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REVIEW ARTICLE

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Time and costs related to computer-assisted versus non-computer-assisted implant planning and surgery. A systematic review

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[Correction added on 9 November 2021, after first online publication: The affiliations and its corresponding link to the authors have been corrected in this version.]

Abstract

Aim: To study the time and costs involved with computer-assisted versus non-computer-assisted implant planning and placement.

Material and methods: Based on the PICO question, "In patients receiving dental implants, is computer-assisted implant planning and surgery (CAIPS) compared to non-computer-assisted implant planning and surgery (non-CAIPS) beneficial in terms of treatment related costs and time involved?", a search path was created to perform an electronic search in the databases PubMed, PubMed Central, EMBASE, and Cochrane. The publication period of eligible publications extended from 01.01.2005 to 04.05.2020. Four independent reviewers reviewed the literature to identify studies that met the eligibility inclusion criteria. A further manual search of articles was performed, and gray literature was excluded. Corresponding authors of potentially eligible manuscripts were contacted for further information.

Results: Of the 1354 retrieved titles after the search were screened. Thirty-one articles have been identified to read the full text, resulting in four articles to be analyzed for the present review all of which were RCTs. In total, 182 partially and completely edentulous patients were treated with 416 implants following either non-computer-assisted or computer-assisted implant planning and surgery to determine the duration of the single working steps and the financial aspects of the different procedures.

Conclusions: When evaluating the time and costs involved with the diagnostic and planning procedures in computer-assisted implant planning and surgery workflow protocols, one can summarize that these are higher than in the non-computer-assisted workflow protocols. The time involved with the procedures appears to be the driving factor when it comes to economic considerations. On the basis of the conclusions, also the time for the prosthetic restoration should be taken into account.

KEYWORDS
computer-assisted implant placement, computer-assisted implant planning, computer-assisted surgery, costs, dental implants, guided implant surgery, implant planning, surgery, time

Tobias Graf and Christine Keul are shared first authorship.

1 | INTRODUCTION

The interdisciplinary planning for a successful implant-based dental therapy is dictated by the final prosthetic result. For a predictable and successful outcome of an individually fabricated implant-supported dental restoration, interdisciplinary communication and cooperation with simultaneous consideration of prosthodontics, periodontology, oral surgery, radiology, and dental technology is a relevant key factor (Joda et al., 2018). Optimal 3D positioning of dental implants is mandatory to achieve predictable prosthetics of standardized high quality, with predictable maintenance expense by preventing biological and technical complications. Paramount here is a precise treatment planning involving all surrounding clinical and anatomic structures in the procedure.

In this context, the computer-assisted implant planning and surgery, based on computer-aided design (CAD) technologies, gives the clinicians the possibility to combine DICOM-data (Digital Imaging and Communication in Medicine) and STL-data (Surface Tessellation Language) in a virtual software environment. This procedure provides clinicians the possibility to plan the optimal implant position in the patient's jaw in relation to all neighboring structures (e.g., teeth, bone, soft tissues, nerves). When following the static surgical approach, the surgical guides used to place the implants can be fabricated based on computer-aided manufacturing (CAM) by generating the toolpath for a subtractive (milling) or additive (3D printing) procedure (Jung et al., 2009). Hence, the planned ideal implant position can be transferred from the computer software to the patient using the surgical guides to direct the implant osteotomy without damaging the surrounding anatomical structures (Widmann et al., 2010).

The widespread method (non-computer-assisted—also named as freehanded—implant surgery based on 2D radiology) gives the clinician full flexibility to place the implant in the position, found to be most appropriate during surgery. However, this may also be challenging, as it often relies on clinical experience and further, due to the limited information of the 3D clinical situation provided by the 3D radiograph hence, the 3D operative area. In this context, 3D radiology and virtual planning of the surgery allows for a computer-assisted planning and surgery (CAIPS) procedure and optional placement of the implants. The obvious advantage of the 3D radiology is the visualization of the intraosseous structures or neighboring anatomical structures. CAD guides used in implant dentistry have been described in the literature as either tooth supported, soft tissue supported, bone supported, and implant supported. The guides themselves are then used either as pilot-drill guides that dictate the location or as guides that dictate the exact position and direction (fully guided) of the implant (Tahmaseb et al., 2014). Generally multiple computer-assisted or non-computer-assisted implant workflows are possible and are graphically displayed in Figure 1.

In the scientific literature, various studies can be found on the topic of a computer-assisted approach. Most of the recent systematic reviews specified clinically related outcomes like the accuracy (Jung et al., 2009), the success rate (prosthesis failure, implant failure, biological or prosthetic complications) (Colombo et al., 2017) or patient-reported outcome measures (Joda et al., 2018), for computer-assisted and non-computer-assisted implant planning and surgery.

