Colloquium of Oral Rehabilitation (CORE) August, 2016

PEKING UNIVERSITY
SCHOOL OF STOMATOLOGY

Digital prosthodontics – limitations and future of current concepts

Professor Asbjørn Jokstad
UiT The Arctic University of Norway
Tromsø, Norway
asbjorn.jokstad@uit.no

Digital technology innovations and impact on own academic career

Dentistry student U. of Oslo → Military dentist North Norway

1974-1979 1979-1982

Digital technology innovations and impact on own academic career

Dentistry student U. of Oslo → Military dentist North Norway → I-C-Tech. studies, U. of Oslo; Dental faculty clinic instructor; Graduate study in general biology

1974-1979 | 1979-1982 | 1982-

Norsk Data 1967 to 1992

- •CERN Nuclear Accelerator Project
- •International F-16 pilot training simulator program
- •French aerospace agency
- •Etc…

"The Norwegian version of the NOKIA cell phone adventure"

ND-100 32-bit minicomputer

Introduction of so-called Object-Oriented Programming; "O.O.P." language: SIMULA (Today: Java, C++, etc.)

Digital technology innovations and impact on own academic career

Dentistry student U. of Oslo → Military dentist North Norway → I-C-Tech. studies, U. of Oslo; Dental faculty clinic instructor; Graduate study in general biology

1974-1979 | 1979-1982 | 1982-1984

University of Oslo
Faculty of Dentistry
Anatomy Department

1984 -

A shift from analog to digital electron microscopy

Digital technology innovations and impact on own academic career

Dentistry student U. of Oslo → Military dentist North Norway → I-C-Tech. studies, U. of Oslo; Dental faculty clinic instructor; Graduate study in general biology

1974-1979 | 1979-1982 | 1982-1984

Oslo Dental Faculty, Anatomy Dept.
SEM / TEM microscopy
Computer /Network infrastructure

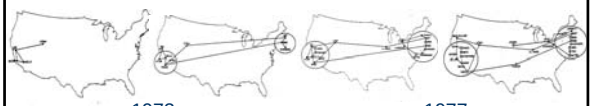
1984 -

Jeol 1200 EXII
Transmission Electron Microscope

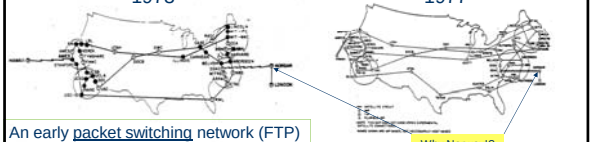
Philips SEM 515
Scanning Electron Microscope

ARPANET - Advanced Research Projects Agency Network

1969 | 1970 | 1971 | 1972



1973 | 1977



An early packet switching network (FTP)

Why Norway!?

Transmission Protocols: Kermit →
TCP + Internet Protocol (IP) →
TCP/IP 1983-01-01 →
WWW (Mosaic 1993)

Professor Ivar A Mjor
Prof. emer. Dept. anatomy
First NIOM director

NIOM Clinical studies program

October 1985:

- Major computer crash!
- All datafiles were corrupted and required reconstruction!!
- All clinical data accumulated over the last 10 years in complete disarray!!!

DEC Vax

A computer geek with a dentistry background was desperately needed!!!

Photo: Wanschitz ea COIR 2002

Digital technology innovations and impact on own academic career

Dentistry student U. of Oslo → Military dentist North Norway → I-C-Tech. studies, U. of Oslo
Dental faculty clinic instructor
Graduate study in general biology

1974-1979 | 1979-1982 | 1982-1984



Electron Microscopy


Then: 8" → 5.25" → 3.5" floppy disks (Kbs)
Now: USB sticks (Gbs) / external disk (Tbs)

Oslo Dental Faculty, Anatomy Dept.
SEM / TEM
Computer /Network infrastructure
&
Nordic Institute of Dental Materials
Clinical trials
Restorative materials
Toxicology

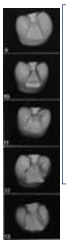
1984- & 1985-


Professor Ivar A Mjor

NIOM Nordic Institute of Dental Materials
Clinical studies program

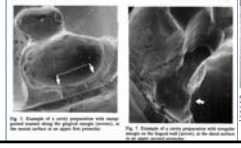
NIOM Clinical studies program

Question: How will a restoration perform as an effect of the qualities of the cavity prepared by the dentist?



