# CAD/CAM Technology for Implant Abutments, Crowns, and Superstructures

Theodoros Kapos, DMD, MMSc[1]/Christopher Evans, BDSc Hons (Qld), MDSc (Melb)[2]

***Purpose:*** *The aim of this systematic review was to compare implant prostheses fabricated by computer-assisted design and computer-assisted manufacturing (CAD/CAM) with conventionally fabricated implant prostheses when assessing esthetics, complications (biologic and mechanical), patient satisfaction, and economic factors.* ***Materials and Methods:*** *Electronic searches for clinical studies focusing on long-term follow-up were performed using the PubMed and Ovid search engines. Concentrating on the restorative aspect of the CAD/CAM technology applicable to implant dentistry, pertinent literature was divided into articles related to implant abutments, crowns, and frameworks.* ***Results:*** *A total of 18 articles satisfied the inclusion criteria. Two articles reported on CAD/CAM crowns, six on abutments, and 10 on implant-supported CAD/CAM frameworks. The mean survival rate for CAD/CAM crowns was 98.85% and for CAD/CAM abutments 100%. The mean survival rate for CAD/CAM frameworks was 95.98%.* ***Conclusion:*** *Based on the current literature, CAD/CAM fabricated crowns, abutments, and frameworks demonstrate survival rates comparable to conventionally fabricated prostheses. Implant survival appears unaffected by fabrication technique. Since this technology encompasses several manufacturing variations, a new definition might be necessary to accurately define the processes under which the CAD/CAM restorations are fabricated. "Complete CAD/CAM product" where no or minimal manual intervention is employed could be a possible term.* Int J Oral Maxillofac Implants 2014;29(suppl):117–136. doi: 10.11607/jomi.2014suppl.g2.3

**Key words:** *abutment, CAD/CAM, crown, dental prosthesis implant-supported, implant-supported framework, implant superstructure*

Computer-assisted design (CAD) and computer-assisted manufacturing (CAM) have been gaining increased use in implant dentistry over the past 10 years. Continuous improvements to CAD/CAM technology have started to challenge the technique of fabricating implant-supported prostheses and abutments using conventional methods. Fundamental to considering the routine use of these techniques for the fabrication of implant-supported prostheses (ISP) in every clinical situation is the premise that the outcomes are improved when compared to traditional fabrication techniques.

[1]Lecturer, Department of Restorative Dentistry and Biomaterials Science, Harvard School of Dental Medicine, Boston, Massachusetts, USA; Private practice, Mayfair, London, United Kingdom.
[2]Private practice, St Brighton, Australia.

**Correspondence to:** Dr Theodoros Kapos, Department of Restorative Dentistry and Biomaterials Science, Harvard School of Dental Medicine, 188 Longwood Avenue, Boston, MA 02120, USA. Fax: +1-617-432-0901. Email: Theodoros_Kapos@hsdm.harvard.edu



The purpose of this systematic review was to answer the focus question: "How do CAD/CAM implant-supported prostheses in patients with missing teeth, who have one or more dental implants, perform compared with conventionally fabricated prostheses, when assessing esthetics, complications (biologic and mechanical), patient satisfaction, and economic factors?"

## MATERIALS AND METHODS

### Focus Question

Framing of the research question was undertaken using the PICO strategy.[1,2] The focus question was constructed based on the four PICO elements: Population, Intervention, Comparison, and Outcome. Following development of the focus question by the authors, it was accepted and confirmed by consensus within the working group.

### Search Strategy

A systematic and comprehensive search of the literature was conducted (Table 1). The search was started in August 2012 and completed in January 2013. Electronic databases (Medline) were searched using the MeSH

**Table 1 Systematic Search Strategy**

| | |
|---|---|
| **Focus question:** | **How do CAD/CAM implant prostheses in patients with missing teeth who have one or more dental implants perform comparable to conventionally fabricated implant prostheses when assessing esthetics, complications (biologic and mechanical), patient satisfaction, and economic factors.** |
| **Search strategy** | |
| Population | #1 (partially dentulous) OR (partially edentulous) OR (edentulous) |
| Intervention or exposure | #2 (Computer-Aided Design [MeSH]) AND (Dental Prosthesis, Implant-Supported) [MeSH]<br>#3 (Computer-Aided Design [MeSH]) AND (Dental Implant-Abutment Design [MeSH])<br>#4 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND crown<br>#5 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND denture<br>#6 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND prosthesis<br>#7 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND reconstruction<br>#8 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND restoration<br>#9 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND superstructure<br>#10 CAD CAM (keywords and select subject Heading) + Dental Prosthesis, implant supported (keywords and select subject Heading)<br>#11 CAD CAM (keywords and select subject Heading) + Dental Abutment (keywords and select subject Heading)<br>#12 CAD CAM + dental implant + crown<br>#13 CAD CAM + dental implant + dentures<br>#14 CAD CAM + dental implant + dental restoration |
| Comparison | #15 ((conventional techniques) OR (cast techniques) OR (stock abutments) OR (prefabricated abutments)) |
| Outcome | #16 ((complications) OR (precision) OR (patient satisfaction) OR (esthetics)) |
| Search combination | #1 AND #2 (or #3, #4, #5, #6, #7, #8, #9) AND #15 AND #16<br>#10 (or #11, #12, #13, #14) AND #15 AND #16 |
| **Database search** | |
| Electronic | PubMed, Ovid |
| Journals | Peer reviewed journal |
| **Selection criteria** | |
| Inclusion criteria | All levels of the hierarchy of evidence except for expert opinion and case reports<br>Studies with 10 case series or more<br>Clinical observational or experimental studies reporting a minimum of 12 mo follow-up<br>Studies with CAD/CAM techniques designed for implant use or/as directed by implant manufacturer |
| Exclusion criteria | Case reports and case series<br>Clinical experimental studies with less than 1 y follow-up<br>Laboratory studies<br>Non-prosthetic publications<br>Papers with no abstract available<br>Finite element analyses<br>Studies with non-endosseous root form implants<br>Not dentally related articles and review or commentary articles |

terms: "Computer-Aided Design" [MeSH] AND "Dental Prosthesis, Implant-Supported" [MeSH] (201 results) and "Computer-Aided Design" [MeSH] AND "Dental Implant-Abutment Design"[MeSH] (10 results).

The search was expanded using MeSH terms including keyword (prosthesis, crown, denture, reconstruction, restoration, and superstructure): "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "crown" (25 results); "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "denture" (86 results); "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "prosthesis" (220 results); "Computer-Aided Design"[MeSH] AND "Dental Implants" [MeSH] AND "reconstruction" (18 results); "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "restoration" (74 results); "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "superstructure" (6 results).

All results were filtered for human studies and English language, yielding a total of 642 articles.

In addition, an Ovid search was carried out for the headings: "CAD CAM (key words and select subject heading) + Dental Prosthesis, implant supported (key words and select subject heading)" (207 results) and

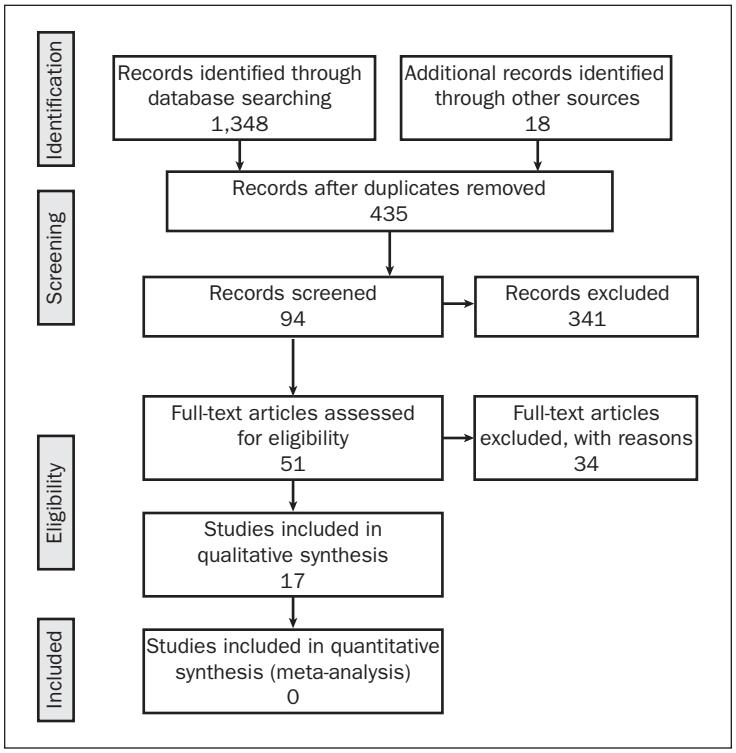


**Fig 1** Literature search and selection of articles.

"CAD CAM (key words and select subject heading) + Dental Abutment (key words and select subject heading)" (236 results). The search was further expanded using the key words: "CAD CAM + dental implant + crown" (66 results); "CAD CAM + dental implant + dentures" (96 results); "CAD CAM + dental implant + dental restoration" (101 results).

A total of 706 articles were identified. Relevant journals were hand-searched to identify additional articles. The bibliographies of selected papers and published review articles on the topic were also scanned for relevant publications. All searches resulted in a total of 1,348 articles, which were collected in the reference manager software Endnote X4 (Thomson Reuters). All duplicates were electronically discarded and 435 articles were considered for review.

## Selection and Exclusion Criteria

All levels of evidence, except for expert opinion, were considered to provide a comprehensive search of the literature. The articles excluded from full-text analysis were:

- Individual case reports
- Case series with less than 10 cases
- Clinical experimental studies with less than 1 year follow-up
- Laboratory studies
- Non-prosthetic publications
- Papers with no abstract available
- Finite element analyses
- Studies on non-endosseous root-form implants
- Articles not related to dentistry
- Review or commentary articles

In addition, the CAD/CAM technology discussed in the article must have been designed for implant use and carried out in accordance to the implant manufacturer's recommendations. The authors screened all 435 articles independently. They then met to review any disagreement on articles inclusion, which was resolved through discussion. After screening, 51 articles were identified as appropriate for full-text review. However, 7 of these were systematic review articles. A total of 17 articles were then selected for data extraction (Fig 1).