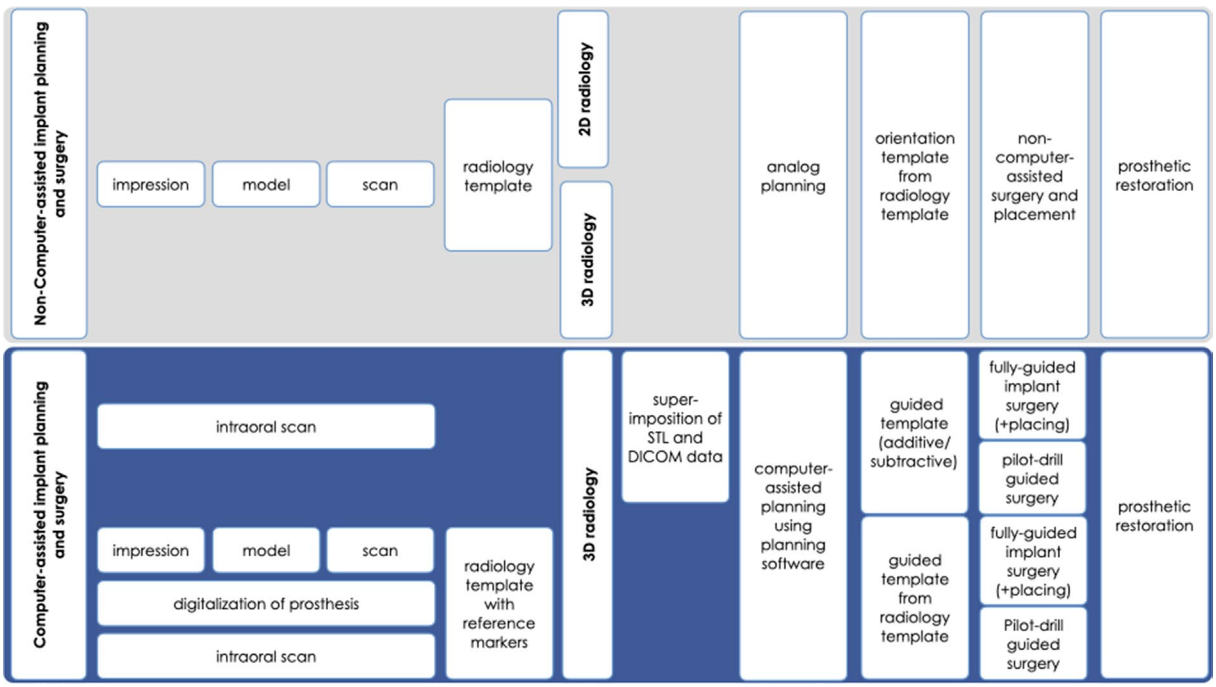


FIGURE 1 Abstracted possible workflows for computer-assisted and non-computer-assisted implant planning and surgery (3D: three-dimensional; 2D: two-dimensional; DICOM: Digital Imaging and Communications in Medicine; STL: Surface Triangulation or Tessellation Language)

TABLE 1 Search tree according to PICO questions

PICO - Question	"In patients receiving dental implants, is computer-assisted implant placement compared to non-computer-assisted implant placement beneficial in terms of treatment related costs and time involved?"
Population (#1)	P = Fully or partially edentulous patients receiving dental implants a. Dental implant, oral implant, endosseous implant, implant fixture b. MeSH: "Dental Implants," "Dental Implantation, Endosseous"
Intervention (#2)	I = Implant placement using computer-assisted surgery or non-computer-assisted surgery a. planning, computer-aided surgery, computer-assisted surgery, computer-guided surgery, surgical template, surgical guide, drill guide, drill template, guided implant planning, guided implant placement, guided surgery, Codiagnostix, Simplant, Nobel guide, exocat, implant Studio, Implant 3D b. MeSH: "Surgery, Computer-Assisted", "Planning Techniques"
Comparison (#3)	C = computer-assisted or non-computer-assisted treatment protocols a. pilot-drill, free hand, non-guided, implant insertion, implant placement, conventional surgery b. MeSH: "Dental Implantation, Endosseous"
Outcome (#4)	O = Time and costs of computer-assisted and non-computer-assisted surgery a. minute, duration, efficiency, costs b. MeSH: "efficiency", "operative time", "duration of therapy", "costs and cost analysis", "economics, dental", "economics, medical"
Search combination	#1 AND (#2 OR #3) AND #4

Information considering costs or time for the single planning and surgical steps is scarce in the literature. Therefore, the primary aim of the present systematic review was to analyze the scientific literature to evaluate whether time and cost involved for computer-assisted implant planning and surgery (CAIPS) is different to non-computer-assisted implant planning and surgery (non-CAIPS). Secondary, additional information of the selected articles was summarized which of both procedures will be beneficial in terms of treatment-related clinical time and costs involved for the complete workflow.

2 | MATERIAL AND METHODS

The present systematic review follows the guidelines of the "Preferred Reporting Items of Systematic Reviews and Meta-Analysis (PRISMA)" (Moher et al., 2015). The aim of the study was to evaluate the differences between implant surgery workflows of computer-assisted versus non-computer-assisted implant planning and surgery. Primary outcome measures of the present review were defined to be time and costs in clinical practice. Factors concerning planning, manufacturing of drill guides, implant placement, and prosthodontic installation have been considered. Therefore, the following PICO question was developed: "In patients receiving dental implants, is computer-assisted implant planning and surgery compared to non-computer-assisted implant planning and surgery beneficial in terms of treatment related costs and time involved?" (Table 1).

2.1 | Definition of terms

With respect to computer-assisted implant planning and surgery, the following steps are included: (a) Implant planning software is applied, (b) implant positioning is determined by prosthetic and 3D radiological information, and (c) the planned osteotomy position is transferred to a dynamic or static implant surgery system. In a static implant surgery system, a surgical stent guides the implant drill into the predetermined position (pilot-drill guided and fully guided); in some clinical workflows, the implant can also be placed through the surgical stent. Non-computer-assisted implant planning and surgery was defined when implants were placed without previous computer-assisted implant planning.

2.2 | Search strategy

Based on the PICO question, a search path was created (Table 1), which was used to perform an electronic search in the databases PubMed, PubMed Central, EMBASE, and Cochrane. The search syntax was built by different combinations of free-text words as well as Medical Subject Headings [MeSH®/EMTREE®].

The following search path is exemplary for the PubMed database: (dental implant*[TIAB] OR oral implant*[TIAB] OR endosseous implant*[TIAB] OR implant fixture*[TIAB] OR "Dental Implants"[Mesh] OR "Dental Implantation, Endosseous"[Mesh]) AND (pilot drill*[TIAB] OR free hand*[TIAB] OR non-guided*[TIAB] OR implant insertion*[TIAB] OR implant placement*[TIAB] OR conventional surgery*[TIAB] OR "Dental

Implantation, Endosseous"[Mesh] OR "Planning Techniques"[Mesh] OR planning*[TIAB] OR "Surgery, Computer-Assisted"[Mesh] OR Computer aided surgery*[TIAB] OR Computer assisted surgery*[TIAB] OR Computer guided surgery*[TIAB] OR guided implant planning [TIAB] OR guided implant placement [TIAB] OR guided surgery [TIAB] OR surgical template*[TIAB] OR drill guide*[TIAB] OR drill template*[TIAB] OR surgical guide*[TIAB] OR Codiagnostix*[TIAB] OR Simplant*[TIAB] OR Nobel guide*[TIAB] OR exocat*[TIAB] OR implant Studio*[TIAB] OR Implant 3D[TIAB]) AND (efficiency[MeSH Terms] OR operative time[MeSH Terms] OR duration of therapy[MeSH Terms] OR costs and cost analysis[MeSH Terms] OR economics, dental[MeSH Terms] OR economics, medical[MeSH Terms] OR (minute*[TIAB] OR min[TIAB] OR duration*[TIAB] OR efficiency*[TIAB] OR costs*[TIAB])). The publication period of eligible publications extended from 01.01.2005 to 04.05.2020. The reviewers did a hand search on the references from the four included articles. Furthermore, gray literature was excluded.