Cavity designs for class II amalgam restorations
A literature review and a suggested system for evaluation

Asbjørn Jokstad and Ivar A. Mjör
Department of Anatomy, School of Dentistry, University of Oslo, and
NIOM, Scandinavian Institute of Dental Materials, Oslo, Norway



Pictures from a Philips SEM 515 Scanning e. microsope

Stereo-photogrammetry?
Computer stereo vision?

Restoration performance over 10 years

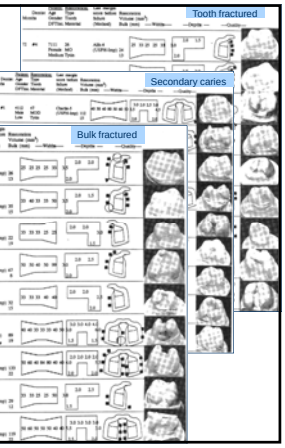
Department of Anatomy, Dental Faculty, University of Oslo
and
NIOM, Scandinavian Institute of Dental Materials

Class 2 Cavity Preparations and Restoration Performance

Asbjørn Jokstad

Thesis

Submitted in partial fulfillment of the requirements for the degree of Doctor Odontologiae at the University of Oslo, 1992



Digital technology innovations and impact on own academic career

Dentistry student U. of Oslo → Military dentist North Norway → I-C-Tech. studies, U. of Oslo; Dental faculty clinic instructor; Graduate study in general biology

1974-1979 | 1979-1982 | 1982-1984

Oslo Dental Faculty, Anatomy Dept.
SEM / TEM
Computer /Network infrastructure
&
Nordic Institute of Dental Materials
Clinical trials
Restorative materials
Toxicology

1984-1992

Graduate prosthodontics
General practice

1992-1994

Dept. Prosthodontics and Stomatognathic function

1994-

Digital Motion Capture System + Electromyography (EMG)

University of Oslo, Department of Prosthodontics and Stomatognathic function

QUALISYS
BIOPAC Systems, Inc.

Purchase 1994: $$$!

The user complexity was too high!
A computer geek with a dentistry background was required!!!

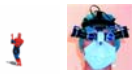


Photo: Wanschitz ea COIR 2002

Digital Motion Capture System + Electromyography (EMG)

QUALISYS
BIOPAC Systems, Inc.

2xIR cameras - 40Hz

Graphic controller EMG

Analogue x-y & y-z video screens

Calibration frame for 3D recording

Fiducial markers (IR reflectors)

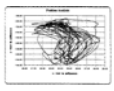
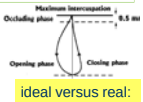
MacReflex software:
Triangulation of centre points (40 Hz)
MacIntosh computer

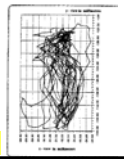
Digital Motion Capture System - chewing

Chewing Movements in TMD Patients and a Control Group Before and After Use of a Stabilization Splint

Una Soboleva, DDS, MSc[a]
Asbjørn Jokstad, LDS, Dr Odont[b]
Thomas Eckersberg, LDS, MSc[c]
Bjørn L. Dahl, LDS, Dr Odont[d]