## Quality Assessment

A quality assessment of each included publication was undertaken. For randomized control trials and controlled clinical trials, the Cochrane Collaboration's tool for assessing risk of bias was utilized.[3] Nonrandomized controlled studies were assessed for quality using the Newcastle-Ottawa Scale.[4]

## Assessment Scale for Observational Studies

Results and conclusions from the included studies and the relevant data were extracted and tabulated. The results were then presented and conclusions drawn.

**Table 2 Selected CAD/CAM Crown Articles**

| Study | Year published | No. of patients | No. of crowns | Retention method | Material | Cumulative survival rate | Implant type |
|---|---|---|---|---|---|---|---|
| Hosseini et al[5] | 2011 | 36 | 75 | All cement-retained | Ti and Zr abutments; Procera Zirconica core crowns (CAD/CAM) | 100% | Astra Tech |
| Henriksson and Jemt[6] | 2003 | 20 | 24 | 13 cement-retained, 11 screw-retained | Procera Alumina Oxide | 100% | Nobel Biocare |

**Table 3 Selected CAD/CAM Abutment Articles**

| Study | Year published | Patients | Abutments | Material | CAD/CAM system | Cumulative survival rate |
|---|---|---|---|---|---|---|
| Zarone et al[11] | 2005 | 44* | 58 | Aluminum Oxide† | Procera, Nobel Biocare | 98.3% (one patient lost to follow-up) |
| Zembic et al[8] | 2009 | 22 | 40 | 20 Zr 20 Ti | Procera, Nobel Biocare | 100% |
| Canullo[10] | 2007 | 25 | 30 | Zr bonded to Ti† | ZirconZahn | 100% |
| Furze et al[12] | 2012 | 10 | 10 | Zr | Straumann Cares | 100% |
| Sailer et al[7] | 2009 | 22 | 40 | 20 Zr, 20 Ti | Procera, Nobel Biocare | 100% |
| Zembic et al[9] | 2012 | 22 | 40 | 20 Zr, 20 Ti | Procera, Nobel Biocare | 88.9% Zr 90% Ti |

*Report included some crowns on natural teeth, but disclosed abutment numbers.
†CAD design reported, scanned wax body used.
NR = not reported.

**Table 4 Study and Patient Characteristics of the Reviewed CAD/CAM Crown and CAD/CAM Abutment Studies**

| Study | Year of publication | Journal | Study design | CAD/CAM system | Restoration type | Patients |
|---|---|---|---|---|---|---|
| **Crowns** | | | | | | |
| Hosseini et al[5] | 2011 | EJOI | RCT | Procera | Single crown | 36 |
| Henriksson and Jemt[6] | 2003 | IJP | Prospective clinical report | Procera | Single crown | 20 |
| **Abutments** | | | | | | |
| Zarone et al[11] | 2005 | CIDRR | Retrospective review | Procera | Single crown | 86 |
| Zembic et al[8] | 2009 | COIR | RCT | Procera | Single crown | 22 |
| Canullo[10] | 2007 | IJP | Prospective | ZirconZahn | Single crown | 25 |
| Furze et al[12] | 2012 | QUINT | Consecutive case series | Straumann Cares | Single crown | 10 |
| Sailer et al[7] | 2009 | COIR | RCT | Procera | Single crown | 22 |
| Zembic et al[9] | 2012 | COIR | RCT | Procera | Single crown | 22 |

NR = not reported; FDPs = fixed dental prostheses; RCT = randomized-controlled clinical trial; IJP = *The International Journal of Prosthodontics*; EJOI = *European Journal Oral Implantology*; CIDRR = *Clinical Implant Dentistry & Related Research*; COIR = *Clinical Oral Implants Research*; QUINT = *Quintessence International*.

### Peer Review

Prior to the consensus conference, each manuscript in the working group was submitted to the *International Journal of Oral and Maxillofacial Implants* for peer review. Corrections, amendments, and revisions were then completed. Once accepted for publication by the editor of the journal, the review papers provided the basis for the formulation of consensus statements and treatment recommendations within each working group.

## RESULTS

The studies included that reported on crowns are presented in Table 2. The studies included that reported on abutments are presented in Table 3. The patient characteristics of the reviewed studies are presented in Table 4.

| Follow-up (mo) | CAD/CAM system | Patients dropped out |
|---|---|---|
| Mean 13.5 (11–22) | Procera (Nobel Biocare) | 0/30 |
| 12 | Procera (Nobel Biocare) | 1 |

| Implant type | Mean follow-up (mo) | Patients dropped out |
|---|---|---|
| Straumann, Brånemark | 48 | NR |
| Brånemark RP | 36 | 4 |
| TSA Implantdent | 40 | NR |
| Straumann Bone Level | 12 | 0 |
| Brånemark RP | 12.6 | 2 |
| Brånemark RP | 67.2 | 4 |

| Age range (y) | Mean age (y) | Setting | Patients dropped out |
|---|---|---|---|
| 19-57 | 28.1 | University | 0 |
| 18-62 | 29 | Private practice | 1 |
| 18-62 | NR | University | NR |
| NR | 41.3 | NR | 2 |
| 25-70 | 52.3 | Private Practice | NR |
| 26-61 | 45.1 | Private practice | 0 |
| NR | 41.3 | NR | 2 |
| NR | 41.3 | NR | 4 |

## CAD/CAM Crowns

Only two studies were identified: one randomized controlled trial (RCT)[5] and a prospective clinical report.[6] Fifty patients were treated with a total of 99 implants supporting single crowns in patients with an age ranging from 19 to 60.1 years of age. The mean age of the patient population was 28 years of age for the study by Hosseini et al[5] and 45.1 years of age for the study by Henriksson and Jemt.[6] The mean survival rate of the crowns was 98.85%. The implant survival rate was unaffected by the crown fabrication technique. The failure rates and survival of implants supporting CAD/CAM crowns are summarized in Table 5. The failure rates, survival rates, and complications rates for CAD/CAM crowns[7–12] are presented in Tables 6 and 7.

Hosseini et al[5] evaluated the biologic, technical, and esthetic outcomes of implant-supported single crowns (ISSC) treating single tooth agenesis in the premolar region. Thirty-eight zirconia abutments and crowns (test group) were compared to 37 metal abutments and metal ceramic crowns (control group). In the test group, 38 zirconia abutments (ZrDesign, Astra Tech) supported all-ceramic crowns fabricated using CAD/CAM milled zirconia copings and layered with HeraCeram zirconia veneering porcelain. KaVo zirconia copings (Ivoclar Vivadent) were used in 27 of 38 cases, and Procera zirconia copings (Nobel Biocare) were used in 11 of 38 cases. In the control group, 37 metal abutments were used to support metal ceramic crowns. In 35 of these cases, TiDesign (Astra Tech) titanium abutments were used and 2 cases used a gold alloy Cast-to abutment (Astra Tech) modified using conventional fabrication techniques. No implant failures were recorded and no difference in mean marginal bone loss was seen between the test and control groups. Two technical complications (2 of 37) were reported, both from the control group. No technical complications were reported for the test group. The esthetic outcomes were evaluated using both patient-reported VAS scores and professionally reported esthetic outcomes employing the Copenhagen Index Score (CIS). No significant difference in esthetic parameters was reported when comparing the test and control group for patient-reported outcomes. However, the professionally reported color match was significantly better for the all-ceramic crowns ($P = .031$). No difference was seen in mucosal discoloration between the all-ceramic crown group and the metal-ceramic crown group. Mucosal inflammation was reported in 7 of 10 (16.3%) of all-ceramic crowns, and 3 of 10 (7%) of metal-ceramic crowns.

Henriksson and Jemt[6] evaluated the clinical performance of customized ceramic single-implant Procera abutments in combination with two different crown types. This prospective clinical study evaluated 20 patients consecutively treated for single-unit implant restorations in the maxillary anterior region. Customized Procera alumina oxide abutments were fabricated for the 24 implants. In 13 cases, the crowns were fabricated using Procera techniques and cemented onto the abutment using zinc phosphate cement. In 11 cases, porcelain was fused directly onto the abutment to provide a direct screw-retained restoration with a screw access hole on the palatal surface.

**Table 5 Failure Rates and Survival of Implants Supporting CAD/CAM Crowns and Abutments**

| Study | Year of publication | Restoration type | Loading | Implants | Mean follow-up time (mo) |
|---|---|---|---|---|---|
| **Crowns** | | | | | |
| Hosseini et al[5] | 2011 | Single crown | Delayed | 75 | 13.5 |
| Henriksson and Jemt[6] | 2003 | Single crown | Delayed | 24 | 12 |
| **Abutments** | | | | | |
| Zarone et al[11] | 2005 | Single crown | Delayed | 58 | 48 |
| Zembic et al[8] | 2009 | Single crown | Delayed | 40 | 36 |
| Canullo[10] | 2007 | Single crown | Delayed | 30 | 40 |
| Furze et al[12] | 2012 | Single crown | Delayed | 10 | 12 |
| Sailer et al[7] | 2009 | Single crown | Delayed | 40 | 12.6 |
| Zembic et al[9] | 2012 | Single crown | Delayed | 40 | 67.2 |

ZR = zirconia group; Ti = titanium group.