2.3 | Eligibility criteria

Following inclusion criteria were defined:

- Clinical trials (randomized controlled trials, prospective or retrospective cohort studies)
- Human studies
- Articles in English language
- Cohort studies including at least 10 patients
- Studies reporting on conventional and/or digital implant planning including the used systems (software, applications, techniques, etc.)

Following exclusion criteria were defined:

- Animal studies
- In vitro studies
- Case reports
- No control group
- Finite element analysis
- Technical reports
- Systematic reviews
- Insufficient information on defined outcome criteria
- Absence of objective parameters
- Multiple publications on the same patient population
- Zygoma, pterygoid, and/or orthodontic implant planning
- Root-analogue implant planning
- Information older than 15 years

2.4 | Study selection and data extraction

Initially, all articles were checked for possible relevance to the topic by means of their title and, if not applicable, excluded [executed by TG, CK, DW, JG]. Then, the abstracts of the remaining articles were examined for eligibility criteria and possible relevance [executed by TG, CK, DW, JG]. Finally, in a third stage, the full texts were checked whether they met the inclusion criteria and contained relevant information concerning computer-assisted and/or non-computer-assisted planning and surgery in terms of time and costs [executed by TG, CK, DW, JG]. Furthermore, only articles were included which reported on objective numbers such as minutes or currency, as well as if precise information was given on what exactly was measured (e.g., time frame or procedure). This was carried out independently by four reviewers. Disagreements during the selection process were discussed and resolved after each stage; articles were only included if consensus between all four authors could be found. No articles were excluded due to non-consensus. Data were collected and filed in an Excel database and in EndNote.

The following data were extracted by two independent reviewers [executed by TG and CK] from each relevant full-text article, as far as available and summarized in a data extraction form:

- Author(s), year of publication
- Study design, outcomes
- Number of patients, of implants, of implants/patient, mean number of implants/patient, implant indications
- Planning software (brand and type)
- Specifications/type of drill guide
- Support of drill guide (soft tissue, tooth, bone, implant)
- Flap design
- Duration/time involved
- Costs
- Results and conclusions

The collected information was once again compared by the four reviewers [executed by TG, CK, DW, JG]. In addition, the corresponding authors were requested for further written explications if the information provided by the article was either not clear or missing.

2.5 | Quality assessment

The quality of the selected observational studies was evaluated according to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statements. CONSORT (Consolidated Standards of Reporting Trials) statements were applied for randomized clinical trials. The assessment of the bias risk of each study was evaluated using the "Rob 2 Tool," a tool to assess risk of bias in randomized trials. (Sterne et al., 2019) This tool includes algorithms that map responses to signaling questions to a proposed risk-of-bias judgment for each domain in the five domains included the following: (a) bias arising from the randomization process, (b) bias due to deviations from intended interventions, (c) bias due to missing outcome data, and (d) bias in measurement of the outcome and bias in selection of the reported result (see the full documentation at www.riskofbias.info for details). By the algorithm's specific mappings of each possible combination of answers to the signaling questions (including responses of “No information”) were comprised to grade the risk of bias into the classification low risk of bias, some

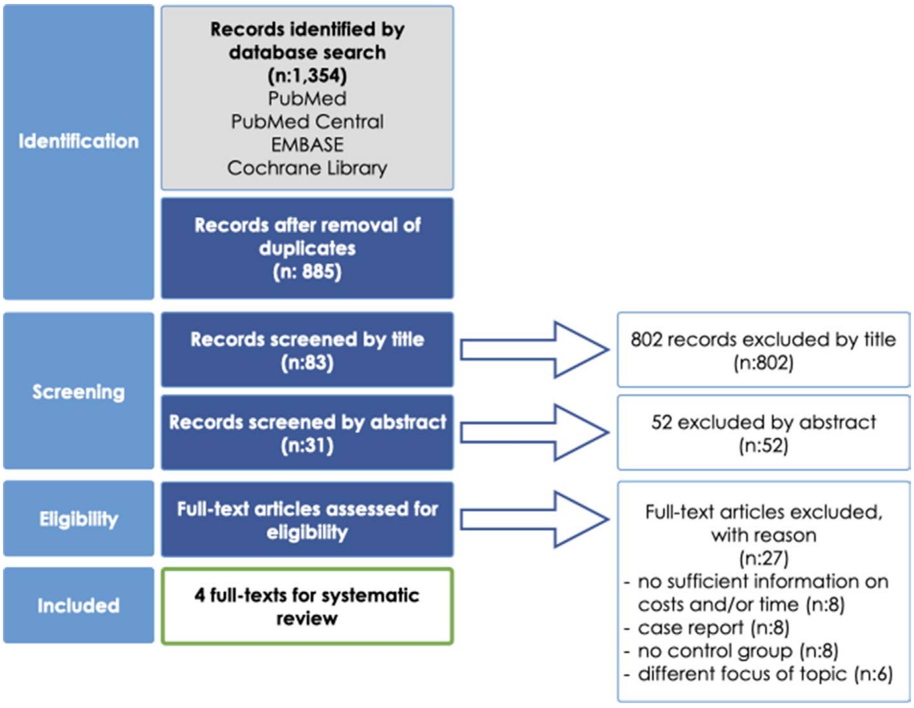
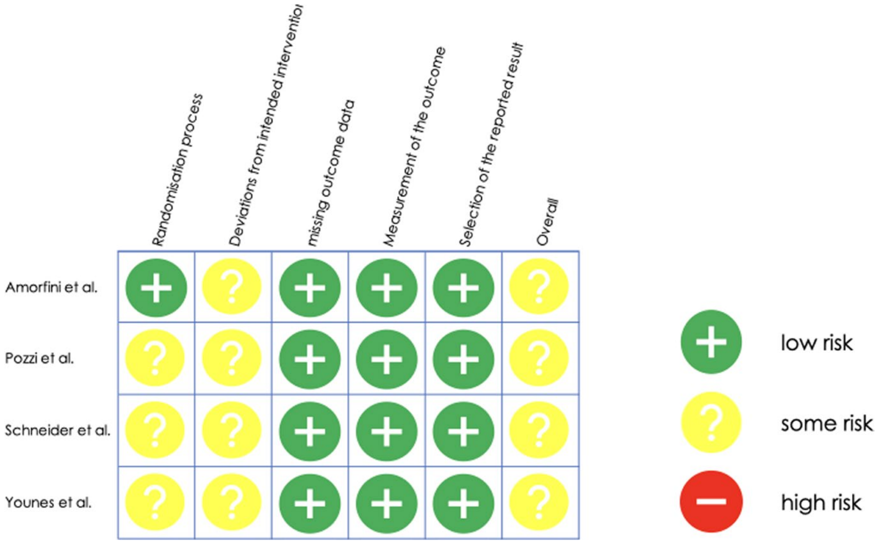


FIGURE 2 Traditional PRISMA flow diagram: Iterative evaluation process of literature

FIGURE 3 The "robvis (visualization tool)" graphically represent the bias risk assessment of the selected studies



concerns, or high risk of bias. (Higgins et al., 2019) The "robvis (visualization tool)" web application was used to graphically represent the bias risk assessment of the selected studies.