Purpose: This study assessed the effect of using an occlusal stabilization splint in the maxilla for 6 weeks on certain parameters of chewing movements in subjects with and without temporomandibular disorder symptoms. **Materials and Methods:** Twelve male and 30 female temporomandibular disorder patients with and without a prior whiplash incidence, and individuals without signs and symptoms of temporomandibular disorders participated. The participants formed three groups matched according to gender and age ($n = 3 \times 14$). A maxillary stabilization splint was used during sleep for 6 weeks. An optoelectronic system (MacReflex, Qualisys) was used to record chewing movements at baseline, before using the splint, and after 6 weeks' use of the splint. Calculated parameters were the duration of the chewing cycles, the spatial displacement, and the mean velocity of the mandible while chewing paraffin wax for 20 seconds. **Results:** On a group basis, the use of an occlusal stabilization splint for 6 weeks did not change the jaw movement parameters in a predictable pattern as recorded under the conditions of this study. On an intraindividual basis, large variations in changes of chewing parameters over time were observed. **Conclusion:** The use of an occlusal stabilization splint for 6 weeks did not alter the jaw movements when chewing a substance with a soft consistency. *Int J Prosthodont 1998;11:158–164.*



ideal versus real:

Computer performance in 1996

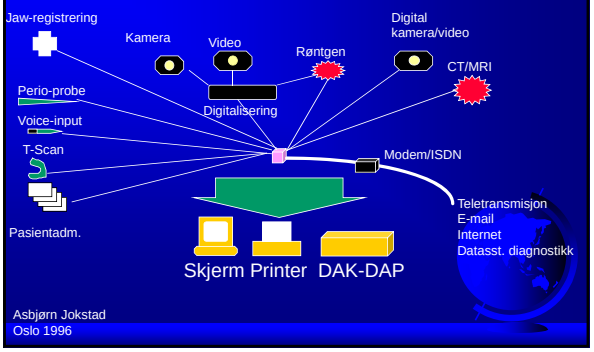
The clock rate is the frequency of the clock in any synchronous circuit, such as a central processing unit (CPU)

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)
6 – 25	1982-85	Intel 80286 DOS(1981); (IBM-AT (1984))
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)


From
← minicomputers
to → PC


From: http://www.old-computers.com/museum

Mikroprosessoren i tannklinikken



Computer performance in 1996 and Digital technology innovationsin dentistry

Clock speed (MHz)

<1 1971 Intel4004/ Texas Instrument TMS100

...

...

...

...

110 1994 IBM PowerPC 601 (Power Macintosh 8100)

Digital technology innovations~1996

Virtual smile

Digitized intraoral camera

Chairside patient education / communication

Digital radiography

Digital technology innovations~1996

Use of the Internet for educational applications in prosthodontics

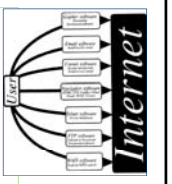
Meade C. van Putten, Jr., DDS, MS[a]
The Ohio State University, College of Dentistry, Columbus, Ohio

Internet is the common term for the information superhighway. The Internet has become a major information resource for educational, governmental, and business institutions. This article reviews the current operation of the Internet as a background for discussing educational opportunities for instruction in prosthodontics. Electronic mail, news groups, file transfer protocol, Gopher, and network navigators are discussed. The use of the World Wide Web for educational purposes by The Ohio State University College of Dentistry Department of Restorative and Prosthetic Dentistry is described. (J Prosthet Dent 1996;76:200-8.)

Health education institutions are undergoing significant changes in the delivery of information. One of the most notable technologic changes is the evolution of computerized network systems that allow storage and dissemination of information in a variety of multimedia formats. The Internet is undoubtedly the most significant of these systems. This powerful, universal network will have a significant impact on how health educators process and present information in the coming decades.[1-36] As of August 1995, the Internet has provided worldwide access to information for more than 30 million users.[37] This complex of networks forms the initial pathway for the global information revolution that currently provides a link for