**Table 6 Failure Rates and Survival of CAD/CAM Crowns and Abutments**

| Study | Year of publication | Restoration type | Loading | Total restorations | Restorations lost to follow-up |
|---|---|---|---|---|---|
| **Crowns** | | | | | |
| Hosseini et al[5] | 2011 | Single crown | Delayed | 75<br>AC = 38<br>MC = 37 | 0 |
| Henriksson and Jemt[6] | 2003 | Single crown | Delayed | 24 | 1 |
| **Abutments** | | | | | |
| Zarone et al[11] | 2005 | Single crown | Delayed | 58 | 1 |
| Zembic et al[8] | 2009 | Single crown | Delayed | 40<br>AC = 20<br>MC = 20 | 11<br>AC = 1<br>MC = 10 |
| Canullo[10] | 2007 | Single crown | Delayed | 30 | NR |
| Furze et al[12] | 2012 | Single crown | Delayed | 10 | 0 |
| Sailer et al[7] | 2009 | Single crown | Delayed | 40<br>AC = 20<br>MC = 20 | 9<br>AC = 1<br>MC = 8 |
| Zembic et al[9] | 2012 | Single crown | Delayed | 40<br>AC = 20<br>MC = 20 | 11<br>AC = 1<br>MC = 10 |

AC = all-ceramic group, MC = metal-ceramic group, NR = not reported.
*Implant but not restoration failure

Nineteen patients were examined at the 1-year recall, with all implants stable. One ceramic abutment fractured in the laboratory and was remade before clinical placement. All crowns in both groups were stable during the 12-month period. One patient in the cement crown group experienced a buccal fistula (1 of 13) and a further two cement-retained crowns (2 of 13) experienced buccal recession for an estimated annual biologic complication rate of 12.5%.

No studies reported any data regarding CAD/CAM implant prostheses or conventional prostheses in terms of cost effectiveness.

## CAD/CAM Abutments

The six studies that met inclusion criteria for data extraction on CAD/CAM dental implant abutments are shown in Table 3. These comprise three RCTs, which describe the same patient cohort at 12, 36, and 67 months[7–9]; one prospective clinical report[10]; one retrospective case report[11]; and one case series.[12] A further case report by Vafiadis[13] had to be excluded due to lack of detail regarding patient recruitment and treatment details. A total of 101 patients were treated with a total of 138 CAD/CAM implant abutments to support single-crown restorations. The patients' ages

| Implant failures | Estimated annual failure rate | Cumulative survival rate |
|---|---|---|
| 0 | 0% | 100% |
| 0 | 0% | 100% |
| 0 | 0% | 100% |
| 0 | 0% | 100% |
| 0 | 0% | 100% |
| 0 | 0% | 100% |
| 0 | 0% | 100% |
| 3 | 1.30% | 88.9% Zr<br>90% Ti |

| Mean follow-up time (mo) | Restoration failures | Total restoration exposures | Estimated annual failure rate |
|---|---|---|---|
| 13.5 | 1, MC group, remade | 75 | MC: 2.6%<br>AC: 0% |
| 12 | 0 | 23 | 0% |
| 48 | 1 | 57 | 0.80% |
| 36 | 0 | 29 | 0% |
| 40 | 0 | 30 | 0% |
| 12 | 0 | 10 | 0% |
| 12 | 0 | 31 | 0% |
| 67.2 | 3* | 28* | 0% |

ranged from 18 to 70 years with the mean ages of each study group ranging from 41.3 to 52.3 years. Three different CAD/CAM systems were used to fabricate the abutments for the included studies; Procera technique (Nobel Biocare) was used in 4 studies,[7–9,11] Straumann Cares for one study,[12] and Zirconzahn for one study.[10] No abutment complications, including screw loosening or fracture, were reported for any of the publications reviewed. The CAD/CAM abutment survival rate is 100%. The survival rate of the crowns supported by CAD/CAM abutments is 99.8%. The failure rates and survival of implants supporting CAD/CAM abutments are summarized in Table 5. Tables 6 and 7 detail the failure rates, complication rates, and survival rates for CAD/CAM fabricated implant abutments. While no technical complications were reported for the CAD/CAM abutments, most studies reported a low incidence of veneering porcelain chipping (0% to 3% estimated annual chipping rate) from the crown on the abutment.

The papers by Sailer et al and Zembic et al[7–9] evaluated the survival and complication rate of customized zirconia and titanium abutments in a randomized controlled clinical trial. Twenty-two consecutively recruited patients were included in this study that evaluated 40 fixed implant-supported crowns replacing missing canines, premolars, and molars. Patients were randomly assigned to a test or control group. The test group consisted of 20 customized Procera zirconia abutments to support all-ceramic crowns. The control group of 20 single-tooth implant replacements received customized Procera titanium abutments for the support of metal-ceramic crowns. All patients received a regular platform (RP) Nobel Biocare implant installed according to standard surgical protocol. The all-ceramic crowns were fabricated from glass ceramic or two high-strength ceramics, alumina or zirconia. Metal-ceramic crowns were fabricated for the titanium abutments. Clinical examinations were made at baseline, 6, 12, and 36 months with four patients lost to follow-up at the 36-month review. Implants in the test group replaced crowns in 2 canines, 11 premolars, and 5 molars. All implants showed a 100% survival rate for both implant groups. No technical complications were seen in either group for the abutments with the survival rate being 100% for both groups.

Zembic et al[9] reported that between the 3- and 5-year reviews, two patients lost three implants due to loss of integration. These were supporting 2 of 20 zirconia abutments and 1 of 20 titanium abutments. In spite of these three implant failures, biologic complications associated with CAD/CAM abutments were rare. Plaque and bleeding scores were low, and bone levels were reported as stable at follow-up. At 12 months' review, Sailer et al[7] reported that the mean bleeding on probing (BOP) was more often observed around the implant crowns than teeth and zirconia abutments had a higher mean BOP than titanium (60% vs 30%). However, at the 3-year review these changes were no longer reported[8] and this remained the same at the 5-year review.[9] Only one case was reported showing facial tissue recession at the CAD/CAM zirconia abutment.[12]

Canullo[10] studied the efficacy of a zirconia abutment cemented to an antirotational titanium component attached to the implant in a prospective clinical report. Twenty-five patients requiring 30 single-implant–supported crowns were selected for the

**Table 7 Complications for CAD/CAM Crowns and Abutments**

| Study | Year of publication | Type of restoration | Total restorations | Mean follow-up time (mo) | Estimated annual rate of screw loosening | Estimated annual rate of abutment fracture |
|---|---|---|---|---|---|---|
| **Crowns** | | | | | | |
| Hosseini et al[5] | 2011 | Single crown | 75<br>AC = 38<br>MC = 37 | 13.5 | 0 | 0 |
| Henriksson and Jemt[6] | 2003 | Single crown | 24 | 12 | 0 | 0 |
| **Abutments** | | | | | | |
| Zarone et al[11] | 2005 | Single crown | 58 | 48 | 0 | 0 |
| Zembic et al[8] | 2009 | Single crown | 40<br>AC = 20<br>MC = 20 | 36 | 0 | 0 |
| Canullo[10] | 2007 | Single crown | 30 | 40 | 0 | 0 |
| Furze et al[12] | 2012 | Single crown | 10 | 12 | 0 | 0 |
| Sailer et al[7] | 2009 | Single crown | 40<br>AC = 20<br>MC = 20 | 12 | 0 | 0 |
| Zembic et al[9] | 2012 | Single crown | 40<br>AC = 20<br>MC = 20 | 67.2 | 0 | 0 |

MC = metal-ceramic crown group; AC = all-ceramic crown group; BOP = bleeding on probing.

study. The abutments were designed such that for one group, zirconia contacted the implant shoulder and in the other group, the titanium structure contacted the implant shoulder. No abutment screws fractured and no screw loosening occurred. The survival rate was 100%. One crown demonstrated marginal porcelain chipping at the 1-year follow-up. Periodontal and gingival indices showed healthy tissue at both natural tooth and implant sites.

In a retrospective evaluation of 86 patients treated with CAD/CAM fabricated restorations, Zarone et al[11] evaluated the performance of Procera all-ceramic maxillary anterior restorations over a period of 48 months. The crowns were fabricated on both natural teeth (28/86) and implant-supported abutments (58/86). Both non-submerged (Institut Straumann, Waldenberg) and submerged (Nobel Biocare) implants were restored. Alumina oxide Procera abutments where fabricated for the submerged implants and titanium abutments for the non-submerged ones. The implants were restored with crowns fabricated using Procera aluminum oxide copings, which were machined and finished with layering porcelain by the dental technician in the laboratory. All restorations were cement retained using a hybrid glass ionomer cement (RelyX, 3M ESPE). One implant-supported restoration failed during the follow-up, but it is not stated which implant type and how the implant failed. One implant crown exhibited porcelain fracture at the incisal edge of the veneering porcelain. Although marginal adaption was reported to be very good, the other indices evaluated (Plaque, Gingival, BOP, and patient satisfaction) while showing generally very high scores, were not distinguished between implant and natural teeth. No abutment complications were reported.

Furze et al[12] evaluated the clinical and esthetic outcomes of 10 consecutive single-tooth implant restorations in the anterior maxilla. Ten Straumann SLActive bone-level implants were used to replace six central incisors, one lateral incisor, two canines, and one premolar. Implants were restored with provisional prostheses customized to the mucosa before restoration with CAD/CAM zirconia abutments (Straumann Cares) and zirconium-based all-ceramic crowns (Straumann Cares). Pink and white esthetic scores (PES and WES) were made after 12 months of loading. The only reported complication was fracture of the provisional restoration. The mean PES score was 7.9 and mean WES was 7.

No studies reported any data regarding CAD/CAM implant prostheses or conventional prostheses in terms of cost effectiveness.

## CAD/CAM Frameworks

Nine studies were included under the search of clinical trials of CAD/CAM frameworks. These comprised one RCT,[14] six prospective,[15–20] and two retrospective

| | Total veneer chipping/fracture | Estimated annual rate of veneer chipping/fracture | Total loss retention | Estimated annual loss retention | Biologic complications | Estimated annual rate of biologic complication |
|---|---|---|---|---|---|---|
| | | | | | | |
| | 1 chip, MC group | 2.4% MC<br>0% AC | 1, MC group | 2.4% MC<br>0% AC | 7/10 inflammation, AC group; 3/10, MC group | 11.80%<br>16.3% AC<br>7% MC |
| | 0 | 0% | 0 | 0% | 1 fistula, 2 buccal recession | 12.50% |
| | | | | | | |
| | 1 chip,<br>1 fracture | 0.80% | 0 | 0% | 0 | 0% |
| | 2 chip, MC group | 3% MC<br>0% AC | 0 | 0% | 0, but greater mean BOP at implants | 0% |
| | 1 chip | 1% | 0 | 0% | 0 | 0% |
| | 0 | 0% | 0 | 0% | 1, facial recession | 10% |
| | 2 chip, MC group | 3% MC<br>0% AC | 0 | 0% | 0 (BOP similar for teeth and implants) | 0% |
| | 2 chip, MC group | 3% MC<br>0% AC | 0 | 0% | 0, but greater mean BOP at implants and 3 implant failures | 1.30% |

clinical reports[21,22] published between 2005 and 2012. The study and patient characteristics are summarized in Table 8.

