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CONSENSUS REPORT

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# Group 2 ITI Consensus Report: Technological developments in implant prosthetics

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## Abstract

**Objectives:** Group-2 reviewed the scientific evidence in the field of «Technology». Focused research questions were: (1) additive versus subtractive manufacturing of implant restorations; (2) survival, complications, and esthetics comparing prefabricated versus customized abutments; and (3) survival of posterior implant-supported multi-unit fixed dental prostheses.

**Materials and Methods:** Literature was systematically screened, and 67 publications could be critically reviewed following PRISMA guidelines, resulting in three systematic reviews. Consensus statements were presented to the plenary where after modification, those were accepted.

**Results:** Additively fabricated implant restorations of zirconia and polymers were investigated for marginal/internal adaptation and mechanical properties without clear results in favor of one technology or material. Titanium base abutments for screw-retained implant single crowns compared to customized abutments did not show significant differences concerning 1-year survival. PFM, veneered and monolithic

W. Derksen and T. Joda contributed equally as first authors to this manuscript.

zirconia implant-supported multi-unit posterior fixed dental prostheses demonstrated similar high 3-year survival rates, whereas veneered restorations exhibited the highest annual ceramic fracture and chipping rates.

**Conclusions:** For interim tooth-colored implant single crowns both additive and subtractive manufacturing are viable techniques. The clinical performance of additively produced restorations remains to be investigated. Implant single crowns on titanium base abutments show similar clinical performance compared to other type of abutments; however, long-term clinical data from RCTs are needed. The abutment selection should be considered already during the planning phase. Digital planning facilitates 3D visualization of the prosthetic design including abutment selection. In the posterior area, monolithic zirconia is recommended as the material of choice for multi-unit implant restorations to reduce technical complications.

**KEYWORDS**
clinical research, clinical trials, material sciences, patient centered outcomes, prosthodontics

## 1 | INTRODUCTION

The rapid technological progress influences our society like no other—and in dentistry this is no different. Due to the continuous development in the IT sector, completely new possibilities have emerged today. The MedTech industry is developing and marketing (digital) applications and tools faster than they can be scientifically investigated. Moreover, the technological turnover is so rapid that updates and follow-on products are already commercially available before the first generation of this technology could be sufficiently investigated.

Additive manufacturing in terms of 3D printing is one such example. A multitude of device manufacturers and an even greater variability of materials are on the market. Another example is the so-called titanium base abutment. As a prefabricated implant prosthetic component in combination with monolithic restorations, they have become indispensable in implantology, if the many case reports published on social media are to be believed. Last but not least, however, we clinicians are concerned about the long-term results to the whole of our patients. Is it just fancy and hip to use new technologies or is there scientific evidence? To what extent can these technologies be used without hesitation in daily practice today?

Working Group-2 «Technology» of the 7th ITI Consensus Conference has addressed these questions. The aim was to systematically examine the available scientific literature on the three core topics: (Ioannidis et al., 2023) additive versus subtractive manufacturing of implant restorations; (Chantler et al., 2023) survival and complications rates as well as esthetic outcomes comparing prefabricated versus customized abutments; and (Pjetursson et al., 2023) clinical performance of implant-supported fixed dental prostheses with different prosthetic designs and restorative material for treatment of multiple missing teeth in the posterior area. In the context of the above-mentioned core topics, Group-2 also addressed the patient perspective. Possible answers to questions that patients may ask the dentist in daily routine were formulated. The answers to these questions are based on both the consensus statements and the clinical recommendations of Group-2.

## 2 | SYSTEMATIC REVIEW PAPER 1

### 2.1 | Manuscript title

Additively and subtractively manufactured implant-supported fixed dental prostheses (iFDPs): A systematic review.

### 2.2 | Preamble

With the advent of digital technologies in implant dentistry, there has been an increasing shift from conventional to digital workflows, which employ computer-aided design (CAD) and computer-aided manufacturing (CAM). The CAM process relies on subtractive (SM) or additive manufacturing (AM). Subtractive manufacturing methods entail milling of a restorative material to obtain interim or definitive restorations and have become a well-established technology to produce iFDPs. Conversely, AM—commonly known as 3D printing—describes the process of successive adding and joining materials layer-by-layer to build a digitally designed three-dimensional object. Additive manufacturing results in less material waste, enables the production of more complex geometries and allows the combination of different material properties in a single workpiece. Given the significant and ongoing interest in AM, it is crucial to analyze and summarize the latest state of evidence. Therefore, the aim of the present systematic review was to compare and report on the performance of iFDPs produced with AM versus SM CAM techniques.

