The benefits and caveats of using computer technologies in the fabrication process to make supra-constructions

Asbjørn Jokstad
University of Toronto, Canada
Microprocessor uses in the dental clinic

- Jaw-tracking
- Perio-probe
- Voice-input
- T-Scan
- Impression
- X-ray
- Digital camera/video +/- Software (e.g. Velscope)
- cbCT/MRI
- Microscope
- Digitalization
- Scanner
- ASCII
- Modem/ISDN
- DICOM
- STL
- Surgery Navigation
- Dies/models/wax-up/etc.
- STL
- Impressions
- Screen Printer
- CAD-CAM
- Pat. Admin.
- Pat. Educ./Commun.
Microprocessor performance

Clock speed (MHz)

<1  1971  Intel4004/ Texas Instrument TMS100
1  1974  Motorola/Intel8008/ZilogZ80  8bit.Cp/M (Commodore 64, Apple II)
4.77  1976/8  Intel 8086  16bit; (Compaq, IBM PC); Intel 8088 (IBM (1981))
8  1978  Motorola 68000 (Macintosh128k, Amiga1000)
12 – 40  1985-90  Intel 80386  32bit; Motorola 68040 (Macintosh, Amiga, NeXT))
20 – 100  1989-94  Intel i486; Cyrix
  1993-95  Intel Pentium, Pentium MMX → Pentium Pro
110  1994  IBM PowerPC 601 (Power Macintosh 8100)
133  1996  AMD K5
500  1997  IBM PowerPC 750 (iMac)

From: 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)

MHz

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
# Computer-aid/-assistance in dentistry

<table>
<thead>
<tr>
<th>Engineering &amp; Production</th>
<th>Teaching</th>
<th>Communication</th>
<th>Dental Clinic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Computer-aided design “CAD”</strong></td>
<td>Computer assisted instruction</td>
<td>Computer-assisted personal interviewing</td>
<td>Computer-aided shade-matching</td>
</tr>
<tr>
<td>Computer-aided drafting</td>
<td>Computer assisted based learning</td>
<td>Computer-assisted telephone interviewing</td>
<td></td>
</tr>
<tr>
<td>Computer-aided engineering</td>
<td>Computer-assisted assessment</td>
<td>Computer-assisted reporting</td>
<td></td>
</tr>
<tr>
<td><strong>Computer-aided manufacturing “CAM”</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer-aided quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer-aided maintenance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Health Care</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer-assisted detection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer-aided diagnosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer-aided tomography</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer-assisted / -guided surgery</td>
<td></td>
<td></td>
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</table>
CURRENT STATUS AND CHALLENGES OF SCANNING DEVICES
### 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><strong>Scan export format</strong></td>
<td>Implant Abutment</td>
</tr>
<tr>
<td>Optical-laser-confocal</td>
<td>Open format (STL, DICOM)</td>
<td>Model</td>
</tr>
<tr>
<td>Mechanico-electric (laser-adjusted)</td>
<td></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>
Intra oral scanning

CEREC BlueCam / AC

LAVA COS (2008)

Cadent Itero (2006)

Laser Triangulation

Confocal light

Per 2010; 4 systems (+E4D)

Hint-Els GmbH (2009)
Intra oral scanning

3Shape: TRIOS /(Dentaswiss)

Intellidenta/ Clõn3D: IODIS

MHT : Cyrtina/3DProgress

Densys3D: MIA3d

Per 2010/2011: 4 additional systems introduced

CEREC
LAVA COS
Cadent Itero
Hint-Els GmbH
Intra oral scanning

Per 2012: 3 additional systems introduced

Zfx / Intrascan
Bluescan / a.tron3D
IOS: Fastscan
Digital Impression with the Itero device of Straumann Implants

(Lab. photos: Slawek Bilko, RDT)
CURRENT STATUS AND CHALLENGES OF DESIGN & MANUFACTURER SOFTWARE
The sum of Hardware + Software Improvements

Design / Manufacturer Software

Parameters

**Import format(s)**
- Open
- Scanner-CAD bundled (Closed)

**Export format(s)**
- Open (e.g. STL)
- CAD-CAM bundled (Closed)

**Applications**
- Wax-ups / temporaries
- Inlays / Onlays
- Single-unit copings
- Crowns / monolithic crowns
- 3 → 16u / 4 → 7cm – FDPs
- Removable Dental Prosthesis (Partial / Full)
- Implant “customised” abutments
- Implant meso-structures
- Implant-Bars
CURRENT STATUS AND CHALLENGES OF 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

Materials
Base alloys
Gold alloys
Non-precious alloys
Titanium / -alloys

Composite resins
Cast Resins / Wax
PMMA

In-Ceram (Porous Al₂O₃)
Al₂O₃ (sintered)
Feldspathic
Li₂Si₂O₅
ZrO₂ (porous/green state)
ZrO₂ (pre-sintered state)
ZrO₂ (sintered)
ZrO₂ (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

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
Emerging 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
Additive manufacturing: Stereolithography (SL / SLA)

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.
Additive manufacturing: Selective Laser Sintering (SLS)

A high power laser (e.g., CO2) fuse 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.
Additive manufacturing: 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
CURRENT STATUS AND CHALLENGES OF RESTORATIVE MATERIALS
Zirconia milling substrates are not all alike!

<table>
<thead>
<tr>
<th></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
- Grain size
- Opacity
- 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!