The implant-supported prostheses were fabricated using CAD/CAM technology to mill the framework from either titanium or zirconia. Three different manufacturing companies were involved in the production of the frames: Decim (Denzir), Nobel Biocare (Procera), and Es-Healthcare.

Eight clinical investigations used CAD/CAM technology to restore completely edentulous patients with full-arch fixed partial dentures (FDPs). In six studies, both the maxilla and the mandible received a full-arch rehabilitation.[15,17,18,20–22] The Engquist et al[16] study restored only mandibular arches and the Katsoulis et al[19] restored only maxillary arches. Only one study reported the application of CAD/CAM framework technology in partially edentulous patients.[14] In this study, FDPs were used to restore both maxillary and mandibular edentulous spaces.

The loading time of the prostheses varied significantly in all these investigations. Three studies described immediate loading protocols of CAD/CAM frameworks.[17,18,20] Four reported on conventional loading[14,15,19,21] and one reported on both immediate and conventional loading.[22] Finally, Engquist et al[16] applied immediate, early, and conventional loading protocols. The definitions of the terms relating to timing of restoration used were: immediate loading (less than 1 week), early loading (at 24 days), and conventional loading (12 weeks or later), and they are all based on the 2007 Cochrane Review.[23]

Larsson et al[14] performed a randomized prospective clinical trial during which two different ceramic systems, Denzir (DZ) and In-Ceram Zirconia (InZ), were compared in partially edentulous patients. Eighteen patients were treated with a total of 25 implant-supported reconstructions ranging in size from two to five units. They were reviewed after 60 months (5 years). In the CAD/CAM arm of the study, nine patients received 13 FDPs with frameworks made out of yttria-stabilized tetragonal zirconia polycrystal material (DZ). Seven of the nine patients (69%) in the DZ group showed chip-off fractures, whereas two out of nine patients (17%) in the InZ group showed such fractures. More specifically, 16 units (52%) in the DZ group and 3 units (9%) in the InZ group were affected. Three of the 16 fractures (19%) in the DZ group were judged to be adhesive between the framework and veneering porcelain. None of the fractures in the InZ group were adhesive, all being cohesive in nature within the layering porcelain. Although the CAD/CAM frameworks did not present any complications, the DZ system exhibited an unacceptable amount of veneering porcelain fractures. Since these complications were superficial, the study reported 100% survival rate for the restorations of both

**Table 8 Study and Patient Characteristics of the Reviewed CAD/CAM Framework Studies**

| Study | Year of publication | Journal | Study design | CAD/CAM system | Restoration type | Arch loaded |
|---|---|---|---|---|---|---|
| Larsson et al[14] | 2010 | IJP | RCT | Denzir, Decim | partial FDPs (2-5 units) | Mandible and maxilla |
| Engquist et al[16] | 2005 | CIDRR | Prospective cohort | Procera, Nobel Biocare | Full-arch FDPs | Mandible |
| Komiyama et al[18] | 2008 | COIR | Prospective | Procera, Nobel Biocare | Full-arch FDPs | Mandible and maxilla |
| Ortorp and Jemt[15] | 2012 | CIDRR | Prospective control | Procera, Nobel Biocare | Full-arch FDPs | Mandible and maxilla |
| Sanna et al[17] | 2007 | JPD | Prospective cohort | Procera, Nobel Biocare | Full-arch FDPs | Mandible and maxilla |
| Tahmaseb et al[20] | 2012 | IJOMI | Prospective | Es-Healthcare | Full-arch FDPs | Mandible and maxilla |
| Katsoulis et al[19] | 2011 | IJOMI | Prospective controlled cohort | Procera, Nobel Biocare | Full-arch FDPs | Maxilla |
| Papaspyridakos and Lal[22] | 2013 | COIR | Retrospective | Procera, Nobel Biocare | Full-arch FDPs | Mandible and maxilla |
| Malo et al (1)[21] | 2012 | JP | Retrospective | Procera, Nobel Biocare | Full-arch FDPs | Mandible and maxilla |
| Malo et al (2)[21] | 2012 | JP | Retrospective | Procera, Nobel Biocare | Full-arch FDPs | Mandible and maxilla |

NR = not reported; FDPs = fixed dental prostheses; RTC = randomized-controlled clinical trial; IJP = *The International Journal of Prosthodontics*; CIDRR = *Clinical Implant Dentistry and Related Research*; COIR = *Clinical Oral Implant Research*; JDP = *The Journal of Prosthetic Dentistry*; IJOMI = *The International Journal of Oral & Maxillofacial Implants*; JP = *Journal of Prosthodontics*.

groups after 5 years. The differences in the success rates from baseline to the 5-year follow-up were statistically significant for the two groups at both the FDP level (31% DZ vs 83% InZ) ($P < .05$) and the unit level (48% DZ vs 91% InZ) ($P < .001$).

Ortorp et al,[15] in their prospective control study, evaluated and compared the clinical and radiographic performance of implant-supported prostheses during 10 years of function. Patients were randomly assigned to the test or control group. The test frameworks (n = 67) were constructed using a computer numeric-controlled (CNC) titanium technique (All-in-One Procera, Nobel Biocare) while the control group frameworks (n = 62) were cast from gold alloy. Acrylic resin teeth were processed to each metal framework. This university-based study (The Brånemark Clinic, Gotenberg, Sweden) originally included 126 edentulous patients. After 10 years, there were 52 patients lost to follow-up, of which 29 belonged to the test group (36 remaining patients). At the implant level the overall 10-year implant cumulative survival rate (CSR) was 95.0% and 97.9% for the test and control groups, respectively. The titanium framework group had five framework incidents out of which three were recorded as "survival and modified" since the modification shortened the prosthesis span. In the remaining two cases, the first prosthesis was lost due to failure of the supporting six implants after 2 years of function, and the second one fractured after 9 years in function. As a result the 10-year prosthesis CSR was 89.0% for the test group and 94.4% for the control group ($P > .05$). In addition, there were three incidents of prosthesis loosening in the test group. These were all from the same case. Thirty-five incidents of acrylic chipping in 19 cases were reported from the test group. Eight of these incidents from seven cases were uncomplicated while the remaining 27 incidents from 12 cases required removal and management in the dental laboratory. There were no significant differences in bone loss around the implants between the two groups. The mean marginal bone loss after 10 years was 0.7 mm (SD = 0.77) and 0.6 mm (SD = 0.57) in the test and control groups, respectively ($P > .05$).

In the Engquist et al[16] prospective cohort study, the results of early loading in the edentulous mandible were evaluated and compared with delayed loading, for both one- and two-stage implant surgery protocols. One hundred and eight patients each received four Brånemark (Nobel Biocare) implants. A total of 432 implants were placed to support 108 prostheses that were followed for up to 36 months. The superstructure used for all patients was a titanium frame (Procera All-in-One, Nobel Biocare) combined with acrylic teeth. The frameworks were milled from a titanium block in a computer-steered three-dimensional milling machine. Due to the vertical placement of the four implants, the bridges were constructed with cantilevers having two teeth on each side. Nine patients were lost to follow-up and of the 418 remaining implants, 24 failed due to loss of integration. As a result 98 cases were surviving at the 3-year period. Prosthetic outcomes were not

| Loading type | Patients | Age range (y) | Mean age (y) | Setting | Drop out (% of patients/ cases lost to follow-up) |
|---|---|---|---|---|---|
| Delayed | 9 | 37–70 | NR | Malmö University Hospital, Sweden | 0% |
| Delayed + early + Immediate | 108 | 25–75 | 64.9 | University Hospital, Linkoping, Sweden & Vrinnevi Hospital, Norrkoping, Sweden | 9.25% (10 patients/cases) |
| Immediate | 26 (excluding 5 carbon frames) | 42–90 | 71.5 | University Karolinska Institutet, Huddinge Sweden | NR |
| Delayed | 65 | 49–85 | 66.8 | Brånemark Clinic, Göteborg, Sweden | 44.6% (29 patients/cases) |
| Immediate | 30 | 38–74 | 56 | University Hospital Leuven, Belgium | 13.3% (4 patients/cases) |
| Immediate | 35 | NR | NR | University of Amsterdam School of Dentistry, ACTA, Amsterdam, The Netherlands | 0% |
| Delayed | 13 | 52-78 | 63.3 | University of Bern, Switzerland | 0% |
| 13 delayed and 3 immediate | 14 | 35-71 | 58 | Columbia University, New York, USA | 0% |
| Delayed | 52 | 38-81 | 59.5 | Private Center: Malo Clinic Lisbon, Portugal | 11% (12 patients/cases) |
| | 56 | 34-82 | 57.6 | Private Center: Malo Clinic Lisbon, Portugal | |

reported, and the study concentrated on implant survival and marginal bone loss. The survival rate of the early-loaded implants did not significantly differ from that of implants inserted with the conventional two-stage procedure. Survival rates of the implants showed a tendency toward better results with the two-stage technique, but the differences were not significant. The mean marginal bone loss from fixture insertion to the 3-year examination was significantly lower with early loading than with the conventional two-stage technique (range 1.24 to 1.68 mm). Finally, the survival rates and marginal bone changes of the one-piece implants did not differ from those of the two-piece implants.