An electronic search was performed with the focused PICO-question: In partially edentulous patients with missing single or multiple teeth undergoing dental implant therapy (P), do AM iFDPs (I) compared to SM iFDPs (C) result in an improved clinical performance (O). The electronic search was conducted up to November 1, 2022. No clinical trial met the inclusion criteria, whereas six in vitro studies proved to be eligible out of a total of 2′184 titles. Performance of a total of 184 single implant crowns was evaluated in the included studies by assessing marginal and internal adaptation as well as mechanical properties, as fracture loads and bending moments. Additive manufacturing iFDPs were made of zirconia and polymers. For SM iFDPs, zirconia, lithium-disilicate, resin-modified ceramics, and different types of polymer-based materials were used. Due to the considerable heterogeneity among the included studies, no meta-analysis could be performed.

## 2.3 | Consensus statements

### 2.3.1 | Consensus statement 1 (*technology*)

Subtractive manufacturing (SM) technologies have been widely used for the fabrication of tooth-colored iFDPs, while AM techniques are increasingly being explored. At the present time, there are no comparative clinical data and six comparative in vitro studies.

### 2.3.2 | Consensus statement 2 (*marginal and internal adaptation*)

Additive and subtractive CAM techniques have the potential to influence the marginal and internal adaptation of tooth-colored iFDPs on both prefabricated and customized abutments. Current data are insufficient to draw comparative conclusions.

Based on three in vitro studies, directly comparing AM versus SM.

### 2.3.3 | Consensus statement 3 (*mechanical properties*)

Both additive and subtractive CAM techniques can influence the mechanical properties (fracture loads and bending moments) of tooth-colored iFDPs. Current data are insufficient to draw comparative conclusions.

Based on four in vitro studies, directly comparing AM versus SM.

## 2.4 | Clinical recommendations

### 2.4.1 | Clinical recommendation 1

*Which CAD/CAM technology can be recommended for the production of an interim implant-supported fixed dental prosthesis?*

For interim tooth-colored single implant crowns both additive- and subtractive manufacturing are viable techniques; however, for interim multi-unit iFDPs SM is currently recommended to minimize complications.

### 2.4.2 | Clinical recommendation 2

*Which CAD/CAM technology can be recommended for the production of a definitive implant-supported fixed dental prosthesis?*

For CAD/CAM definitive single- and multi-unit iFDPs subtractive manufacturing is recommended. Clinicians and dental technicians are encouraged to follow the rapid development of AM technology and related materials as significant improvements are expected in the near future.

### 2.4.3 | Clinical recommendation 3

*Is CAD/CAM technology simple to use, once the devices are installed?*

To achieve the intended results, it is necessary that both AM and SM technologies are applied with careful consideration requiring technical expertise and ongoing training. It is essential to follow specific manufacturing protocols and to maintain the devices.

## 2.5 | Patient perspectives

### 2.5.1 | Patient perspective 1

Question: I have heard about a new technology 3D printing. Would you recommend this technology for my implant crown?
Answer: 3D-printed implant crowns can be recommended for temporary use. When it comes to implant bridges, we are still in the development phase. For definitive implant restorations, 3D printing cannot be recommended at the present time.
Based on expert opinion.

### 2.5.2 | Patient perspective 2

Question: I have heard that there is also the option of milling implant crowns. Are 3D-printed implant crowns cheaper and faster than milled ones?
Answer: As both technologies require manual post-processing adjustments, 3D printed restorations are not necessarily cheaper or faster. As the technology for printing implant bridges evolves it may prove to be faster than milling but it is too early to say or to recommend.
Based on expert opinion.

### 2.5.3 | Patient perspective 3

Question: Do 3D-printed implant crowns look good?
Answer: As with any other temporary implant restoration, with manual adjustments an esthetic result can be achieved.
Based on expert opinion.

### 2.5.4 | Patient perspective 3

Question: Have 3D resins proven to be safe?
Answer: 3D printing materials for dental restorations are officially approved for use in the mouth. However, we can only recommend them for provisional/temporary implant restorations as only the results for shorter term use in the mouth are available.
Based on expert opinion.

## 2.6 | Recommendations for future research

### 2.6.1 | Recommendation 1 for future research

Randomized controlled trials on AM versus SM are needed to evaluate the clinical performance of iFDPs in terms of long-term survival, technical and biological complications, esthetics, and PROMs under different indications: interim/definitive; anterior/posterior; single-/multi-units.

### 2.6.2 | Recommendation 2 for future research

The potential of AM to produce iFDPs combining different optical and mechanical properties in a workpiece should be explored with the aim to achieve esthetic integration and reduce the inherent human intervention.

