CAD / CAM Technology for Implant Abutments, Crowns and Superstructures

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UiT The Arctic University of Norway
# Computer-aid/-assist usage in dentistry

## Engineering & Production
- **CA design “CAD”**
- CA drafting
- CA engineering
- **CA manufacturing “CAM”**
- CA quality management
- CA maintenance

## Teaching
- CA instruction
- CA learning
- CA assessment

## Communication
- CA personal interviewing
- CA telephone interviewing
- CA reporting

## Dental Clinic
- CA (i.active) shade-matching
- CA (i.active) treatment planning

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The 5th ITI Consensus Conference, Bern 2013
# Microprocessor performance

<table>
<thead>
<tr>
<th>Clock Speed (MHz)</th>
<th>Year</th>
<th>Processor/Manufacturer</th>
<th>Operating System/Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>1971</td>
<td>Intel 4004/ Texas Instrument TMS100</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1974</td>
<td>Motorola/Intel 8008/ZilogZ80 8bit.</td>
<td>Cp/M (Commodore 64, Apple II)</td>
</tr>
<tr>
<td>4.77</td>
<td>1976/8</td>
<td>Intel 8086 16bit;</td>
<td>(Compaq, IBM PC); Intel 8088 (IBM (1981))</td>
</tr>
<tr>
<td>8</td>
<td>1978</td>
<td>Motorola 68000</td>
<td>(Macintosh 128k, Amiga 1000)</td>
</tr>
<tr>
<td>12 – 40</td>
<td>1985-90</td>
<td>Intel 80386 32bit;</td>
<td>Motorola 68040 (Macintosh, Amiga, NeXT))</td>
</tr>
<tr>
<td>20 – 100</td>
<td>1989-94</td>
<td>Intel i486; Cyrix</td>
<td></td>
</tr>
<tr>
<td>1993-95</td>
<td></td>
<td>Intel Pentium, Pentium MMX → Pentium Pro</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>1994</td>
<td>IBM PowerPC 601 (Power Macintosh 8100)</td>
<td></td>
</tr>
<tr>
<td>133</td>
<td>1996</td>
<td>AMD K5</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>1997</td>
<td>IBM PowerPC 750 (iMac)</td>
<td></td>
</tr>
</tbody>
</table>

From: [http://www.old-computers.com/museum](http://www.old-computers.com/museum)
Microprocessor performance

(The clock rate is no longer considered as a reliable benchmark since there are different instruction set architectures & different microarchitectures – MIPS more common today)

<table>
<thead>
<tr>
<th>Year</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>&lt;1 MHz</td>
</tr>
<tr>
<td>1974</td>
<td>1 MHz</td>
</tr>
<tr>
<td>1976</td>
<td>4.77 MHz</td>
</tr>
<tr>
<td>1978</td>
<td>8 MHz</td>
</tr>
<tr>
<td>1982</td>
<td>6 – 25 MHz</td>
</tr>
<tr>
<td>1985</td>
<td>12 – 40 MHz</td>
</tr>
<tr>
<td>1989</td>
<td>20 – 100 MHz</td>
</tr>
<tr>
<td>1993</td>
<td>110 MHz</td>
</tr>
<tr>
<td>1994</td>
<td>133 MHz</td>
</tr>
<tr>
<td>1996</td>
<td>500 MHz</td>
</tr>
<tr>
<td>1997</td>
<td>2000 MHz</td>
</tr>
</tbody>
</table>

0.6 → 1400 1997-2002 Intel Pentium III (Celeron/Zeon)
0.8 → 3000 2001 IBM PowerPC950 (PowerPC G5)
1.3 → 3800 2000-2008 Intel Pentium 4 (Pentium M/D)
1 → 3000 2003 AMD Athlon 64 → 64X2
3300 2011 Intel Core i7
Microprocessor use in the dental clinic

- Subtractive (Milling) & Additive Manufacturing
- Screen Printer
- CAD-CAM
- Digital camera/video +/- Software (e.g. Velscope)
- cbCT/MRI
- Microscope
- Impressions
- Dies/models/wax-up/ etc.
- T-Scan
- Jaw-tracking
- Perio-probe
- Voice-input
- Digitalization
- Impression
- ASCII
- Modem/ISDN
- DICOM
- STL
- Surgery Navigation
- Pat. Admin.
- Pat. Educ./Commun.
- 1997
- 2013
The diffusion of innovations

- People have different levels of readiness for adopting new innovations
- Clinicians can be classified into five groups
- The characteristics of a product affect overall adoption.