Komiyama et al[18] reported on the treatment of 29 edentulous patients, 9 women and 20 men, using the Nobel Guide immediate loading Teeth-in-an-Hour protocol. In this prospective clinical investigation, 176 Brånemark MKIII TiUnite (Nobel Biocare) implants were placed in 31 edentulous jaws. Twenty-six edentulous jaws were restored with prostheses fabricated from machined titanium frameworks supporting acrylic resin teeth and 5 edentulous jaws used carbon fiber reinforced resin prostheses. All cases were followed up to 1 year and thereafter annually for up to 44 months. Upon delivery the authors experienced abutment/prosthesis misfit in five cases, and there was extensive occlusal adjustment in three cases. This resulted in prosthesis disconnection in two cases for retreatment. At the implant level, 157 of 176 implants (89%) survived over 44 months (92% in maxilla and 84% in mandible). Nineteen implants (11%) were removed within 18 months of implant installation, with 10 of 124 from the maxilla and 9/52 from the mandible. At the prosthesis level, 26 of 31 prostheses were surviving at 44 months (84%); 19 of 21 in the maxilla (90%) and 7 of 10 in mandible (70%). Superstructure failure occurred in five patients (17%); two due to fixture loss, two due to prosthesis misfit, and one due to a combination of both complications. These superstructures were removed within the first 6 months.

In a prospective cohort study Sanna et al[17] evaluated 30 consecutive patients, who were treated with a full-arch implant-retained reconstruction, in either the maxillary or mandibular arch. Two hundred and twelve TiUnite Brånemark implants (Nobel Biocare) were placed (Department of Periodontology at the University Hospital in Leuven) and 30 edentulous arches were restored following an immediate loading protocol. All patients received a prefabricated CAD/CAM framework veneered with acrylic resin teeth. Four patients were lost to follow-up (29 implants) although they were contacted to confirm that their prostheses remained in function. Twenty-six patients with 183 implants were followed for a mean time of 2.2 years. Overall 9 out of 183 implants were lost (4.9%), 8 of which were from a smoking group. The CSR after 5 years was 91.5%. Digital panoramic radiographs were taken at annual recalls and were used to evaluate bone loss. The mean bone loss was 2.6 mm (± 1.6 mm) for the smoker group and 1.2 mm (± 0.8 mm) for the nonsmoker group. There was no report for any prosthetic complications or prosthetic survival rates.

Tahmaseb et al[20] evaluated the immediate loading of 40 full-arch cases in both the mandibular and maxillary jaw in a prospective study. The definitive fixed full-arch restorations were fabricated prior to surgery using CAD/CAM technology. A total of 35 patients, including 20 edentulous maxillae, 10 edentulous mandibles, and 5 patients with edentulism in both arches were treated with 240 Straumann Standard Tissue level implants (Straumann). A total of 40 superstructures were made out of a prefabricated CAD/CAM framework (Es-Healthcare), which was veneered with resin and connected directly to the implants without using Straumann abutments. All patients were followed for at least 1 year with a range of 12 to 36 months. All metal frameworks (n = 40) showed a clinically passive fit at the time of surgery and no adjustments were needed. Thirty-nine finished superstructures (97.5%) showed satisfactory occlusion and only one case required significant occlusal adjustment. Of the 240 inserted implants, 229 (95.4%) survived after 12 months, with 146 (93.6%) and 83 (98.8%) implants in the maxillary and mandibular arches, respectively. Four implants in one patient failed 6 months post-surgery and as a result the superstructure was lost as well (1 of 40 arches). No other additional prosthetic complications were reported at the 1-year follow-up period.

Katsoulis et al[19] in a prospective controlled cohort study compared the outcomes of three different treatment modalities in the maxilla: overdentures with conventional soldered gold bars (Dolder bars), overdentures with CAM-fabricated titanium bars, and fixed prostheses with CAM-fabricated titanium frameworks. Forty-one patients were treated in the study. Thirteen patients received between four to six implants to support a CAD/CAM implant–supported fixed prosthesis that was conventionally loaded. The titanium frameworks were fabricated using Procera and veneered with acrylic resin denture teeth (Candulor). The frameworks were screw-retained at the implant level and followed for 2 years. At the end of the follow-up period there were no fractures reported (100% survival rate) and there was no need for re-tightening of occlusal screws. There were 14 repair incidents reported (five acrylic resin denture base fractures, eight teeth fractures, one redesign of prosthesis). In addition, there were 11 prosthesis adaptation incidents (one sore spot, three prosthesis relinings, five occlusal corrections, one excessive tooth wear, and one discoloration of acrylic resin teeth). Furthermore, there were no implant failures reported for the fixed CAD/CAM group, yielding a 100% implant survival rate. Finally, the Oral Health Impact Profile (OHIP) was used to investigate the patients' oral health–related quality of life (QoL). The OHIP confirmed high satisfaction, but QoL appeared to be slightly higher with fixed CAD/CAM prostheses.

Malo et al,[21] in a retrospective study with mean follow-up of 5 years (range: 9 months to 10 years), compared milled titanium frameworks, restoring edentulous patients using a delayed loading protocol, with two different all-ceramic crown systems. In the first group (development group), a CAD/CAM fabricated Procera titanium frame had Duceram (Ducera Dental) veneering porcelain used to replicate the gingival tissue replacement. Multiple individual crowns were fabricated and luted to the framework. The crowns were made out of Alumina copings (Nobel Biocare), and Allceram porcelain (Ducera Dental). A total of 66 full arches (both maxilla and mandible) were restored and followed for a mean of 6.5 years (range: 9 to 127 months). In the second group (routine group), similar titanium Procera frameworks and a gingival replacement veneering material of PalaXpress Ultra (Heraeus Kulzer) was used to replicate the gingival tissues. Individual crowns were made out of zirconia copings (Nobel Biocare) and Nobel Rondo Zirconia Ceramic (Nobel Biocare) porcelain. Fifty-nine arches were restored (both maxilla and mandible) and followed for a mean of 3.8 years (range: 12 to 67 months). A total of 634 Nobel Speedy Brånemark (Nobel Biocare) implants were placed. The cumulative survival rates for the implant-supported fixed prostheses were 92.4% for the alumina crown group at 10 years and 100% at 5 years (overall 96%) for the zirconia crown group. The authors reported six lost frameworks (including one that was lost due to the implant failure) for the first group and none for the second. Veneer chipping occurred in 36 and 14 cases, respectively, for the development and routine groups.

Papaspyridakos and Lal[22] in their retrospective cohort study evaluated 14 patients who were restored with screw-retained implant-supported superstructures. Thirteen edentulous arches were treated with conventional loading protocols and three with an immediate loading protocol. Ten cases were in the mandibular jaw and six were in the maxillary jaw. The frameworks were zirconia frameworks made with Procera CAD/CAM. Veneering porcelain was applied to the framework. Out of the 16 edentulous arches, 14 received one-piece restoration and 2 received a segmented two-piece fixed restoration. The mean clinical follow-up period was 36 months (3 years). One hundred and three Tiunite implants were placed, distributed as 57 implants in the mandible and 46 implants in the maxilla. There were five to six implants placed to support mandibular prostheses and six to eight to support the maxillary prostheses. No screw loosening was observed throughout the follow-up period. The prostheses in 11 of 16 arches were structurally sound, whereas porcelain veneer chipping/fracture was observed in five prostheses (four patients), yielding a ceramic chipping rate of 31.25% at the prosthesis level. Great

patient satisfaction with function and esthetics was recorded for all patients both at baseline and recall.

Statistical analysis was thus based on nine studies, with one reporting on partial FDPs with CAD/CAM-fabricated zirconia frameworks veneered with porcelain,[14] eight reporting on implant-supported full-arch FDPs with CAD/CAM-fabricated titanium frameworks (seven with acrylic teeth and one with porcelain veneering),[15–21] and one reporting on implant-supported full-arch FDPs with CAD/CAM-fabricated zirconia frameworks veneered with porcelain.[22]

No studies reported any data regarding CAD/CAM implant prostheses or conventional prostheses in terms of cost effectiveness.

## DISCUSSION

This literature search revealed a total of 17 studies which used CAD/CAM techniques to restore implants. The first observation that needs to be made is that in most investigations the primary goal of the authors was not the assessment of the actual CAD/CAM prosthesis. Instead, in several cases there was a focus on the surgical aspect of the treatment. As a result, acquiring the relevant prosthetic data was challenging and in some cases not possible since there was no prosthetic outcome reported.

In addition, the selected studies evaluated a variety of factors such as the fit of the prosthesis, bone loss, and numerous complications using different assessment techniques or parameters. For this reason, the comparison of the presented data would not be accurate or even feasible in certain occasions. Parameters that could be easily reported and compared were the survival rate of the implants that supported the prostheses and the survival rate of the actual prostheses. This data could be easily determined in most of the investigations. Any technical complications could be reported but not included in the analysis.

The purpose of this systematic review was to compare the clinical outcomes of restorations that were fabricated using CAD/CAM technology with the ones that were fabricated conventionally. Two recent systematic reviews[24,25] have assessed and reported the survival and complication rates of implant-supported restorations for both single crowns and FDPs, respectively, for a mean observation period of at least 5 years.

### Crowns

The use of all-ceramic CAD/CAM restorations in the short term appears to provide acceptable clinical outcomes. The difference in materials used for ceramic core fabrication, choice of ceramic veneering porcelain and crown retention between the studies makes direct comparison between studies difficult. Hosseini et al[5] in their randomized controlled trial restored single missing teeth in the maxillary or mandibular premolar region. All implants survived and no mobility was recorded. No significant differences were seen between all-ceramic (AC) and metal-ceramic (MC) crowns for Plaque or Bleeding Indices. Mean marginal bone loss was not significantly different. Inflammatory reactions were seen at the 1-year examination for seven AC crowns and three MC crowns. The inflammatory reactions were believed to be due to poor marginal adaption with five of seven AC crowns showing poorer marginal adaption than the MC crowns (one of three). No abutment complications were seen and porcelain chipping was seen in one MC crown. Patient-reported VAS score did not report differences in outcomes from the AC versus MC crowns; however, professionally reported color matching was found to be significantly better in the AC crowns. No difference was seen between MC and AC crowns for crown morphology or papilla index, and the frequency of mucosal discoloration was unchanged for both types. None of the studies were able to employ a pure CAD/CAM technique (devoid of human intervention) for the crown fabrication. Currently, to achieve optimal esthetic outcomes, coloration, staining, or layering of a core is needed to appropriately match natural tooth color. The CAD/CAM technique was used for the core fabrication, onto which layering porcelain was applied. Henriksson and Jemt[6] reported one abutment fracture in the laboratory during crown fabrication in their prospective clinical evaluation; however, all crowns in both groups were stable during the 12-month period. One patient in the cement crown group experienced a buccal fistula and a further two experienced buccal recession. The recession exposed the cement-abutment joint. While comparable outcomes were seen with both techniques, the issue of recession and increased bone loss on two implants in the cement-retained group possibly point toward a trend that the direct screw-retained group may yield better outcomes with less risk of tissue-related complications.