3 | RESULTS

Based on the PICO criteria, an electronic search was executed for the library databases PubMed, PubMed Central, EMBASE, and Cochrane Library. The evaluation process with the resulting literature for the use for the systematic review is given in Figure 2.

3.1 | Included studies

Of the 1354 retrieved titles after the search, 885 articles were screened after deleting all duplicates by means of the title. From these, 802 articles were excluded based on the title and 83 articles left were screened based on information in the abstract. In the further process, 52 articles were excluded after reading the abstract. Thirty-one articles have been identified to read the full text, resulting in four articles to be analyzed for the present review all of which were RCTs. (Amorfini et al., 2017; Pozzi et al., 2014; Schneider et al., 2019; Younes et al., 2019) Relevant publication dates ranged from

TABLE 2 Study characteristics of the involved full-text articles

Study characteristics				
First author	**Study year**	**Country**	**Study design**	**Outcomes**
Amorfini	2017	Italy	Prospective RCT (2 arms) • Fully guided • Non-computer-assisted	Duration (Secondary outcome)
Pozzi	2014	Italy	Multicenter RCT (2 arms) • Fully guided • Non-computer-assisted	Duration and costs (Secondary outcome)
Schneider	2019	Switzerland	RCT (3 arms) • Fully guided group 1: CBCT with splint • Fully guided group 2: CBCT and digital model data • Non-computer-assisted	Duration and costs (Primary outcome)
Younes	2019	Belgium	RCT (3 arms) • Pilot-drill guided • Fully guided • Non-computer-assisted	Duration and costs (Primary outcome)

2014 to 2019. The bias according to the "robvis (visualization tool)" web application is shown in Figure 3 and graphically represents the bias risk assessment of the selected studies.

Tables 2 and 3 give information on the included studies when evaluating study and patient characteristics. In total, 182 partially and completely edentulous patients were treated with 416 implants following either non-computer-assisted or computer-assisted (pilot-drill guided or fully guided surgical) procedures to determine the duration of the single working steps and the financial aspects of the different procedures.

The following software packages for implant placement planning have been used (Table 4): CoDiagnostix (Amorfini et al., 2017), NobelGuide (Pozzi et al., 2014), SimPlant versus SMOP (Schneider et al., 2019), and SimPlant Pro (Younes et al., 2019). Three studies used tooth-supported implant guides (Amorfini et al., 2017; Schneider et al., 2019; Younes et al., 2018), Pozzi et al. (2014) used a combination of soft tissue and tooth-supported drill guides. Schneider et al. (2019) placed only one implant per patient whereas for the three other studies, more than one implant per patient (between 2.22 and 3.96) was placed (Amorfini et al., 2017; Pozzi et al., 2014; Younes et al., 2019).

3.2 | Outcome for the parameter duration (time involved)

All of the four studies reported on the duration of the surgical procedure itself. Amorfini et al. provided written information to the authors for the time involved with the diagnostic and planning procedures. Pozzi et al. (2014) measured the time involved with planning and surgical procedure. Younes et al. (2019) registered the time involved with the planning. The most comprehensive registration of time involved was performed by Schneider et al, stating the duration for different diagnostic steps (e.g., alginate impression and cast production), planning steps (e.g., starting the hardware and software and import of DICOM), and surgical steps (e.g., guided bone regeneration and suture) (Schneider et al., 2019). Figure 4 displays the data on the time involved in diagnostics and planning, as well as the surgery. Amorfini et al. (2017) and Pozzi et al. (2014) presented additional information for the following prosthetic restoration. Amorfini et al. (2017) measured the time involved with the installation of the provisional restoration and gave written information for the time for the installation of the final prosthetic restoration. Pozzi et al. (2014) measured the time for installation of the prosthetic restorations and the time involved with the management of complications. Table 5 reports on the outcomes for the time involved (duration). The additional written information provided by the corresponding authors is colored in green.

3.3 | Outcome for the parameter costs

Two of the four studies stated the costs as EUR (Pozzi et al., 2014; Younes et al., 2019), while one study is based on CHF (Schneider et al., 2019). Amorfini et al. provided the costs as written information to the authors in EUR for the diagnostics, the planning, and the surgical guide. Also, additional information was presented for the therapy and the follow-up. Pozzi et al. (2014) stated specifically the additional costs for the CAIPS procedure. Schneider et al. (2019) stated higher costs for CAIPS procedures than for non-CAIPS differentiated for the different sub-procedures planning, splint production, and surgery. Younes et al. (2019) stated higher costs for the computer-assisted surgery. Table 5 reports on the outcomes for the costs. The additional written information provided by the corresponding authors is colored in green.