Table I. Computer equipment and software requirements for Internet access

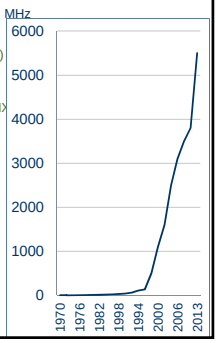
Hardware	Software
Computer (486, Pentium, Mac II, PowerPC)	Windows, Windows 95, UNIX, MacOS 7.0+
RAM 8 megabytes or greater	Navigator software (Mosaic, Netscape etc.)
Internet access device (Ethernet card or modem 14.4 bps or greater)	TCP/IP connection software (InterCon Syst Corp., Herndon, Va.)
Storage device (hard drive)	HTTP gateway software (MacHttp, Webstar)



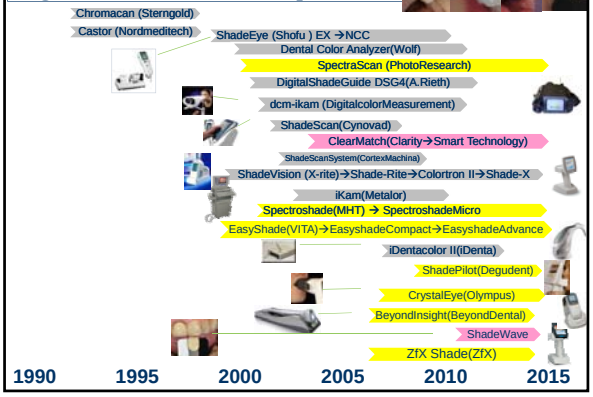
Current computer performance

Different benchmarking tests provide different performance indicator
Clock rate is no longer considered as a reliable benchmark since there are different instruction set architectures & different microarchitectures – "MIPS" is more common)

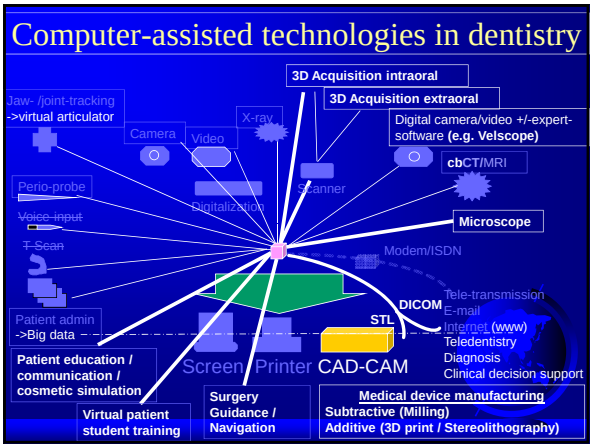
<1	1971	Intel 4004/ Texas Instrument TMS100
1	1974	8bit.Cp/M (Commodore 64, Apple II)
4.77	1976	16bit; (Compaq, IBM PC); Intel 8088 (IBM 1981)
12 – 40	1985	Intel 80386 32bit; Motorola 68040 (Macintosh, Amiga, NeXT))
20 – 100	1989-94	Intel i486; Cyrix, Intel Pentium, Pentium MMX → Pentium Pro
110	1994	IBM PowerPC 601 (Power Macintosh 8100)
.....		
500	1997	IBM PowerPC 750 (iMac)
1400	2002	Intel Pentium III (Celeron/Zeon)
3000	2001	IBM PowerPC950 (PowerPC G5)
3800	2001	Intel Pentium 4 (Pentium M/D)
3000	2003	AMD Athlon 64bit
3200	2005	AMD Athlon 64bit X2
.....		
5500	2013	IBM zEC12