Everett Rogers (1962)
There is continuous industry controlled development in CAD/CAM devices, techniques and materials. The dentist and technician should be aware that product hardware and software, as well as support, will change with generational advances.

The implementation of CAD/CAM technologies should lead to acceptable clinical outcomes.
The early adopters ~10 years ago

cad-esthetics® /DECIM
Cercon smart ceramics®
Cerec® 1→3 / InLab®
DCS Precident®
Digident®
KaVo Everest®
Lava® system

Compact unit: Digital acquisition → Design-software → Manufacturer-software → CNC-Milling, generally an Al₂O₃-ceramic
Innovations in CAD-CAM technologies

Manufacture Process
- Device
- Applications
- Materials

Scanning
- Technology Acquisition
- Scan Items
- Data export format(s)

Design Software
- Data import/export formats / formatting
- Design applications

Manufacture Software
- Data import/export formats / formatting
- Manufacturing applications
Continuous training for both the restorative dentist and technician is essential to successfully implement CAD/CAM techniques for the restoration of dental implants.
INNOVATIONS IN
SCANNING DEVICES
Intra oral scanning

CEREC
BlueCam / AC

Lava COS
(2008)

Laser Triangulation
Confocal light
Per 2010;
4 systems
(+E4D)

Cadent Itero
(2006)

Hint-Elgs GmbH
(2009)
Intra oral scanning

3Shape: TRIOS/(Dentaswiss)

Intellidenta/Clõn3D: IODIS

MHT: Cyrtina/3DProgress

CEREC

LAVA COS

Per 2010/2011: 4 additional systems introduced

Cadent

Itero

Hint-Els GmbH

Densys3D: MIA3d
Intra oral scanning

Per 2012: 3 additional systems introduced

Bluescan /a.tron3D

Zfx / Intrascan

IOS: Fastscan
Digital Impression with the Itero device of Straumann Implants

(Lab. photos: Slawek Bilko, RDT)
# Scanning - Parameters

<table>
<thead>
<tr>
<th>Technology</th>
<th>Acquisition</th>
<th>Scan Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical-white light</td>
<td>Intra-oral</td>
<td>Antagonist</td>
</tr>
<tr>
<td>Optical-blue light</td>
<td>Extra-oral</td>
<td>Bite registration</td>
</tr>
<tr>
<td>Optical-stripe light</td>
<td>Intra-&amp; extra-oral</td>
<td>Die</td>
</tr>
<tr>
<td>Optical-laser/video</td>
<td></td>
<td>Full arch</td>
</tr>
<tr>
<td>Optical-laser-triangulate</td>
<td>Scan export format</td>
<td>Implant Abutment</td>
</tr>
<tr>
<td>Optical-laser-confocal</td>
<td>Open format (STL,</td>
<td>Model</td>
</tr>
<tr>
<td>Mechanico-electric (laser-adjusted)</td>
<td>DICOM)</td>
<td>Prostheses</td>
</tr>
<tr>
<td>Conoscopic Holography</td>
<td>Closed</td>
<td>Wax-up</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO-standard(?)</td>
</tr>
</tbody>
</table>
INNOVATIONS IN THE DESIGN & MANUFACTURER SOFTWARE
The sum of Hardware + Software Improvements

CEREC 1
(~1986)