The studies of Zarone et al[11] and Furze et al[12] also employed high strength ceramic cores, of different material, which appear to have been fabricated using CAD/CAM processes. Unfortunately, the description of the process for crown fabrication was not detailed enough to be certain of the CAD/CAM process, and thus were excluded from the CAD/CAM crown section. These studies reported overall low complication rates and good esthetics. It was interesting that in the publication by Furze et al[12] the clinician wished to reject the color of one crown but the patient did not feel it necessary. This reduced the mean WES score by 0.2. Newer generation color- and translucency-graded ceramic blocks

are becoming available for use in CAD/CAM milling machines, which may reduce the need for routine manual intervention in achieving optimal coloration of the anterior restoration.

## Abutments

Very few technical complications were reported with the CAD/CAM abutments from the studies reviewed. This indicates that in the short- to medium-term, CAD/CAM abutments demonstrate acceptable clinical performance with no reported incidence of screw loosening or abutment fracture of either ceramic or metallic materials. Zembic et al[8] reported many of the test group ceramic abutments (16 of 18 cases) were in posterior areas of the mouth subjected to high masticatory load with no technical complications reported. However, the rate of veneering porcelain fracture from the prostheses upon the abutments is still comparable to other reviews. The rate of porcelain chipping for the cohort did reduce dramatically from 16.7% in the metal-ceramic group in the first 12 months[7] to 0% at the 3-year review.[8] The majority of the crowns were cement-retained. A modest number of abutments, totaling 11 at the 3-year review and mostly titanium,[10] were lost to follow-up. The study by Zarone et al[11] had one crown chipping and one fracture, which was in the incisal edge region.

The study by Ekfeldt et al[26] evaluated the clinical outcome of custom-made zirconia abutments for implant-supported single-tooth restorations. Unfortunately, this study was excluded since during the first follow-up (1 year), the implant-supported restorations (185 single-tooth implant restorations placed in 130 patients) were evaluated retrospectively using only patient records. This action could involve a possible bias in the values presented since the evaluation did not include an actual clinical examination. During the second follow-up of this cohort (greater than 3 years), only 37% of the original 130 patients were invited for a clinical examination. Out of these patients, only 25 (40 restorations) could be examined, which means that 105 were lost to follow-up. The paper was thus considered to be highly biased and was therefore not included in the data analysis.

The latest generation CAD/CAM techniques are utilizing newer technologies, which allow the clinician or technician to fully customize the abutment contour to match carefully the clinical situation[12] after tissue customization with provisional restorations. Of further interest is the ability of the abutment material choice to influence the mucosal color and have a negative affect on the final esthetic outcome. Zembic et al[8] reported that both the zirconia and titanium abutments induced a visible color change in the mucosa when compared with natural teeth. No difference in mean mucosal thickness was seen when comparing abutment type. The average thickness of the mucosa over the abutments (1.8 ± 0.7 mm) was slightly higher than the gingival thickness overlying natural teeth (1.5 ± 0.9 mm). However, the tissue thickness was reduced over the zirconia abutments from 2.1 to 1.9 mm and the tissue thickness increased from 1.3 to 1.5 mm over teeth in the follow-up period from 12 to 36 months. This may be as a result of the technique used to measure the overlying tissue thickness. This is different than the data published by Bressan et al,[27] who reported less change with zirconia abutments. Unfortunately, the publication of Bressan et al[27] was excluded from the review as the abutments were only installed for a period of 10 minutes prior to color evaluation. The mucosal thickness overlying the abutments in the cases presented by Zembic et al[8] was less than that reported by Bressan et al[27] and this could explain the differences seen, as could the different measurement techniques. However, they did not seek to classify the tissue thickness and measurements were made using different techniques, which may also explain the difference in spectrophotometric evaluation. Only one publication reviewed the esthetic outcome using the objective PES/WES scale.[12] More widespread use of these objective evaluation scales will enable better comparison of the studies.

One of the true advantages of the latest generation CAD/CAM techniques is the ability for the clinician or technician to fully customize the abutment contour without the need for human intervention. The distinction between these generational technology changes should be considered by clinicians when evaluating these techniques. One of the limitations of this technology, which is progressing at a rapid rate, is that direct comparisons of "old" and "new" generation technologies become difficult. For the purposes of this review, the design of the abutment needed to include some computer-aided design process, if not exclusively CAD/CAM produced. Scanning of a manually-produced wax pattern could be argued to be non–computer-aided design, as the majority of the design is not performed in the digital environment. Vanlioglu et al[28] describes a technique for manually-aided design (MAD) and/or manually-aided manufacturing technique (MAM) of abutments. Often, similar materials for abutment production as those employed in CAD/CAM strategies are used for this technique. Two papers were excluded from evaluation due to the employment of a MAD/MAM technique used to produce abutments.[28,29] Additionally, any hand modification to the abutment after return from the laboratory where digitally design and production occurs breaks the chain of "purity" of CAD/CAM production. Zafiropoulos et al[30] was also excluded, as this study required multiple manual

interventions to achieve the abutment outcome. These manual interventions may cloud the true accuracy of the CAD/CAM systems at precision output of a product for clinical use.

The review conducted by Jung et al[24] reported a total of 46 studies that met the inclusion criteria and a mean follow-up of at least 5 years. This can serve as a comparison for these techniques. Based on the meta-analysis, survival of implants supporting SCs at 5 years amounted to 97.2% (95% CI: 96.3% to 97.9%), and at 10 years to 95.2% (95% CI: 91.8% to 97.2%). While three late implant failures were reported in one publication between the 3- and 5-year review, no other papers reported implant failure for a mean cumulative survival rate of 98.3%. It is unlikely that these failures were a result of the CAD/CAM technology.

The survival of implant-supported SCs was 96.3% (95% CI: 94.2% to 97.6%) after 5 years and 89.4% (95% CI: 82.8% to 93.6%) after 10 years. While only two papers were found which met inclusion for crowns fabricated with a CAD/CAM technique, the mean survival rate of 98.85% for these two studies is comparable. The survival rate of CAD/CAM abutments was 100% indicating good success of this technology, with the crowns supported by CAD/CAM abutments having a mean survival rate of 99.8%.

For biologic complications, a 5-year cumulative soft tissue complication rate of 7.1% (95% CI: 4.4% to 11.3%) and a cumulative complication rate for implants with bone loss > 2 mm of 5.2% (95% CI: 3.1% to 8.6%) were calculated. Technical complications reached a cumulative incidence of 8.8% (95% CI: 5.1% to 15.0%) for screw-loosening, 4.1% (95% CI: 2.2% to 7.5%) for loss of retention, and 3.5% (95% CI: 2.4% to 5.2%) for fracture of the veneering material after 5 years. The cumulative 5-year esthetic complication rate amounted to 7.1% (95% CI: 3.6% to 13.6%). The mean cumulative complication rate for CAD/CAM crowns based on only two studies was 0%. Compared to the control group for Hosseini et al,[5] which had a technical complication rate for metal-ceramic restoration similar to Jung et al's 4.8% compared to 3.8%, no technical complications were observed for abutments fabricated with CAD/CAM technology. The crowns supported by these appeared to suffer technical complications with similar frequency to that reported by Jung et al.[24] The mean rate of biologic complications for the CAD/CAM techniques was almost twice as high when compared to that reported previously (14.4% vs 7.1%), however, the use of CAD/CAM abutments did not approach this previously reported rate (2.5% vs 7.1%).

## Frameworks

There were two articles that were initially considered but excluded from statistical calculation. Both of these studies warrant discussion. Pieri et al[31] reported a 1-year follow-up of 26 patients that received a full-arch CAD/CAM-fabricated FDP. However, patients had a temporary prosthesis for the first few months, and the definitive CAD/CAM composite resin restoration was then delivered 4 to 5 months after surgery. This would imply that the follow-up time would apply only for the implants placed and not the final prosthesis. Since the time followed was less than 1 year, the study was excluded. In the second excluded study, by Yong and Moy,[32] there were 14 arches restored with an immediate loading protocol. Patients received either carbon fiber frameworks with acrylic teeth or acrylic denture teeth on a milled titanium frame (Procera Implant Bridge, Nobel Biocare). The mean follow-up period was 26.6 months. Unfortunately, the exact number of titanium-milled cases was not reported and the complications presented included both treatment modalities. Since it was not possible to distinguish the outcomes of the CAD/CAM prosthesis, the study was excluded.

During the analysis of the CAD/CAM data for frameworks, the terminology needs to be addressed again. It seems that the techniques used to produce CAD/CAM frames vary significantly between the different investigations. A technique that seems to be very prominent is the scanning of a framework, usually fabricated out of resin, composite, or wax. Jemt at al[33] first introduced the concept in 1999 as a CNC milling technique. It was an innovative protocol under which a titanium framework could be fabricated. Following a clinically acceptable tooth try-in, "a resin pattern was made to reproduce the design of the final titanium framework. This resin pattern was then placed in a laser scanner to feed information on the contour of the framework into a computer. Following measurement of the positions of the implant replicas in the master cast, a block of grade 2 titanium was milled in a CNC milling machine with 5 degrees of freedom. An identical copy of the resin pattern was achieved in one piece of titanium". Several authors in their clinical investigations have used this protocol with some minor modifications.[15,16,19,21,22]

Since then, dental technology and adjunctive computer techniques have advanced, and the software and the available materials have also improved significantly. As a result, there is now the option of completely designing the CAD/CAM parts virtually using a computer and not by scanning a prototype. This virtual protocol is encountered in most of the immediate loading cases where the final prosthesis is designed prior to the implant placement**.** There were three studies that followed this model in the present review.[17,18,20] The existing dental technology allows clinical information to be fed into computer software as digital data by scanning an actual implant master cast or even by taking a digital intra-oral impression of the clinical situation.