Digital tooth shade acquisition

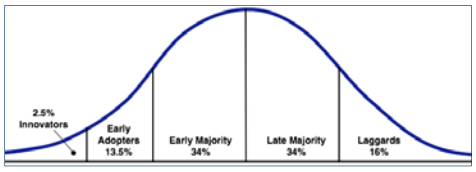


Computer-assisted technologies in dentistry



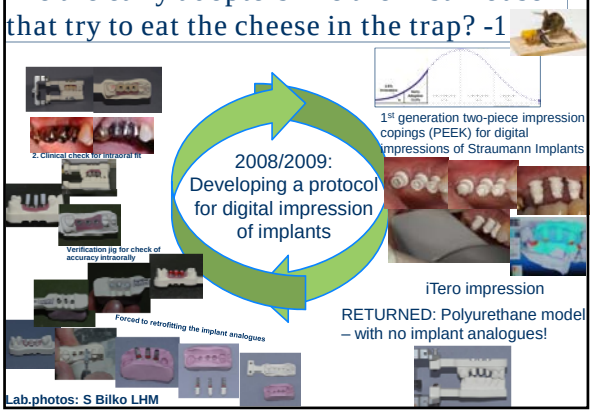
The diffusion of innovations*

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



*according to Everett Rogers (1962)

Are the early adopters like the first mouse that try to eat the cheese in the trap? -1



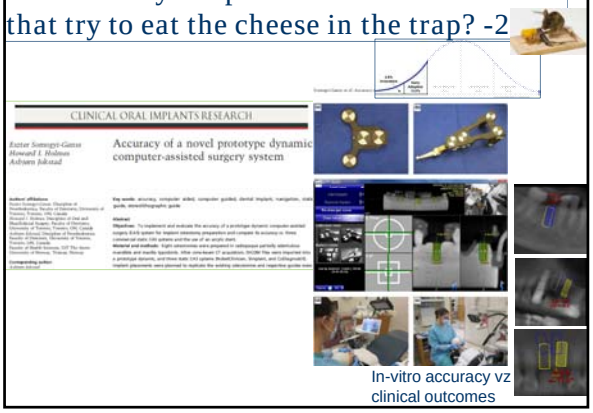
1st generation two-piece impression copings (PEEK) for digital impressions of Straumann Implants

iTero impression

RETURNED: Polyurethane model – with no implant analogues!

Lab.photos: S Bilko LHM

Are the early adopters like the first mouse that try to eat the cheese in the trap? -2



In-vitro accuracy vz clinical outcomes

Are the early adopters like the first mouse that try to eat the cheese in the trap? -2

Another early attempt to develop a dynamic implant surgery concept 'VISIT'

Photo: Wanschitz ea COIR 2002

In-vitro accuracy vz clinical outcomes

Are the early adopters like the first mouse that try to eat the cheese in the trap? -3

Intraoral scan (iTero) Perforated PMMA stent →STL-file

–

Desktop scan (D810, 3Shape) of cleaned FDP →STL-file

= "Summarized STL" *w/* use of industrial metrological software (Convince Premium, 3Shape)

FDPs 12-32 years (mean 19 yrs)

History of screw issues

Computer- aided/assisted tools and concepts relative to prosthodontics

Patient administration
Electronic charting→"Big data"

Education
Student learning / assessment

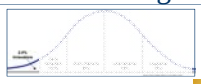
Patient management
Detect/diagnose pathology
Radiography / tomography
Jaw-/TMJ-joint-tracking→"virtual articulator"
Decision support system (AKA expert system)
Treatment (surgery) planning
Surgery guidance (dynamic /static)

Patient communication
Visualization of procedures
Virtual treatment outcome

Medical device* production
Shade-matching
Designing "CAD"
Manufacturing "CAM"
*Intra- / Extra- -oral / -tissue /-tooth or interface constituents
Tissue-engineering constructs

Other applications
Quality assurance "Registration"
Tele-dentistry

Innovations in CA additive / subtractive manufacturing methods ~1986



W. Mörmann / M. Brandestini
University of Zurich

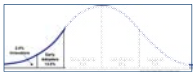
Prototype 1985

CONCEPT:
Intraoral data acquisition by structured light
→ Point cloud (polygon mesh)
→ Surface reconstruction
→ Milled inlays/onlays from blocks of ceram

Commercial product:
Cerec, Siemens, Germany

CEREC from 1987

Innovations in CA additive / subtractive manufacturing methods ~1996



"Closed systems"