CEREC 2
(~1992)
## Design / Manufacturer Software

### Parameters

<table>
<thead>
<tr>
<th>Import format(s)</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>Wax-ups / temporaries</td>
</tr>
<tr>
<td>Scanner-CAD bundled (Closed)</td>
<td>Inlays / Onlays</td>
</tr>
<tr>
<td><strong>Export format(s)</strong></td>
<td>Single-unit copings</td>
</tr>
<tr>
<td>Open (e.g. STL)</td>
<td>Crowns / monolithic crowns</td>
</tr>
<tr>
<td>CAD-CAM bundled (Closed)</td>
<td>3 → 16u / 4 → 7cm –FDPs</td>
</tr>
<tr>
<td><strong>Removable Dental Prosthesis</strong></td>
<td>(Partial / Full)</td>
</tr>
<tr>
<td></td>
<td>Implant “customised” abutments</td>
</tr>
<tr>
<td></td>
<td>Implant meso-structures</td>
</tr>
<tr>
<td></td>
<td>Implant-Bars</td>
</tr>
</tbody>
</table>
INNOVATIONS IN ADDITIVE AND SUBTRACTIVE MANUFACTURING CONCEPTS
## Manufacturing Parameters

**Device - additive**
- 3D Laser sintering
- 3D Printing

**Device - subtractive**
- 3/3.5/4/5/6-axis-milling

### Applications
- Wax-ups
- In-/Onlays
- Single-unit copings
- Crowns
- Monolithic Crowns
- 3 → 16 unit(/4 → 7 cm)-FDPs
- Custom abutments
- Implant-Bars
- implant-suprastructure-Meso-structures
- Partial Removable Prosthesis
- Full Removable Prosthesis

### Materials
- Base alloys
- Gold alloys
- Non-precious alloys
- Titanium / -alloys
- Composite resins
- Cast Resins / Wax
- PMMA
- In-Ceram (Porous Al\(_2\)O\(_3\))
- Al\(_2\)O\(_3\) (sintered)
- Feldtspanthic
- Li\(_2\)Si\(_2\)O\(_5\)
- ZrO\(_2\) (porous/green state)
- ZrO\(_2\) (pre-sintered state)
- ZrO\(_2\) (sintered)
- ZrO\(_2\) (sintered & HIP-ed state)

with / without
- Sintering-furnace
Milling in Dentistry – From 3 axes $\rightarrow$ 5 $\rightarrow$ 5+5 milling axes

Milling machines today are manually operated, mechanically automated, or digitally automated via computer numerical control (CNC) re. e.g. torques, feed-rate, nature of cutters, etc..
Software algorithm compensation for errors introduced during milling processes

Often based on finite-element-modeling calculations

• Geometrical compensation

• Force compensation

• Thermal compensation

• Errors in the final dimensions of the machined part are determined by the accuracy with which the commanded tool trajectory is followed, combined with any deflections of the tool, parts/fixture, or machine caused by the cutting forces

• The effect of geometric errors in the machine structure is determined by the sophistication of the error compensation algorithms

• The cutting tools’ trajectories are subject to performance of the axis drives and the quality of the control algorithms
Submarine’s propellers

1. as thin as possible so the submarine can produce low noise
2. as strong as possible so the submarine can achieve speed

• The accuracy of parts produced in milling is crucial in high-precision industry
• No advanced milling technology = no possibility for production

State-of-the-art manufacturing of propellers
1. Bronze continuous/industrial casting
2. Quenching
3. Milling
4. Berillium layer on the bronze
5. Repeat milling
CoCom is an acronym for Coordinating Committee for Multilateral Export Controls. CoCom was established by Western bloc powers in the first five years[1] after the end of World War II, during the Cold War, to put an arms embargo on COMECON (Warsaw Pact) countries.

CoCom ceased to function on March 31, 1994.
During this same period the U.S. Government was pushing its Allies to increase the resources they devoted to export licensing and enforcement. The plans for increased effort fell on deaf ears until the uncovering the now-famous sale of precision machine tools and software by Kongsberg Vaapenfabrik of Norway and the Toshiba Machine Company of Japan. In the fall of 1986, U.S. intelligence agencies discovered an on-going scheme by these two companies to supply nine-axis submarine propeller milling machines and the necessary software to the Soviet Navy propeller production facility in Leningrad—the Baltic Shipyard. The equipment included computer-aided design and computer aided manufacturing software, so-called CAD/CAM, as well as the numerical controllers from Kongsberg and the actual machine tools supplied by Toshiba Machine. The transaction began in 1981 and continued until the time of its discovery in 1986. It involved shipment and installation of the machine tools, as well as modification of the software to meet the specifications of the shipyard.
Cutters for dental (5 axis) milling

From: ZirconZahn
Additive manufacturing technologies

E.g.: 3D printing / Additive (freeform) fabrication / Layered manufacturing / Rapid prototyping/-manufacturing / Robocasting /Solid freeform fabrication (SFF)

3D geometries physically constructed directly from 3D CAD.