**Table 9 Failure Rates and Survival of CAD/CAM Frameworks Supporting Implants**

| Study | Year of publication | Restoration type | Implant Placement | Implants | Type of implants |
|---|---|---|---|---|---|
| Larsson and Vult von Steyern[14] | 2010 | Partial FDP (2–5 units) | Delayed | NR | Astra Tech standard or ST |
| Engquist et al[16] | 2005 | Full-arch FDP | Delayed | 432 | Brånemark (Nobel Biocare) |
| Komiyama et al[18] | 2008 | Full-arch FDP | Delayed | 176 | Brånemark MKIII, TiUnite |
| Ortorp and Jemt[15] | 2012 | Full-arch FDP | Delayed | 367 | Brånemark (Nobel Biocare) |
| Sanna et al[17] | 2007 | Full-arch FDP | Delayed | 183 | Brånemark TiUnite (Nobel Biocare) |
| Tahmaseb et al[20] | 2012 | Full-arch FDP | Delayed | 240 | Straumann Standard Tissue Level |
| Katsoulis et al[19] | 2011 | Full-arch FDP | Delayed | 74 | Replace Select tapered (Nobel Biocare) |
| Papaspyridakos and Lal[22] | 2013 | Full-arch FDP | Delayed | 103 | Brånemark TiUnite (Nobel Biocare) |
| Malo et al (1)[21] | 2012 | Full-arch FDP | Delayed | 634 | Brånemark system, Nobel Speedy; (Nobel Biocare) |
| Malo et al (2)[21] | 2012 | Full-arch FDP | Delayed | 634 | Brånemark system, Nobel Speedy; (Nobel Biocare) |

NR = not reported; FDPs = fixed dental prostheses;
*Mean follow-up time for combined studies: 60 (range, 9 months–10 years).

A digital wax-up is usually evaluated and the abutment or framework can then be designed virtually. This technique seems to follow the designation of CAD, computer-aided design, most closely.

For this reason, the authors feel that a distinction needs to be made between the products that require a pattern to be scanned, and the ones that can be fully designed using only a computer software program. A new definition of the dental CAD/CAM procedures would be beneficial to more accurately define the processes under which these restorations are manufactured. "Complete CAD/CAM product" vs "Partial CAD/CAM product" (product referring to abutment, mesostructures, frameworks, and prostheses) could be two terms that would provide a classification of the implant-supported prosthesis fabrication technique that more accurately reflects the processes used.

To compare the CAD/CAM literature with the conventional implant-supported frameworks, a scientific systematic review was assessed and analyzed. The search for this clinical investigation was conducted by Pjetursson et al[25] and reported a total 32 studies that met the inclusion criteria. A meta-analysis of these studies indicated an estimated survival of implants supporting fixed dental prostheses (FDPs) of 95.6% after 5 years and 93.1% after 10 years. When machined-surface implants were excluded from the analysis and only rough-surfaced implants included, the survival rate increased to 97.2% after 5 years. Under the selected CAD/CAM publications, there was a total of 2,209 rough-surfaced implants that were evaluated (excluding the paper by Larsson and Vult von Steyern,[14] which did not report the number of implants related to CAD/CAM prosthesis). The range of the survival rate for those implants varied between 89.2% and 100%. If only the studies that reported on a purely delayed loading protocol[15,16,21] (1,001 implants) were chosen, then the survival rate range becomes 95% to 100%. The failure rates and the survival of CAD/CAM supporting implants are summarized in Table 9.

For the Pjetursson et al[25] review, the survival rate of implant-supported FDPs was 95.4% after 5 years and 80.1% after 10 years of function. When the analysis was done exclusively for metal-ceramic FDPs and excluding gold-acrylic FDPs, the survival rate increased to 96.4% after 5 years and 93.9% after 10 years. Those values can be compared with the ones reported by the CAD/CAM publications. The total number of prostheses evaluated was 438, and the range of the prosthesis survival rate (excluding the Engquist et al[16] study that did not report on survival rates) was between 80.7% and 100% for a follow-up range of 2 to 5 years.[17–19,21] Concentrating on the studies that reported on a delayed loading protocol[14,15,19,21] for a total of 218 prostheses changes the survival rate range to 90.1% to 100% over a follow-up range of 3.5 from 6 years.[14,21] The failure rates and survival of the CAD/CAM frameworks are summarized in Table 10.

Under the Pjetursson et al[25] report only 66.4% of the patients were free of any complications after 5 years

| Mean follow-up time (mo) | No. of implant failures | CSR | Mean marginal bone loss |
|---|---|---|---|
| 60 | NR | NR | NR |
| 36 | 24 | 92.30% | 1.24 mm (Group D) – 1.68 mm (Group B) |
| 44 | 19 | 89.20% | |
| 120 | 17 and 161 lost to follow-up | 95% | 0.7 mm (SD, 0.77) |
| 26.4 | 9 | 95% | Smokers, 2.6 mm (± 1.6); nonsmokers, 1.2 mm (± 0.8) |
| 12 months minimum (range: 12–36 mo) | 11 | 95.40% | Radiographic analysis showed bone loss on 2 implants up to second thread, both in posterior augmented maxillae, 15 implants not measurable |
| 24 | 0 | 100% | NR |
| 36 | 0 | 100% | NR |
| 78 (range: 9–127)* | Implants NR, failures in 2 patients | 98.10% | NR |
| 46 (range: 12–67)* | 0 | 100% | NR |

(biological and technical complications were present in 33.6% of cases). The most frequent complications over the 5-year observation period were fractures of the veneering material (13.5%), peri-implantitis and soft tissue complications (8.5%), loss of access hole restoration (5.4%), abutment or screw loosening (5.3%), and loss of retention of cemented FDPs (4.7%).

The evaluated CAD/CAM framework investigations presented great variations between them. Studies differed in the number of implants that supported the prostheses, the loading protocols, the presence or absence of cantilevers, the type of restorations present in the opposing arch, and the type of veneering material. These differences as well as the variations in the techniques used for CAD/CAM framework fabrication made direct comparison between studies impossible. Table 11 summarizes the data of the observed CAD/CAM framework complications. Not all authors reported on complications and even when that was done, the methodology of assessment varied significantly. As with conventional fabrication techniques, veneering material fractures were the most common complication to be encountered. A total of 104 incidents were recorded from a total of 221[15,19,21,22] prostheses. On several occasions the fracture took place in the same prosthesis, increasing the overall number of fracture incidents. A total of six screw-loosening incidents were reported out of 221 cases[15,19,21,22] and nine occlusal adjustments out of 79 cases.[18–20] Malo et al[21] was the only study which reported in detail soft tissue complications. Nineteen incidents of peri-implant pathology and 12 of soft tissue inflammation were recorded in total.

In summary, the use of CAD/CAM frameworks for implant-supported restorations appears to provide acceptable clinical outcomes. When a delayed loading protocol was followed, the implant survival values between CAD/CAM restorations and conventional implant-supported frameworks seemed to be similar. In the relatively short-term, (3.5 to 6 years follow-up) the survival of prostheses fabricated by CAD/CAM (delayed loading protocol) and conventional also presented comparable values.

## CONCLUSION

CAD/CAM technology is currently available which can be used to predictably facilitate the restoration of dental implants from single-unit cases to complex full-arch reconstructions. The purpose of this systematic review was to compare the outcomes of CAD/CAM generated restorations and abutments to those generated using conventional techniques. For crowns, abutments, and frameworks, CAD/CAM technology is able to provide results which, based on the current literature, are comparable to that of conventional techniques for implant survival, prosthesis survival, technical, and biologic complications. The authors believe that with the advent of a wide variety of CAD/CAM techniques being

**Table 10 Failure Rates and Survival of CAD/CAM Frameworks**

| Study | Year of publication | Restoration type | Material |
|---|---|---|---|
| Larsson and Vult von Steyern[14] | 2010 | partial FDP (2–5 units) | Zr frame (Denzir, Decim) veneered with Esprident Triceram (Dentaurum) porcelain |
| Engquist et al[16] | 2005 | Full-arch FDP | Tiframe (Procera All-in-One, Nobel Biocare) combined with acrylic teeth |
| Komiyama et al[18] | 2008 | Full-arch FDP | Ti frame (Procera Implant Bridge, Nobel Biocare) combined with acrylic teeth |
| Ortorp and Jemt[15] | 2012 | Full-arch FDP | Ti frame (Procera All-in-One, Nobel Biocare) combined with acrylic teeth |
| Sanna et al[17] | 2007 | Full-arch FDP | Ti frame (Procera All-in-One, Nobel Biocare) combined with acrylic teeth |
| Tahmaseb et al[20] | 2012 | Full-arch FDP | Ti frame (Es-Healthcare) combined with acrylic teeth |
| Katsoulis et al[19] | 2011 | Full-arch FDP | Ti frame (Procera, Nobel Biocare) combined with acrylic resin Candulor |
| Papaspyridakos and Lal[22] | 2012 | Full-arch FDP | Zr frame (Procera, Nobel Biocare) + veneering porcelain |
| Malo et al (1)[21] | 2012 | Full-arch FDP | Ti frame (Procera, Nobel Biocare), Alumina copings (Nobel Biocare), Allceram (Ducera Dental) + Duceram (Ducera Dental) veneering porcelain |
| Malo et al (2)[21] | 2012 | Full-arch FDP | Titanium frame (Procera, Nobel Biocare), Zirconia copings (Nobel Biocare), Nobel Rondo Zirconia Ceramic (Nobel Biocare), PalaXpress Ultra (Heraeus Kulzer) |

NR = not reported.
*Mean follow-up time for combined studies: 60 (range, 9 months-10 years).