### 2.6.3 | Recommendation 3 for future research

Given the wide use of zirconia in prosthetic implant dentistry, research should focus on AM of this material. To integrate this new technology into clinical practice, it is crucial to conduct in vitro and clinical trials that compare the performance of additively versus subtractively manufactured monolithic zirconia iFDPs.

# 3 | SYSTEMATIC REVIEW PAPER 2

## 3.1 | Manuscript title

Clinical performance of single screw-retained implant prostheses restored using titanium base abutments: A systematic review and meta-analysis.

## 3.2 | Preamble

Most dental implant abutments have a prefabricated implant connection and are either used as a stock or customized abutment. Titanium base abutments (TBA) have been proposed as a stock abutment for the restoration of single dental implants. The abutment allows the clinician to utilize a complete digital workflow. The TBAs are available with variable geometries of the transmucosal and the retentive attachment segments that are captured within an associated digital library. This allows for the restorative cemented crown or intermediate layer (coping) to be fabricated from. The combination of a prefabricated base and customizable restorative crown, enables the clinician to optimize the emergence profile with the benefits of a traditional stock and customizable abutment. The long-term efficacy of this abutment has been a topical debate since its inception. The majority of studies do not include direct comparisons between TBA and other categories of abutments. The aim of this systematic review and meta-analysis was to analyze the clinical performance of TBA compared to other abutments for single implant crown (iSC). The primary outcome was to compare the 1-year survival rates of TBA versus other abutments. Secondary outcomes were as follows: biological outcomes including marginal bone loss, PPD, BOP; and technical complications such as loss of retention of the abutment to the restorative material (debonding), veneer chipping, abutment fracture, screw loosening, or screw fracturing; and esthetic outcomes. A PICO strategy was executed following the PRSIMA guidelines. The electronic search was conducted in the databases PubMed/MEDLINE, Scopus, and Cochrane Library to identify publications in English from January 1, 2000 to May 5, 2023. The search provided 1′159 titles, whereas six RCTs fulfilled the inclusion criteria and were considered for data extraction of the meta-analysis. Fifteen prospective and eight retrospective cohort studies were collated for descriptive results. A total of 857 iSCs fabricated with a TBA were analyzed.

## 3.3 | Consensus statements

### 3.3.1 | Consensus statement 1

Implant-supported single crowns (iSC) on titanium base abutments show similar short term survival rates (1 year) to iSC restorations with other type of abutments.

Based on a meta-analysis including six RCTs.

### 3.3.2 | Consensus statement 2

The geometric designs of titanium base abutments vary considerably in transmucosal height, width, and contours. Current data does not provide solid guidelines for abutment selection criteria.

Based on 21 prospective cohort studies and eight retrospective studies.

### 3.3.3 | Consensus statement 3

Technical complications of titanium base abutments occur at a low rate. Separation of the suprastructure from the titanium base abutment is the most frequent reported complication.

Based on 21 prospective cohort studies and eight retrospective studies.

## 3.4 | Clinical recommendations

### 3.4.1 | Clinical recommendation 1

*When should the implant abutment be selected?*

Since abutments have important biological implications, the abutment selection should be considered during the implant-prosthetic treatment planning phase prior to implant placement. Digital planning facilitates 3D visualization of the final prosthetic design and pre-operative abutment selection. The final selection is made after the maturation of the soft tissues.

### 3.4.2 | Clinical recommendation 2

*Which titanium base abutment shoulder height should be selected for bone level conical-connection implants?*

The selection of the titanium base abutment is conducted so that the shoulder is located sufficiently distanced from the bone and in a submucosal position with sufficient space for an optimal emergence profile.

### 3.4.3 | Clinical recommendation 3

*Which factors do contribute to retention of suprastructures to the titanium base abutments?*

Overall retention of the restorative material on the titanium base abutment is determined by: the retentive-attachment height and shape, resistance features and the adhesive cementation protocol. Clinicians are encouraged to maximize overall retention considering the available restorative space.

### 3.4.4 | Clinical recommendation 4

*Can titanium base abutments be used for all single implant crowns?*

When a titanium base abutment is considered for use but the standardized shapes do not allow for an adequate emergence profile contour or provide inadequate resistance and retentive features, the use of a customized abutment is recommended.

## 3.5 | Patient perspectives

### 3.5.1 | Patient perspective 1

Question: What material will my implant crown be made of?
Answer: Nowadays we usually use monolithic ceramic materials for the suprastructure, meaning it is made entirely of one material, such as zirconia. These crowns are designed on a computer using CAD.
Based on scientific evidence.