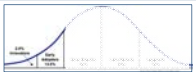
Cerec 2, Siemens→Sirona, Germany (1994)
Cicero, Elephant, Netherlands
DENStech, Dens, Germany
Decsy, Media Corp., Japan
Precident-DCS, DCS-Dental, Switzerland (1989)
Procera, Nobel Biocare, Sweden (1993)

"Milling centres"

Compact unit: Surface rendering + Design- & manufacturing-software + CNC-Milling (Al_2O_3 -ceramic)

(A cheaper alternative: (Celay)Copy milling

Innovations in CA additive / subtractive manufacturing methods ~2006



"Closed systems"

DECIM system (cad-esthetics)(1997)
Cercon smart ceramics®(2001)
Cerec 3 (2000) / InLab® (2001)
Cynovad Pro50 (1997)
Digident (1999)
KaVo Everest® (2002)
Lava® system (2002)
Procera Zirconia (2002)
Wol-Dent EPC 2019 (1999)

Intraoral scanner
CEREC 2003
(iTero 2007)
(Lava COS 2008)

"Open system (.stl)"
stand-alone scanners
BEGO (2002):
Etkon es1 (2000)

Innovations in CA additive / subtractive manufacturing methods ~2016 and beyond

Fabrication process

New methods
New materials
New designs

Restorative dentistry:
Zirconia
Hybrids
Tissue-engineering
Tissue constructs
(stress vs seeding)

Innovations in CAD-CAM technologies

Surface / volume rendering

Merging of surface (.stl) and volumetric (DICOM*) data

*Digital Imaging and Communications in Medicine

"Open systems"

Manufacturing software **Designing software**

Innovations in CA additive / subtractive manufacturing methods ~2016 and beyond

CA fabrication of oral prostheses

Object

Physical Impression of surface – tooth / dentition

Conventional laboratory process

Scale model from physical impression

Conventional laboratory process

Virtual Impression of surface (tooth / dentition / face) and/or core (jaw / TM-joint / head)

CAM process
- Additive
- Subtractive

Scale model from CAM – surface (and/or core)

+/- digital tomography (DICOM*)

*Digital Imaging and Communications in Medicine

CAD of virtual medical device

CAM process
- Additive
- Subtractive

Physical medical device tailored to object

CAD of virtual implant placement (→ surgical stent)
virtual implant placement and medical device fitted to implant

Innovations in CA additive / subtractive manufacturing methods ~2016 and beyond

Fabrication process

Innovations in CAD-CAM technologies

Surface / volume rendering
Technology
Acquisition
Data export format(s)
Scan items

Manufacturing software **Designing software**

Surface/volume rendering - parameters

Technology

Surface:
- Mechanical-electric +/- laser-adjusted
- Optical-structural light
- Optical-laser/video
- Optical-laser-triangulate/confocal
- Optical conoscopic holography

Volumetric:
- X-ray tomography
- Magnetic res. tomo
- Optical coh. tomo
- Ultrasound tomo

Acquisition
- Intraoral
- Extraoral
- Intra-& extraoral

Scan export format
- "Open system" format
- Closed systems

Scan Items
- Antagonist
- Bite registration
- Die
- Full arch
- Implant Abutment
- Model
- Prostheses
- Wax-up
- Reflex/Opacity
- Surface preparation
- Surface coating

Apart from DICOM*, there are no ISO-standards specific to dentistry

*Digital Imaging and Communications in Medicine

Intraoral surface scanning – pre 2010

CEREC BlueCam

Laser Triangulation

Confocal light

LAVA COS (2008)

Per 2010; 4 systems (+E4D)

Cadent Itero (2006)

Hint-Els (2009)

Intraoral surface scanning

2010/2011: 4 new systems

CEREC Bluecam

LAVA COS

Cadent Itero

Hint-Els

Densys3D: MIA3d

Intellidenta/ Clõn3D: IODIS

MHT: Cyrtina/3DProgress

3Shape: TRIOS /(Dentaswiss)