Process introduced in the mid-1980s. Original name was rapid prototyping since the first use was to make prototypes of parts without having to invest the time or resources to develop tooling or other traditional methods.

As the process and quality controls have evolved additive manufacturing has grown to include production applications

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy (mm/mm)</th>
<th>Maximum part size (mm)</th>
<th>Process time (hh:mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fused deposition modelling</td>
<td>0.005</td>
<td>254 x 254 x 254 (Stratasys)</td>
<td>12:39</td>
</tr>
<tr>
<td>Laminated object modeling</td>
<td>0.01</td>
<td>812 x 558 x 508 (Cubic Technologies)</td>
<td>11:02</td>
</tr>
<tr>
<td>Selective laser sintering</td>
<td>0.005</td>
<td>381 x 330 x 457 (3D Systems)</td>
<td>4:55</td>
</tr>
<tr>
<td>Solid ground curing</td>
<td>0.006</td>
<td>508 x 355 x 508 (Cubital)</td>
<td>11:21</td>
</tr>
<tr>
<td>Stereolithography</td>
<td>0.003</td>
<td>990 x 787 x 508 (Sony)</td>
<td>7:03</td>
</tr>
<tr>
<td>Robocasting</td>
<td>0.1 (Fab@Home)</td>
<td>240 x 240 X 240 (Fab@Home)</td>
<td>TBD</td>
</tr>
</tbody>
</table>

From: wikipedia.com
AMT: Selective Laser Sintering (SLS)

A high power laser (e.g., CO2) fuses small particles of plastic, metal, ceramic, or glass powders into a desired 3-dimensional shape.

The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part on the surface of a powder bed.

After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed.

SLS does not require support structures due to the fact that the part being constructed is surrounded by unsintered powder at all times.

From: Traini ea Dent Mater 2008
The method and apparatus make solid objects by successively “printing” thin layers of an UV-curable material one on top of the other.

The concentrated UV-light-beam focuses onto the surface of a vat filled with liquid photopolymer. The light beam draws the object onto the surface of the liquid layer by layer, causing polymerization or cross-linking to give a solid.
AMT: Robocasting

A material is deposited at room-temperature material -- in the form of a viscous gel or ceramic slurry -- from a robotically controlled syringe or extrusion head.

The material hardens or cures after deposition.

From: Silva ea. NYU J Prosthodont 2011
INNOVATIONS IN RESTORATIVE MATERIALS
Zirconia milling substrates are not all alike!

<table>
<thead>
<tr>
<th>Substance</th>
<th>Composition</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>TZP*</td>
<td>ZrO₂ / Y₂O₃</td>
<td>95 / 5</td>
</tr>
<tr>
<td>TZP-A</td>
<td>ZrO₂ / Y₂O₃ / Al₂O₃</td>
<td>~95 / ~5 / 0.25</td>
</tr>
<tr>
<td>FSZ</td>
<td>ZrO₂ / Y₂O₃</td>
<td>90 / 10</td>
</tr>
<tr>
<td>PSZ</td>
<td>ZrO₂ / MgO</td>
<td>96.5 / 3.5</td>
</tr>
<tr>
<td>ATZ</td>
<td>ZrO₂ / Al₂O₃ / Y₂O₃</td>
<td>76 / 20 / 4</td>
</tr>
</tbody>
</table>

Great variations regarding:

- Hardness
- Fracture resistance
- Tension strength
- Elasticity module
- Opacity
- Grain size
- Sintering time

Who do you believe checks:

- Veneering ceramic compatibility?
- Optimal core-veneer layering thickness?