### 3.5.2 | Patient perspective 2

Question: How will the crown be attached to my implant?
Answer: The crown is connected to the implant via a component called an abutment. There are many different types and designs of abutments including ones that are ready made and others that are custom made. Most abutments are made of a ceramic or metal material. The choice of abutment will depend on your specific situation.
Based on scientific evidence.

### 3.5.3 | Patient perspective 3

Question: Is there a difference in cost between the different types of abutments?
Answer: Ready-made components such as titanium abutments are usually less expensive. However, in some situations a customized abutment is required to achieve the best result.
Based on scientific evidence.

## 3.6 | Recommendations for future research

### 3.6.1 | Recommendation 1 for future research

Randomized controlled trials on titanium base abutments versus customized abutments to analyze the clinical performance in terms of long-term survival, technical and biological complications, esthetics, and patient-reported outcome measures (PROMs).

### 3.6.2 | Recommendation 2 for future research

In vivo studies investigating the influence of a submucosally located restorative-abutment-junction on the marginal bone level and supra-implant soft tissues.

## 4 | SYSTEMATIC REVIEW PAPER 3

### 4.1 | Manuscript title

Systematic review evaluating the influence of the prosthetic material and prosthetic design on the clinical outcomes of implant-supported multi-unit fixed dental prosthesis in the posterior area.

### 4.2 | Preamble

The primary aim of this systematic review was to evaluate the survival rates as well as the incidence of technical complications of implant-supported partial fixed dental prosthesis in the posterior area exploring the influence of different prosthetic materials. The secondary aim, the influence of the design, differentiating reconstructions in formation as «bridge» including non-supported pontic units or «splinted crowns» was analyzed. The study protocol of this systematic review was designed according to the Cochrane and PRISMA guidelines for systematic reviews and meta-analyses. An electronic and manual search was performed up to October 10, 2022 to identify randomized controlled trials (RCTs), prospective and retrospective clinical trials with a follow-up of at least of 12 months, evaluating the clinical outcomes of implant-supported posterior multi-unit fixed dental prostheses. Survival and complication rates were analyzed using robust Poisson's regression models. A total of 32 studies (24 prospective cohort studies and 8 retrospective case series) reporting on 42 patient cohorts were included. The extracted data was used for meta-analysis to estimate 3-year survival and complication rates.

### 4.3 | Consensus statements

#### 4.3.1 | Consensus statement 1

Implant-supported multi-unit restorations, that is, splinted crowns or fixed dental prostheses with pontic units, in the posterior area are both well-documented and reliable treatment options exhibiting high 3-year survival rates ranging from 97% to 100% regardless of the materials used. The material combinations analyzed were porcelain-fused-to-metal, veneered, micro-veneered and monolithic zirconia, and monolithic lithium disilicate.

Based on 22 prospective cohort studies and seven retrospective case series.

#### 4.3.2 | Consensus statement 2

The prosthetic design—whether using splinted implant crowns or iFDPs with pontic units—for the restoration of multi-unit posterior edentulous sites, does not significantly influence 3-year clinical outcomes in terms of survival and technical complications rates.

Based on 10 prospective cohort studies and six retrospective case series.

#### 4.3.3 | Consensus statement 3

Monolithic and micro-veneered zirconia implant-supported multi-unit restorations with pontic units exhibit superior performance compared to porcelain-fused-to-metal and veneered zirconia in the posterior area in terms of annual ceramic fracture and chipping rates. No applicable data is currently available for monolithic lithium disilicate implant-supported multi-unit restorations with pontic units.

Based on 11 prospective cohort studies and six retrospective case series.

#### 4.3.4 | Consensus statement 4

When splinted implant crowns are made of monolithic and micro-veneered zirconia, they exhibit superior performance when compared to porcelain-fused-to-metal, veneered zirconia, and monolithic lithium disilicate in the posterior area in terms of annual ceramic fracture and chipping rates.

Based on 12 prospective cohort studies and three retrospective case series.

### 4.4 | Clinical recommendations

#### 4.4.1 | Clinical recommendation 1

*What prosthetic design is recommended to treat multiple missing teeth in posterior edentulous sites with a fixed implant restoration?*

Both splinted implant crowns and implant-supported multi-unit restorations with pontic units can be recommended to replace multiple posterior missing teeth.

#### 4.4.2 | Clinical recommendation 2

*How many implants you need to support a fixed restoration to replace at least three missing teeth in the posterior area?*

To minimize invasiveness and treatment cost, it can be recommended to reduce the number of implants by restoring multiple posterior missing teeth with iFDPS with pontic units as long as the mechanical properties of the restorative material and the implants can be respected (e.g., three-unit iFDPs on two implants instead of three splinted implant crowns).