(HIP process: hot isostatic post compaction)

- Partially sintered
- Isostatic
- Uniaxial

- 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

DCS (Hip)

KaVo Everest

ø99 mm x 10 - 25mm

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.
CURRENT STATUS AND CHALLENGES OF OUR DENTAL TEAM PARTNERS – A CONCERN
## Summary

### Quick Facts: Dentists

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010 Median Pay</td>
<td>$146,920 per year, $70.64 per hour</td>
</tr>
<tr>
<td>Entry-Level Education</td>
<td>Doctoral or professional degree</td>
</tr>
<tr>
<td>Work Experience in a Related Occupation</td>
<td>None</td>
</tr>
<tr>
<td>On-the-job Training</td>
<td>Internship/residency</td>
</tr>
<tr>
<td>Number of Jobs, 2010</td>
<td>155,700</td>
</tr>
<tr>
<td>Job Outlook, 2010-20</td>
<td>21% (Faster than average)</td>
</tr>
<tr>
<td>Employment Change, 2010-20</td>
<td>32,200</td>
</tr>
</tbody>
</table>
### Quick Facts: Dentists

<p>| | |</p>
<table>
<thead>
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<th></th>
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</tr>
<tr>
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<td>32,200</td>
</tr>
</tbody>
</table>

### Quick Facts: Dental Hygienists

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>2010 Median Pay</strong></td>
<td>$58,250 per year</td>
</tr>
<tr>
<td></td>
<td>$32.81 per hour</td>
</tr>
<tr>
<td><strong>Entry-Level Education</strong></td>
<td>Associate’s degree</td>
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<tr>
<td><strong>Work Experience in a Related Occupation</strong></td>
<td>None</td>
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<tr>
<td><strong>On-the-job Training</strong></td>
<td>None</td>
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<tr>
<td><strong>Number of Jobs, 2010</strong></td>
<td>181,800</td>
</tr>
<tr>
<td><strong>Job Outlook, 2010-20</strong></td>
<td>38% (Much faster than average)</td>
</tr>
<tr>
<td><strong>Employment Change, 2010-20</strong></td>
<td>68,500</td>
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### Quick Facts: Dental Assistants

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<table>
<thead>
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<tbody>
<tr>
<td><strong>2010 Median Pay</strong></td>
<td>$33,470 per year</td>
</tr>
<tr>
<td></td>
<td>$16.09 per hour</td>
</tr>
<tr>
<td><strong>Entry-Level Education</strong></td>
<td>Postsecondary non-degree award</td>
</tr>
<tr>
<td><strong>Work Experience in a Related Occupation</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>On-the-job Training</strong></td>
<td>None</td>
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<tr>
<td><strong>Number of Jobs, 2010</strong></td>
<td>297,200</td>
</tr>
<tr>
<td><strong>Job Outlook, 2010-20</strong></td>
<td>31% (Much faster than average)</td>
</tr>
<tr>
<td><strong>Employment Change, 2010-20</strong></td>
<td>91,600</td>
</tr>
</tbody>
</table>

### Quick Facts: Dental Laboratory Technicians

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<table>
<thead>
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<tbody>
<tr>
<td><strong>2010 Median Pay</strong></td>
<td>$35,140 per year</td>
</tr>
<tr>
<td></td>
<td>$16.90 per hour</td>
</tr>
<tr>
<td><strong>Entry-Level Education</strong></td>
<td>High school diploma or equivalent</td>
</tr>
<tr>
<td><strong>Work Experience in a Related Occupation</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>On-the-job Training</strong></td>
<td>Moderates-term on-the-job training</td>
</tr>
<tr>
<td><strong>Number of Jobs, 2010</strong></td>
<td>40,900</td>
</tr>
<tr>
<td><strong>Job Outlook, 2010-20</strong></td>
<td>1% (Little or no change)</td>
</tr>
<tr>
<td><strong>Employment Change, 2010-20</strong></td>
<td>300</td>
</tr>
</tbody>
</table>

Job Outlook

Employment of dental laboratory technicians is expected to experience little or no change from 2010 to 2020.

As cosmetic prosthetics, such as veneers and crowns, become less expensive, there should be an increase in demand for these appliances. Accidents and poor oral health, which can cause damage and loss of teeth, will continue to create a need for dental laboratory technician services. Dental technician services will be in demand, as dentists work to improve the aesthetics and function of patients’ teeth.

On the other hand, baby boomers and their children are more likely to retain their teeth than previous generations. This is due to increased visits to dentists, increased use of fluoride, and more dental health education. These factors will likely lead to a decrease in the number of full and partial dentures and other prosthetics used to replace missing teeth and will temper demand for the technicians that make them.

Employment projections data for dental laboratory technicians, 2010-20

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dental Laboratory Technicians</td>
<td>51-9081</td>
<td>40,900</td>
<td>41,200</td>
<td>1</td>
<td>300</td>
</tr>
</tbody>
</table>

NADL Fights Unskilled Labor Label for Technicians

A federal shuffle has reclassified dental technicians as unskilled labor, a false label that could have far-reaching effects on the profession. NADL is lobbying the U.S. Department of Labor to restore technicians to the skilled labor category. “The proposed classification change for dental technicians to another occupational rating could adversely affect the ability of economic

- Typical Entry-Level Education: High school diploma or equivalent
- Previous Work Experience in a Related Occupation: None
- State Licensing: Yes (Editor’s Note: A few states require laboratories or technicians to be registered or certified.)
Rapid Developments combined with compressed learning curves of using

- scanning technologies
- design ("CAD") software
- manufacture ("CAM") software
- additive/subtractive manufacture technologies
- restorative material modifications

give rise to a new “bundle package industry”
Patient

Dentist

Prosthesis designing

Biomaterial selection

Fabrication process

Dental Technician
Prefabicated 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