TABLE 3 Patient characteristics of the elected full-text articles (♂: male, ♀: female)

Patient characteristics					
First author	**No of patients**	**No of implants**	**ø No implants/patient**	**No implants/ patient**	**Implant indications**
Amorfini	26 (8 ♂/18 ♀) • Fully guided: 13 • Non-computer-assisted: 13 Further information: • Original: $n = 40$ • Excluded before randomization: $n = 12$ • Randomized: $n = 28$ • Received allocated intervention: $n = 13$/group • Lost to follow-up: $n = 1$/group • Analyzed: $n = 12$/group	70 • Fully guided: 36 • Non-computer-assisted: 34	2.69	Between 2 and 4	Monolateral partially edentulous
Pozzi	51 (29 ♂/22 ♀) • Fully guided: 25 • Non-computer-assisted: 26	202 • Fully guided: 103 • Non-computer-assisted: 99	3.96	At least 2	Partially and fully edentulous
Schneider	73 • Fully guided group 1: 24 • Fully guided group 2: 23 • Non-computer-assisted: 26	73 • Fully guided group 1: 24 • Fully guided group 2: 23 • Non-computer-assisted: 26	1	1	Partially edentulous
Younes	32 (11 ♂/21 ♀) • Pilot-drill guided: 11 • Fully guided: 10 • Non-computer-assisted: 11	71 • Pilot-drill guided: 24 • Fully guided: 21 • Non-computer-assisted: 26	2.22	At least 2	Partially edentulous

TABLE 4 Surgical guide characteristics of the elected full-text articles

Guide characteristics				
First author	**Planning software**	**Specifications of Guide**	**Support of Guide**	**Flap Design**
Amorfini	CoDiagnostix	• Manual (GonyX Parallelometer)	• Tooth supported	• Flapped minimally invasive for group fully guided • Flapped with vertical release for group non-computer-assisted
Pozzi	NobelGuide	• Fabrication of guides: stereolithography	• No information	• Flappless or with small flaps
Schneider	• Fully guided 1: Simplant • Fully guided 2: SMOP	• Fully guided 1: stereolithography • Fully guided 2: 3D printing	• Tooth supported (Schneider et al., 2018)	• Flapped
Younes	Simplant Pro (Younes et al., 2018)	• Fabrication of guides: stereolithography • Group pilot-drill guided: Simplant pilot-drill guide with depth control • Group fully guided: Simplant SAFE guide with metal sleeves	• Tooth supported	• Flappless for groups computer-assisted • Flapped for group non-computer-assisted

3.4 | Summaries of the articles' conclusions

Table 6 gives an overview on the author´s summaries of the included studies.

Amorfini et al. concluded a significantly reduced surgical duration for fully guided implant planning and placement compared with the non-computer-assisted group. Furthermore, the time for the installation of the provisional restoration was reduced by the fully guided procedure (Amorfini et al., 2017).

Pozzi et al. concluded no significant differences for the duration of the surgical procedure. However, the CAIPS procedure resulted in additional costs of 646 EUR due to the more expensive surgical kit and 32.90 EUR per implant (up to four implants) and 30.00 € per implant (more than four implants) for the surgical guide. Further—in view of the duration—no significant difference was found for the installation of the prosthetic restoration and the management of complications (Pozzi et al., 2014).

Schneider et al. stated similar time for diagnostic, radiographic imaging, and operative treatment duration for fully guided groups and non-computer-assisted group. In addition, a significantly higher duration was found for surgical planning and drill guide fabrication within the fully guided group than in the non-computer-assisted group, as well as higher costs for the fully guided procedure compared with non-CAIPS (Schneider et al., 2019).

Younes et al. (2019) concluded that there was significantly lower planning and surgery time involved with non-CAIPS in comparison with both groups applying CAIPS and no difference in the time involved with planning and surgery between pilot-drill guided and fully guided procedures. Further, significant lower surgical costs arise for non-computer-assisted groups when compared to a pilot-drill-guided group and significant lower surgical costs of pilot-drill-guided groups when compared to fully guided group. Younes et al. summarize that extra surgical costs involved with guided implant surgery are acceptable and clinically justified since cementation of superstructure can be avoided. In addition, the fully guided surgery is the most efficient surgical approach, even though the absolute surgical costs are higher when compared to pilot-drill-guided and non-computer-assisted groups (Younes et al., 2019).

4 | DISCUSSION

This review aimed to analyze and to discuss the factors time and costs regarding a computer-assisted versus a non-computer-assisted implant planning and surgery procedure. From the everyday clinical perspective, these parameters are often decisive for the implementation of new technologies in the clinical routine. For implant-based treatment, different planning and treatment steps can be distinguished and analyzed, starting with the diagnostics, planning, and the surgical treatment itself. A further factor is the subsequent placement of the prosthetic components.

The time regarding diagnostics and pre-surgical planning is reported to differ significantly between computer-assisted and

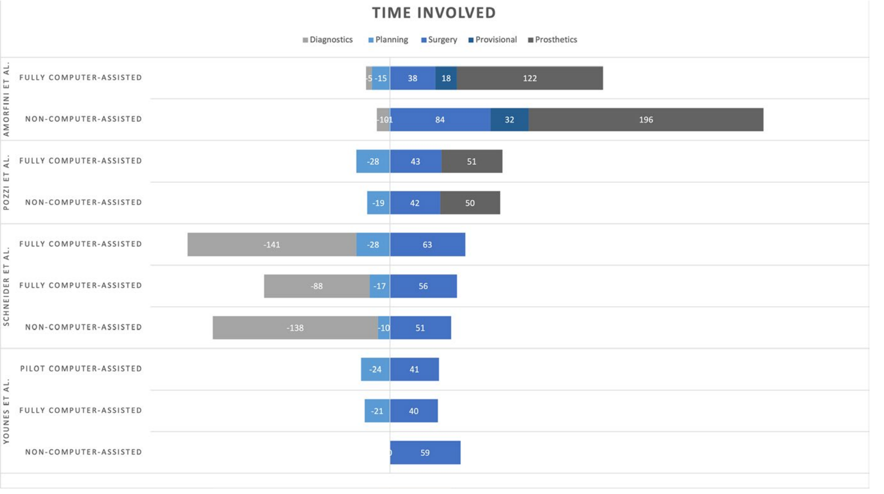


FIGURE 4 Comparison of time involved in diagnostics and planning (negative numbers), as well as the duration of surgery and prosthetic restoration (positive numbers)

non-computer-assisted procedures by Schneider et al. (2019) and Younes et al. (2019), while Pozzi et al. (2014) found no significant differences. However, the planning effort for non-computer-assisted procedures is reported by Amorfini et al. (2017)[1] to be 1 min or by Younes et al. (2019) to be 0 min, which needs to be critically scrutinized. Because one must recognize that there is always time involved with diagnostics and procedure planning. Considering the next step—the surgical procedure of implant placement itself—this trend becomes weaker. Considering only the surgical process itself, Amorfini et al. (2017) report an advantage of in average 23 min for the computer-assisted procedure, as well as Younes et al. (2019) with 18 min. Pozzi et al. (2014) did not find a significant time difference. Schneider et al. reported on 45.7 and 43.4 min for both computer-assisted groups (without guided bone regeneration) compared with 36.9 min for non-computer-assisted group. However, no significant differences were reported (Schneider et al., 2019). When taking the whole treatment workflow into account (diagnostics, planning, and surgery), computer-assisted protocols seem to lead to advantages over non-computer-assisted protocols in terms of time and effort. The question remains, if the described time effort at the beginning of the treatment workflow pays off economically at the end of the treatment, when the full process chain including the prosthetic restoration is considered. Generally, this review combines the two factors of time and costs together—due to the fact—they are in close relation with each other.