**Table 11 Complications of CAD/CAM Frameworks**

| Study | Year of publication | Restoration type | Mean follow-up time (mo) | Occlusion | Passive fit |
|---|---|---|---|---|---|
| Larsson and Vult von Steyern[14] | 2010 | Partial FDP (2-5 units) | 60 | NR | |
| Engquist et al[16] | 2005 | Full-arch FDP | 36 | NR | |
| Komiyama et al[18] | 2008 | Full-arch FDP | 44 | 3/31 | misfit in 5 cases |
| Ortorp and Jemt[15] | 2012 | Full-arch FDP | 120 | NR | |
| Sanna et al[17] | 2007 | Full-arch FDP | 26.4 | NR | NR |
| Tahmaseb et al[20] | 2012 | Full-arch FDP | 12 months minimum (range: 12–36 mo) | 1/40 lab adjustment | 100% |
| Katsoulis et al[19] | 2011 | Full-arch FDP | 24 | 5 corrections | NR |
| Papaspyridakos and Lal[22] | 2013 | Full-arch FDP | 36 | | |
| Malo et al (1)[21] | 2012 | Full-arch FDP | 78 (range: 9–127) | NR | 100% |
| Malo et al (2)[21] | 2012 | Full-arch FDP | 46 (range: 12–67) | NR | 100% |

NR = not reported; FDPs: fixed dental prostheses.

presented in the literature, the following recommendations should be made:

1. Authors should carefully consider how to report their processes for future publications so readers are able to easily and accurately compare the true advantages of newer technology.
2. Two new definitions are recommended for dental CAD/CAM procedures. These would more accurately define the process under which these restorations are manufactured. "Complete CAD/CAM Product," (product referring to abutment, mesostructures, frameworks, and prostheses) where the entire design and manufacturing process is software-implemented and controlled.
3. "Partial CAD/CAM Product," where some design and manufacturing processes involve manual intervention.

| Loading | Arch loaded | Restorations | Mean follow-up time (mo) | Restoration failures | CSR |
|---|---|---|---|---|---|
| Delayed | Mandible and maxilla | 13 | 60 | 0 | 100% |
| Delayed + early + immediate | Mandible | 108 | 36 | NR | NR |
| Immediate | Mandible and maxilla | 26 (5 carbon) | 44 | 5 | 80.70% |
| Delayed | Mandible and maxilla | 67 | 120 | 2 incidents in 2 cases | 95.60% |
| Immediate | Mandible and maxilla | 30 | 26.4 | 0 (phone contact in 4) | 100% |
| Immediate | Mandible and maxilla | 40 | 12 months minimum (range: 12–36 mo) | 1 (due to implant failure) | 97.50% |
| Delayed | Maxilla | 13 | 24 | 0 | 100% |
| 13 delayed and 3 immediate | Mandible and maxilla | 16 | 36 | 0 | 100% |
| Delayed | Mandible and maxilla | 66 | 78 (range: 9–127)* | 5 + 1 (due to implant failure) = 6 | 90.10% |
| Delayed | Mandible and maxilla | 59 | 46 (range: 12–67)* | 0 | 100% |

| Screw loosening | Total no. of veneering material chipping/fracture | Other |
|---|---|---|
| | 16 (52%) | NR |
| NR | NR | NR |
| NR | NR | NR |
| 3 incidents in 1 prosthesis | 35 incidents out of 19 cases | NR |
| NR | NR | NR |
| NR | NR | NR |
| 0 | 14 | Sore spots: 1, Relining: 3, Excessive tooth wear: 1, Discoloration of acrylic: 1 |
| 0 | 5 (4 patients), ceramic chipping rate of 31.25% | NR |
| 2 | 36 | |
| 1 | 14 | |

## REFERENCES


1. Sackett DL, Strauss SE, Richardson WS. Evidence-Based Medicine: How to Practice and Teach EBM. London: Churchill-Livingstone, 2000.
2. Akobeng AK. Principles of Evidence Based Medicine. Arch Dis Child 2005;90:837–840.
3. The Cochrane Collobation's tool for assessing risk of bias. http://ohg.cochrane.org/sites/ohg.cochrane.org/files/uploads/Risk%20of%20bias%20assessment%20tool.pdf.
4. The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Non-randomized Studies in Meta-Analysis. http://www.evidencebased-publichealth.de/download/Newcastle_Ottowa_Scale_Pope_Bruce.pdf
5. Hosseini M, Worsaae N, Schiodt M, Gotfredsen K. A 1-year randomized controlled trial comparing zirconia versus metal-ceramic implant supported single-tooth restorations. Eur J Oral Implantol 2011;4:347–361.
6. Henriksson K, Jemt T. Evaluation of custom-made Procera ceramic abutments for single-implant tooth replacement: A prospective 1-year follow-up study. Int J Prosthodont 2003;16:626–630.
7. Sailer I, Zembic A, Jung RE, Siegenthaler D, Holderegger C, Hammerle CH. Randomized controlled clinical trial of customized zirconia and titanium implant abutments for canine and posterior single-tooth implant reconstructions: Preliminary results at 1 year of function. Clin Oral Implants Res 2009;20:219–225.
8. Zembic A, Sailer I, Jung RE, Hammerle CH. Randomized-controlled clinical trial of customized zirconia and titanium implant abutments for single-tooth implants in canine and posterior regions: 3-year results. Clin Oral Implants Res 2009;20:802–808.
9. Zembic A, Bosch A, Jung RE, Hammerle CH, Sailer I. Five-year results of a randomized controlled clinical trial comparing zirconia and titanium abutments supporting single-implant crowns in canine and posterior regions. Clin Oral Implants Res 2012;24:384–390.
10. Canullo L. Clinical outcome study of customized zirconia abutments for single-implant restorations. Int J Prosthodont 2007;20:489–493.
11. Zarone F, Sorrentino R, Vaccaro F, Russo S, De Simone G. Retrospective clinical evaluation of 86 Procera AllCeram anterior single crowns on natural and implant-supported abutments. Clin Implant Dent Relat Res 2005;7(suppl 1):s95–s103.
12. Furze D, Byrne A, Donos N, Mardas N. Clinical and esthetic outcomes of single-tooth implants in the anterior maxilla. Quintessence Int 2012;43:127–134.
13. Vafiadis DC. Computer-generated abutments using a coded healing abutment: A two year preliminary report. Pract Proced Aesthet Dent 2007;19:443–448.
14. Larsson C, Vult von Steyern P. Five-year follow-up of implant-supported Y-TZP and ZTA fixed dental prostheses. A randomized, prospective clinical trial comparing two different material systems. Int J Prosthodont 2010;23:555–561.
15. Ortorp A, Jemt T. CNC-milled titanium frameworks supported by implants in the edentulous jaw: A 10-year comparative clinical study. Clin Implant Dent Relat Res 2012;14:88–99.

16. Engquist B, Astrand P, Anzen B, et al. Simplified methods of implant treatment in the edentulous lower jaw: A 3-year follow-up report of a controlled prospective study of one-stage versus two-stage surgery and early loading. Clin Implant Dent Relat Res 2005;7:95–104.
17. Sanna AM, Molly L, van Steenberghe D. Immediately loaded CAD-CAM manufactured fixed complete dentures using flapless implant placement procedures: A cohort study of consecutive patients. J Prosthet Dent 2007;97:331–339.
18. Komiyama A, Klinge B, Hultin M. Treatment outcome of immediately loaded implants installed in edentulous jaws following computer-assisted virtual treatment planning and flapless surgery. Clin Oral Implants Res 2008;19:677–685.
19. Katsoulis J, Brunner A, Mericske-Stern R. Maintenance of implant-supported maxillary prostheses: A 2-year controlled clinical trial. Int J Oral Maxillofac Implants 2011;26:648-656.
20. Tahmaseb A, De Clerck R, Aartman I, Wismeijer D. Digital protocol for reference-based guided surgery and immediate loading: A prospective clinical study. Int J Oral Maxillofac Implants 2012;27:1258–1270.
21. Malo P, de Araujo Nobre M, Borges J, Almeida R. Retrievable metal ceramic implant-supported fixed prostheses with milled titanium frameworks and all-ceramic crowns: Retrospective clinical study with up to 10 years of follow-up. J Prosthodont 2012;21:256–264.
22. Papaspyridakos P, Lal K. Computer-assisted design/computer-assisted manufacturing zirconia implant fixed complete prostheses: Clinical results and technical complications up to 4 years of function. Clin Oral Implants Res 2013;24:659–665.
23. Esposito M, Grusovin MG, Willings M, Coulthard P, Worthington HV. Interventions for replacing missing teeth: Different times for loading dental implants. Cochrane Database Syst Rev 2007:CD003878.
24. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and esthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res 2012;23(suppl 6):2–21.
25. Pjetursson BE, Thoma D, Jung R, Zwahlen M, Zembic A. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. Clin Oral Implants Res 2012;23(suppl 6):22–38.
26. Ekfeldt A, Furst B, Carlsson GE. Zirconia abutments for single-tooth implant restorations: A retrospective and clinical follow-up study. Clin Oral Implants Res. 2011;22:1308–1314.
27. Bressan E, Paniz G, Lops D, Corazza B, Romeo E, Favero G. Influence of abutment material on the gingival color of implant-supported all-ceramic restorations: A prospective multicenter study. Clin Oral Implants Res 2011;22:631–637.
28. Vanlioglu BA, Ozkan Y, Evren B, Ozkan YK. Experimental custom-made zirconia abutments for narrow implants in esthetically demanding regions: A 5-year follow-up. Int J Oral Maxillofac Implants 2012;27:1239–1242.
29. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Scharer P. Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 2004;17:285–290.
30. Zafiropoulos GG, Rebbe J, Thielen U, Deli G, Beaumont C, Hoffmann O. Zirconia removable telescopic dentures retained on teeth or implants for maxilla rehabilitation. Three-year observation of three cases. J Oral Implantol 2010;36:455–465.
31. Pieri F, Aldini NN, Fini M, Corinaldesi G. Immediate occlusal loading of immediately placed implants supporting fixed restorations in completely edentulous arches: A 1-year prospective pilot study. J Periodontol 2009;80:411–421.
32. Yong LT, Moy PK. Complications of computer-aided-design/computer-aided-machining-guided (NobelGuide) surgical implant placement: An evaluation of early clinical results. Clin Implant Dent Relat Res 2008;10:123–127.
33. Jemt T, Back T, Petersson A. Precision of CNC-milled titanium frameworks for implant treatment in the edentulous jaw. Int J Prosthodont 1999;12:209–215.