently used with customized implants [30], or to improve the cost-efficiency ratio in operating room with the concept of single-use instrumentation [31, 32]. Even if clear advantages and superiority of these assistive technologies are not yet proven, these innovations allow to progress slowly. Each technique contributes partially to a better understanding of what we are doing and how to achieve it to improve functional results and patient satisfaction after knee arthroplasty. And the robotic surgery would also be a step through achieving a more efficient technique, such as artificial intelligence and machine learning. The goal is thus to improve the surgical tools in knee arthroplasty continuously and not to replace them.

Several limitations can be outlined in our study. First, evaluating the interest for a technique through the number of publications might not be the ideal method; however, this has been used in the past for similar purposes [33]. Second, only some surgical techniques have been assessed and they are relatively recent, such as sensors or accelerometers. Potentially, their follow-up was not enough to assess their decline if any would happen. Nevertheless, CAS, or robotic surgery have sufficient follow-up to evaluate their evolution after the initial craze. Third, marketing has probably an essential part in the publication system. The pressure of some orthopedic device companies could increase the motivation to publish the assistive technologies advantages. That is also the reason why the second goal of the study was to evaluate the actual use of these technologies in the national registries which are independent of these marketing issues. To know the evolution and the use of a surgical technique, it would be preferable to assess the exact number of patients operated with each surgical technique all over the world. There is to date no data bank integrating all these data. On seven available national registries, only two reported some data on the surgical techniques in knee arthroplasty. The registries' follow-up is short, and their completeness is not absolute. For each registry, there are some missing data, whose proportion is not always known. The exactitude of these data is based only on the surgeons' conscientiousness. Despite these limitations, our study based on the analysis of a large amount of articles of the literature and the available

data from the registries is only the first of its kind including the latest technologies [33].

Conclusion

Most of the innovations in modern knee arthroplasties are not following the Scott Parabola. After a fast rise, these assistive technologies and new techniques do not disappear but continue to evolve. Their evolution is synergistic and combined to enhance the knee knowledge on how to restore the anatomy closer to a native knee after knee arthroplasty to improve the patients' clinical outcomes.

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Declarations

Conflict of interest CB: Grant from SoFCOT. SP: Royalties from Zimmer Biomet and Newclip; Consultant for Zimmer Biomet; Treasurer for European Knee Society.

Ethical approval Not applicable (publication metrics).

Informed consent Not applicable (publication metrics).

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