#### 4.4.3 | Clinical recommendation 3

*What restorative material of choice for posterior multi-unit fixed implant-supported restorations?*

In the posterior area, monolithic zirconia is recommended as the material of choice for implant-supported posterior multi-unit restorations in order to reduce technical complications such as ceramic fracture and chipping. The evidence supporting this recommendation is based on studies reporting on 3Y-TZP zirconia with a flexural strength >1000 mPa or multi-layered (3Y-TZP/5Y-TZP) alternatives.

#### 4.4.4 | Clinical recommendation 4

*What must be considered when using zirconia for implant-supported multi-unit fixed dental prostheses?*

The clinician and the dental technician need to be well-informed and should select the restorative material for every indication as a team. Even though zirconia is the best-documented ceramic material for posterior multi-unit restorations, it has to be considered that various types and generations exist. The significant differences in optical and mechanical properties have not all been validated in clinical studies.

### 4.5 | Patient perspectives

#### 4.5.1 | Patient perspective 1

Question: I am missing my upper-right back teeth. Can I have fixed teeth again?
Answer: Yes, if the circumstances are right we can provide you with a fixed solution on implants. Depending on what you would like, your anatomy, health, and budget, we can determine how many teeth need to be replaced and how many implants will be needed.
Based on scientific evidence.

#### 4.5.2 | Patient perspective 2

Question: I have lost three teeth and want to replace them all. How many implants do you think I will need?
Answer: We have the choice between placing two or three implants to support three fixed teeth. In general, we recommend placing just two implants to support a three-unit bridge. This will make the surgical procedure easier, reduce the cost, and the expected outcome is the same.
Based on scientific evidence.

#### 4.5.3 | Patient perspective 3

Question: I guess the material needs to be quite strong if there is a non-supported tooth in the middle. What material do you use to make a bridge like that?
Answer: Today, the material of choice for this type of bridge is monolithic zirconia. Since it is made entirely out of high strength ceramic, there is less chance of the surface breaking or fracturing.
Based on scientific evidence.

#### 4.5.4 | Patient perspective 4

Question: Does monolithic zirconia look like a natural tooth?
Answer: Today's zirconia comes closer to imitating the look of a natural tooth. We can also further improve the parts that are visible when you smile by applying a thin layer of color to the surface of the zirconia.
Based on scientific evidence.

### 4.6 | Recommendations for future research

#### 4.6.1 | Recommendation 1 for future research

Randomized controlled trials with long-term follow-up are needed comparing different types of monolithic zirconia (e.g., 3Y-TZP zirconia, multi-layered 3Y-TZP/5Y-TZP), restoration designs (splinted, non-splinted, pontic-containing, cantilevers), and differences in pontic span length.

#### 4.6.2 | Recommendation 2 for future research

Randomized controlled trials comparing different retention types for multi-implant monolithic zirconia restorations on bone level conical connection implants, for example, intermediate abutments versus direct-to-implant retention (such as with a titanium base abutment), specifically addressing the number and distribution of implants.

#### 4.6.3 | Recommendation 3 for future research

Randomized controlled trials comparing cement-retained versus angulated solutions for multi-implant monolithic zirconia restorations.

#### 4.6.4 | Recommendation 4 for future research

Those RCTs should report on survival and complication rates, esthetics, PROMs, as well as cost- and time-efficiency.

**AUTHOR CONTRIBUTIONS**

W. Derksen: Conceptualization; Methodology; Writing – original draft; Writing – review & editing; Supervision; Project administration; Validation. T. Joda: Conceptualization; Methodology; Supervision; Project administration; Writing – review & editing; Writing – original draft; Validation. J. Chantler: Investigation; Writing – review & editing; Formal analysis; Data curation. V. Fehmer: Writing – review & editing. G. O. Gallucci: Writing – review & editing. P. C. Gierthmuehlen: Writing – review & editing. A. Ioannidis: Investigation; Formal analysis; Data curation; Writing – review & editing. D. Karasan: Writing – review & editing. A. Lanis: Writing – review & editing. K. Pala:

Writing – review & editing. B. E. Pjetursson: Investigation; Formal analysis; Data curation; Writing – review & editing. M. Roccuzzo: Supervision; Writing – review & editing. I. Sailer: Writing – review & editing; Supervision. F. J. Strauss: Writing – review & editing. T. C. Sun: Project administration. S. Wolfart: Writing – review & editing. N. U. Zitzmann: Writing – review & editing.

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## DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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