*TZP=(tetragonal zirconia polycrystals)
**Zirconia milling substrates are not all alike!**

<table>
<thead>
<tr>
<th>Isostatic pressing technique</th>
<th>Uniaxial pressing technique</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Powder</strong></td>
<td><strong>Powder</strong></td>
</tr>
<tr>
<td>Isostatic pressing</td>
<td>Uniaxial pressing</td>
</tr>
<tr>
<td>Green machining</td>
<td>Final sintering</td>
</tr>
<tr>
<td>Final sintering</td>
<td>Pre-sintering</td>
</tr>
<tr>
<td>HIP process</td>
<td>HIP process</td>
</tr>
<tr>
<td>Oxidizing</td>
<td>Oxidizing</td>
</tr>
<tr>
<td>CAD/CAM machining in the dental laboratory</td>
<td>Final sintering</td>
</tr>
<tr>
<td>Processing by the dental technician</td>
<td>Final sintering</td>
</tr>
</tbody>
</table>

(HIP process: hot isostatic post compaction)

Final sintering: ~1350°C (cercon) -1500°C (lava) -1530°C (vita)
Zirconia milling substrates are not alike! 3/3
Prefabricated blanks for supra-construction

Examples:

- **Sirona**
  - Ø99 mm x 10 - 25mm

- **DCS (Hip)**

- **KaVo Everest**

- **E4D**
CAM fabricated bodies – a concern today for problems tomorrow?

Near-surface damage -- a persistent problem in crowns obtained by computer-aided design and manufacturing.

Rekow D, Thompson VP.
College of Dentistry, New York University, New York, NY, USA. edr1@nyu.edu

Abstract
Robust dental systems obtained by computer-aided design and manufacture (CAD/CAM) have been introduced and, in parallel, the strength of the ceramic materials used in fabricating dental crowns has improved. Yet all-ceramic crowns suffer from near-surface damage, limiting their clinical success, especially on posterior teeth. Factors directly associated with CAD/CAM fabrication that contribute to the degree of damage include material selection and machining parameters and strategies. However, a number of additional factors also either create new damage modes or exacerbate subcritical damage, potentially leading to catastrophic failure of the crown. Such factors include post-fabrication manipulations in the laboratory or by the clinician, fatigue associated with natural occlusal function, and stress fields created by compliance or distortion within the supporting tooth structure and/or adhesive material holding the crown to the tooth. Any damage reduces the strength of a crown, increasing the probability of catastrophic failure. The challenge is to understand and manage the combination of competing damage initiation sites and mechanisms, limitations imposed by the demand for aesthetics, and biologically related constraints.
As many different types of zirconia are being introduced into implant dentistry with differing microstructures and performance, they should be obtained from a reputable/qualified manufacturer.
The pace of technological developments compress the learning curve time for

- operating new scanning devices
- mastering CA design software
- handling CA manufacture numerical control programs
- controlling new additive/subtractive manufacturing technologies
- recognizing the technique-sensitivity and clinical properties of new CAD-CAM-biomaterials

The rise of the new “bundle package industry”
Patient

Dentist

- Prosthesis designing
- Biomaterial selection

Dental Technician

- Fabrication process
It is recommended that the dentist approve a virtual final prosthesis that dictates abutment/framework design. (Virtual diagnostic wax-up)
Prefabricated blanks for customised implant abutments

**ESSENTIAL:**

- It’s the **Doctor’s responsibility** to maintaining the control of and overview of the chain of materials and fabrication methods
- Fabrication processes and material choices may be incompatible
- Stay with a validated concept or upgrade your knowledge about modern material properties as well as modern additive & subtractive manufacturing methods
Innovations in CAD-CAM technologies

Manufacture Process
- Device
- Applications
- Materials

Scanning
- Technology
- Acquisition
- Scan Items
- Data export format(s)

Design Software
- Data import/export formats / formatting
- Manufacturing applications

Manufacture Software
- Data import/export formats / formatting
- Manufacturing applications

Device
- Applications
- Materials

Design Software
- Data import/export formats / formatting
- Design applications
The clinician must have full ownership of all patient data.

It is recognized that digitally derived prostheses can be remanufactured from stored data sets. It is recommended that digital data sets be stored/protected for this eventuality and that digital technology work platforms maintain programming compatibility/transparency.
Thank you for your kind attention