The included articles report that also the planning process seems to cost a higher effort and is more expensive when following a computer-assisted procedure. The comparison of time and costs within studies shows that for CAIPS diagnostic and planning, procedures take more time (3%–45%) and involve higher costs (58%–73%). Contradictory findings are reported on the time and costs involved with the implant surgery procedure itself.

Schneider et al. reported higher costs for a CBCT examination (350 CHF)—needed for the computer-assisted surgery—versus those involved with classical 2D X-rays (140 CHF). These costs consist additionally of the software costs for virtual planning, as well as the necessary time for planning. Considering both diagnostics and planning together, the trend is still clear: Higher effort and costs involved with computer-assisted planning. In this context, one effort- and cost-driver for the computer-assisted procedure seems to be the possibly necessary fabrication of a radiology template. The decision where the guiding surgical template is physically fabricated can be taken individually due to factors such as location of the 3D printer or mill, know how as well as workflow and economic considerations. However, even when no radiology template is necessary the investment in the CBCT scanner and the extensive operating costs for the digitalization of the clinical situation need to be balanced.

When following the alternative approach of superimposing DICOM (Digital Imaging and Communication in Medicine) and the digital STL-datasets (Surface Triangulation/Tessellation Language) of the clinical situation—without using a radiology template—the involved time and costs can be reduced. For sure, the implant surgeon is still responsible for the planning and outcome of the surgery. So only the prearrangements for planning, like importing the DICOM and STL-datasets and their alignment, as well as creating the digital mockup can be delegated. The important control of the superimposition of STL and DICOM as well as the choice of implant and final decision concerning the positioning is a clear task for the implant surgeon and in his/her responsibility. This approach in the restorative team has previously been described (Schubert et al., 2019).

Against this background—when considering the full process chain including the prosthetic restoration—it places the CAIPS procedure in a different light. When evaluating the full workflow (diagnostics, implant surgery, the manufacturing of the prosthetic parts, and insertion of the final implant restoration), the costs involved are still higher (8%–11%) for computer-assisted implant surgery protocols. When evaluating the time involved regarding the full workflow (diagnostics, implant surgery, the manufacturing of the prosthetic parts, and insertion of the final implant restoration), results are contradictory, reported to be either longer (9%) or shorter (39%) when computer-assisted implant surgery protocols are applied.

[1]Information received after correspondence with the author

TABLE 5 Time involved (duration) and cost outcomes of the elected full-text articles. Written additional information of the authors is colored in green

Time and costs outcome		
First Author	**Time [min]**	**Costs**
Amorfini	Diagnostic • Fully guided: 5 • Non-computer-assisted: 10 Planning • Fully guided: 15 • Non-computer-assisted: 1 Surgery (mean ± standard deviation) • Fully guided: 38 ± 2 • Non-computer-assisted: 47 ± 6 Installation of provisional (mean ± standard deviation) • Fully guided: 18 ± 2 • Non-computer-assisted: 32 ± 4 Installation of superstructure • Fully guided: 122 • Non-computer-assisted: 196	Diagnostic [EUR] • Fully guided: 150 • Non-computer-assisted: 75 Planning [EUR] • Fully guided: 350 • Non-computer-assisted: 100 Surgical guide [EUR] • Fully guided: 500 • Non-computer-assisted: 250 Therapeutic [EUR] • Fully guided: 2400 • Non-computer-assisted: 2600 Follow-up [EUR]: • Fully guided: 250 • Non-computer-assisted: 250
Pozzi	Planning Fully guided: 28.20 Non-computer-assisted: 18.85 Surgery (mean ± standard deviation) • Fully guided: 42.68 ± 21.44 • Non-computer-assisted: 42.31 ± 2 ± 3.33 Installation of superstructure (mean ± standard deviation) • Fully guided: 51.40 ± 3.34 • Non-computer-assisted: 50.40 ± 15.34 Complication time (mean ± standard deviation) • Fully guided: 5.20 ± 14.54 • Non-computer-assisted: 3.08 ± 11.92	• 646 Euro additional treatment costs for computer-assisted procedure (higher cost for the computer-assisted surgical kit) • Additional costs for the surgical guide: 32.90 Euro per implant up to four implants and 30 Euro per implant over four implants
Schneider	Diagnostic—Alginate impression (median) • Fully guided (1): 5.9 • Fully guided (2): 5.9 • Non-computer-assisted: 5.8 Diagnostic—Cast production/articulator (median) • Fully guided (1): 37 • Fully guided (2): 33 • Non-computer-assisted: 40 Diagnostic—Wax-up (median) • Fully guided (1): 17 • Fully guided (2): 17 • Non-computer-assisted: 14 Diagnostic—Digitalization of cast (median) • Fully guided (1): 9.9 • Fully guided (2): 19.5 • Non-computer-assisted: 0 Diagnostic—Radiographic template production (median) • Fully guided (1): 62 • Fully guided (2): 0 • Non-computer-assisted: 70	Planning—Diagnostics and patient information (CHF) • Fully guided (1): 211 • Fully guided (2): 211 • Non-computer-assisted: 211 Planning—Alginate impression (CHF) • Fully guided (1): 74 • Fully guided (2): 74 • Non-computer-assisted: 74 Planning—Intermaxillary registration (CHF) • fully guided (1): 34 • fully guided (2): 34 • non-computer-assisted: 34 Planning—Cast production (CHF): • Fully guided (1): 89 • Fully guided (2): 89 • Non-computer-assisted: 89 Planning—Cast articulation (CHF): Fully guided (1): 28 Fully guided (2): 28 Non-computer-assisted: 28

(Continues)

TABLE 5 (Continued)

Time and costs outcome		
First Author	**Time [min]**	**Costs**
	Diagnostic—Radiographic examination (median) • Fully guided (1): 9 • Fully guided (2): 13 • Non-computer-assisted: 8.2 Planning—Start hardware (median) • Fully guided (1): 1.7 • Fully guided (2): 1.0 • Non-computer-assisted: 0 Planning—Start software (median) • Fully guided (1): 0.6 • Fully guided (2): 0.6 • Non-computer-assisted: 0 Planning—Import DICOM (median) • Fully guided (1): 1.7 • Fully guided (2): 1.1 • Non-computer-assisted: 0 Planning—Prepare data (median) • Fully guided (1): 2.4 • Fully guided (2): 5.9 • Non-computer-assisted: 0 Planning—Implant planning (median) • Fully guided (1): 3.5 • Fully guided (2): 2 • Non-computer-assisted: 5.5 Planning—Export of data (median) • Fully guided (1): 2.9 • Fully guided (2): 2.1 • Non-computer-assisted: 0 Template—Surgical template production (median) • Fully guided (1): 15.120 • Fully guided (2): 4.320 • Non-computer-assisted: 4.4 Surgery—Flap elevation (median) • Fully guided (1): 6.5 • Fully guided (2): 6.5 • Non-computer-assisted: 6.1 Surgery—Implant placement (median) • Fully guided (1): 23.2 • Fully guided (2): 18.5 • Non-computer-assisted: 20.9 Surgery—Guided bone regeneration (median) • Fully guided (1): 20 • Fully guided (2): 15.2 • Non-computer-assisted: 14.8 Surgery—Suture (median) • Fully guided (1): 13.4 • Fully guided (2): 15.4 • Non-computer-assisted: 9.1	Planning—Antagonist cast calculation (CHF) • Fully guided (1): 27 • Fully guided (2): 27 • Non-computer-assisted: 27 Planning—Wax-up per unit (CHF) • Fully guided (1): 39 • Fully guided (2): 39 • Non-computer-assisted: 38 Planning—Radiographic template production (CHF) • Fully guided (1): 299 • Fully guided (2): 5,9 • Non-computer-assisted: 299 Planning—Cast digitalization (CHF) • Fully guided (1): 28 • Fully guided (2): 56 • Non-computer-assisted: 0 Radiography—Examination (CHF) • Fully guided (1): 350 • Fully guided (2): 350 • Non-computer-assisted: 140 Surgical splint—Production (CHF) • Fully guided (1): 463 • Fully guided (2): 409 • Non-computer-assisted: 0 Surgery—Anesthesia (CHF) Fully guided (1): 34 Fully guided (2): 34 Non-computer-assisted: 34 Surgery—Implant placement (CHF) • Fully guided (1): 595 • Fully guided (2): 595 • Non-computer-assisted: 595

(Continues)

TABLE 5 (Continued)

Time and costs outcome		
First Author	**Time [min]**	**Costs**
Younes	Planning (mean ± standard deviation) • Pilot-drill guided: 23.73 ± 10.96 • Fully guided: 21.40 ± 3.34 • Non-computer-assisted: 0 Surgery (mean ± standard deviation) • Pilot-drill guided: 41.36 ± 13.87 • Fully guided: 40.10 ± 17.03 • Non-computer-assisted: 58.64 ± 14.32 Total (mean ± standard deviation) • Pilot-drill guided: 65.09 ± 21.38 • Fully guided: 61.50 ± 18.86 • Non-computer-assisted: 58.64 ± 14.32	Standard costs [EUR] (mean ± standard deviation) • Pilot-drill guided: 2130 ± 0 • Fully guided: 2130 ± 0 • Non-computer-assisted: 2130 ± 0 Fixed costs for all groups [EUR] • CBCT: 130 • Implant: 900 • Superstructure: 1100/restoration Additional costs for computer-assisted groups [EUR] • Preoperative impression both jaws: 75 • Models, wax-up, scan: 78.64–87.10 • Surgical guide for pilot-drill-guided group: 230 • Surgical guide for fully guided group: 275 • Sleeve: 18 Additional costs [EUR] (mean ± standard deviation) • Pilot-drill guided: 176.34 ± 27.03 • Fully guided: 222.52 ± 24.60 • Non-computer-assisted: 0 Total [EUR] (mean ± standard deviation) • Pilot-drill guided: 2306.54 ± 27.03 • Fully guided: 2352.53 ± 24.60 • Non-computer-assisted: 2130 ± 0 Increase of costs compared with non-computer-assisted • Pilot-drill guided: 108.29% • Fully guided: 110.45%

When assuming practice operating costs in Europe of 300 €/h (5 €/min) in a dental office and combining those with the data of Amorfini et al. (2017), it will result in the following thought experiment: The time involved with diagnostics and planning, surgery, and prosthetics, the duration of the computer-assisted protocol is reported to be 198 min versus 286 min for the non-computer-assisted one, resulting in operating costs of 990 € (198 min*5 €/min) for the computer-assisted versus 1430 Euros (286 min*5 €/min) for the non-computer-assisted approach. Combining these numbers with the reported costs of 3400 € (computer-assisted) versus 3025 € (non-computer-assisted), the overall financial effort is 4390 € for the computer-assisted surgery versus 4455 € for the non-computer-assisted surgery procedure. This displays that—when the economic aspects of computer-assisted surgery procedures are evaluated—the whole workflow from planning to final superstructure should be taken into account. Based on the presented literature, a time difference of about 286−198 = 88 min emerges, when comparing the computer-assisted versus the non-computer-assisted protocol. Hence, depending on the abovementioned operating costs per hour in Europe of around 300 €, this means and extra financial amount of 440 € for the computer-assisted approach.

Considering the economics in view of time and costs, the cost structure of the individual dental office plays a decisive role. Taking into consideration that about 40% of the operating costs are related to staff, the chair-time involved with treatments seems to offer the highest advantage (Bundeszahnärztekammer_und_Kassenzahnärztliche_Bundesvereinigung, 2020). One solution to enhance the economic aspect could be the outsourcing of the prearrangements for the planning procedure to for instance the dental laboratory or a specialized dental technician. However, when taking the time, cost, and technique sensitivity into account for all disciplines, a practical routine for successful use is necessary. The outsourcing can offer a high potential for cost reduction and enhancing time efficiency for the dentist, considering that operating costs of a dental laboratory are mostly below those of a dental office. Based on the economies of scale, this could offer some major advantages: (a) The software can be optimally used, because the laboratory has multiple customers that send their planning cases which can significantly reduce the software costs/case analyzing costs; (b) due to the high number of cases, the dental technician/laboratory can develop a high level of routine and knowledge that leads to high level of efficiency; and (c) the dental technician is immediately involved at the beginning of the treatments. Thus, important considerations and decisions within the restorative team of surgeon, prosthodontist, and technician can be made before the treatment is initiated, for example, regarding the material choice of the restoration and technical feasibility.

Following limitations should be considered for the present review: First, scientific evidence of the time and cost involved with computer-assisted implant planning and surgery (CAIPS) protocols versus non-computer-assisted implant surgery protocols is rare.

TABLE 6 Information for summary according to the authors of the evaluated full-text articles

Summary	
First author	**Results/Conclusions**
Amorfini	• Significantly reduced surgical duration for fully guided group compared with group non-computer-assisted • Significantly reduced duration for installation of provisional fully guided for group compared with non-computer-assisted group
Pozzi	• No significant difference in surgical duration • No significant difference in prosthetic duration • No significant difference in complication duration
Schneider	• Similar time for diagnostic, radiographic imaging, and operative treatment duration for fully guided groups and non-computer-assisted group • Fully guided groups need significantly higher duration for surgical planning and splint fabrication than non-computer-assisted group • Fully guided groups result in higher costs than non-computer-assisted group
Younes	• Significant lower planning duration and longer surgery duration for non-computer-assisted group in comparison with both computer-assisted groups • No difference for planning duration and surgery duration between pilot-drill-guided group and fully guided group • Significant lower surgical costs of non-computer-assisted groups when compared to pilot-drill-guided group • Significant lower surgical costs of pilot-drill-guided groups when compared to fully guided group • The extra surgical cost for computer-assisted implant surgery is acceptable and clinically justified since cementation of superstructure can be avoided • Fully guided group is the most efficient surgical approach, even though the absolute surgical cost is higher when compared to pilot-drill-guided and non-computer-assisted groups

Only two RCTs report on duration and costs as the primary outcome, two as secondary outcomes. Hence, a statistical meta-analysis would be underpowered to detect statistically significant differences between the computer-assisted and non-computer-assisted surgical procedures for the parameters duration and cost. Second, the data extracted are too heterogeneous, as the single treatment steps are defined and reported in various ways by the authors. To ensure that no information from other studies will be missed all references of the included remaining four articles were additionally screened for further information. Based on this additional screening process, 129 articles were found, but no further relevant information could be found, and no article met the inclusion criteria.

So even when there is no clear immediate economic advantage of a computer-assisted surgery procedure, significantly enhancement of the implant positions and angulations is reported. These computer-assisted systems have been developed to facilitate optimal implant placement in relation to the planned prosthesis. Non-CAIPS gives the clinician full flexibility to place the implant in the position, found to be most appropriate. The appropriate position is hereby often based on clinical experience. The non-computer-assisted technique does display adequate success rates in the hands of experienced clinicians, but shortcomings have been described (Alevizakos et al., 2019; Choi et al., 2017; Schnitman et al., 2014; Vermeulen, 2017). The angular and vertical discrepancies for non-computer-assisted method of implant placement were reported to be up to three times higher when compared to computer-assisted implant placement (Vermeulen, 2017). Systematic reviews showed a mean overall inaccuracy for computer-aided implant surgery of the final three-dimensional position of the implant of 1.1 mm at the entry point, 1.4 mm at the apex, and a deviation of the implant angulation of around 4 degrees (Jung et al., 2009; Schneider et al., 2009; Tahmaseb et al., 2014, 2018; Vercruyssen et al., 2014). However, in their systematic review, Tahmaseb et al. demonstrated that although the accuracy on average remained within a clinically acceptable range, the maximal deviations were unacceptable. The analyzed data showed a mean inaccuracy at the implant entry point of 1.12 mm with system outliers of 4.5 mm, and a mean inaccuracy of 1.39 mm at the apex of implants with outliers of 7.1 mm (Tahmaseb et al., 2014).

The higher accuracy and repeatability lead to multiple advantages. One is a "simpler" laboratory workflow with a more predictable and technically reliable outcome with fewer compromises in quality, material choice, and construction of the prosthetic supply. Amorfini et al. (2017) mirror this by the fact that the placement of the prosthetic components is significantly faster. Further, the data of Pozzi et al. (2014) show a lower standard deviation for the time needed for installation of the prosthetic components, which indicate a higher predictability of the prosthetic procedure. Also, in view of the efficiency, it could be indicated that the more implants are placed for a prosthetic restoration the lower the price will be for the extra precision of the individual implant placed. Besides, this could lead to higher planning reliability in the daily routine with less unexpected surprises during surgery and final superstructure. In addition, the fact that more often screw retained restorations could be placed as reported by Younes et al. supports this finding (Korsch et al., 2014; Staubli et al., 2017; Younes et al., 2019). Even though the initial costs involved with non-computer-assisted implant placement were lower, computer-assisted implant placement showed higher implant survival rates and comparable long-term costs (Ravidà et al., 2018).

5 | CONCLUSIONS

1. When evaluating the time and costs involved with the diagnostic and planning procedures for CAIPS, it can be shown that these are higher than for non-CAIPS.
2. As operating costs are one of the driving economic factor in the implant dentistry practice not only material costs but especially the time involved for different procedure steps need to be considered.

6 | CLINICAL RECOMMENDATIONS

1. When calculating both the economic aspects and time involved with implant placement and implant restoration clinicians need to consider the total workflow to understand the benefits of CAIPS.
2. When evaluating the full workflow (diagnostics, implant placement, the fabrication of the prosthetic parts, and insertion of the final implant restoration) in both the computer-assisted and non-computer-assisted protocols, the differences in time and costs involved are reported contradictive.
3. The extra costs involved with computer-assisted surgery become less per implant the more implants are placed simultaneously and the effort and time involved with the procedure workflow becomes less per unit as well. Therefore, clinicians should consider weighing the extra efforts in time and costs against the improvement in predictability and precision when placing multiple implants.
4. When balancing economic factors against quality-related factors, CAIPS seem to lead to a more predictable procedure.

CONFLICT OF INTEREST

The authors declare no conflicts of interest. No funding was received for this review.

AUTHOR CONTRIBUTION

Christine Keul wrote—original draft (equal). **Tobias Graf** wrote—original draft (equal). **Jan Frederik Güth** wrote—review & editing (equal). **Daniel Wismeijer** supervised the study (equal).

ETHICAL APPROVAL

For this systematic review, an ethical approval was not required.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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