Intra oral surface scanning

2012:
3 new systems

Zfx / Intrascan

Bluescan /a.tron3D

IOS: Fastscan

Intraoral surface scanning

2016: 22 products

1. 3M True Definition Scanner (← Lava™ C.O.S.)	3M ESPE, Germany/USA
2. TRIOS® 3	3Shape A/S, Denmark
3. TRIOS® Digital impression solution	3Shape A/S, Denmark
4. Bluescan®-I ← a.tron 3D® intraoral scanner	a.tron 3D®, Klagenfurt, Austria
5. Itero Element ← Itero Digital impression system	Align Technology, USA <- Cadent, Israel
6. CS3500 / CS3600	Carestream Dental, USA
7. Clon Progress IODIS (Intra Oral Digital Impression System)	Clon 3D / IODIS / Intellidenta (Europe)
8. Condor intraoral scanner	Condorscan Remedent, Belgium
9. MIA3D Digital Dental Impression System	Densys Ltd., Israel
10. dwio ← DigImprint Steinbichler	Dental Wings, Canada
11. Dentium rainbow iOS	Dentium, Korea
12. IOS Fastscan Digital Impression System	Glidewell Laboratories, USA <- IOS technologies, USA
13. directScan	Hint-Els GmbH, Germany
14. Lythos Digital Impression system	KaVo, Germany <-2015 <- Ormo corporation
15. 3D Progress MHT	MHT, Medical High Tecnologies,S.p.a. Italy, Switzerland
16. PlanScan Intraoral Scanner ← Evolution 4D	Planmeca, Finland <- e4D
17. Apollo DI Digital Impression System	Sirona Dental Systems, Germany <-Siemens
18. CEREC AC with BlueCam chairside CAD/CAM system	Sirona Dental Systems, Germany
19. CEREC 3.8 / Biogeneric Digital Impression System	Sirona Dental Systems, Germany
20. CEREC OmniCam Dental CAD/CAM system	Sirona Dental Systems, Germany
21. IntraScan Zfx	zfx gmbH, Germany
22. Detection Eye	Zirkonzahn, Italy

Innovations in CA additive / subtractive manufacturing methods ~2016 and beyond

Fabrication process

Surface or volume rendering

Innovations in CAD-CAM technologies

Manufacturing software
Data import/export formats/ - formatting
Manufacturing applications

Designing software
Data import/export formats / formatting
Designing applications

Open (data / file / system) formats-("free files")

.STL (Standard Tessellation Language)

- a format native to stereolithography and supported by several software packages; it is widely used for rapid prototyping and computer-aided manufacturing
- describes only the surface geometry of a three dimensional object with no representation of color, texture or other common CAD model attributes
- describes a raw unstructured triangulated surface by the unit normal and vertices of the triangles using a three-dimensional Cartesian coordinate system

.OBJ (Object files)

- include surface texture/color, was developed originally for 3D graphics animation applications

.AMF (Additive Manufacturing File)

- describe color, materials, lattices, and constellations of objects for additive manufacturing processes (e.g., acellular scaffold manufacturing by printing)

Design / Manufacturing software - Parameters

Import & export format(s)
Open system (.stl, .obj, .amf)
CAD-CAM bundled (Closed)

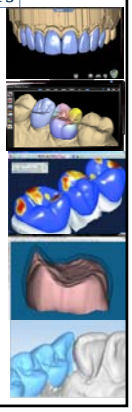
Top 3 O.S. market leaders:
3shape
exocad
dental wings

Applications
Wax-up / temporary

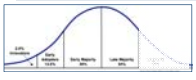
Inlay / Onlay
Single-unit coping
Crown / monolithic crown
3 → 16unit / (4 →7cm) FDP

Removable Dental Prosthesis (Partial / Full)

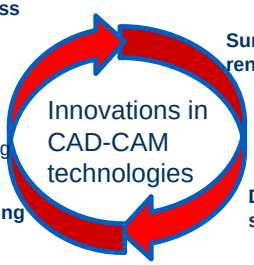
Implant "customised" abutment
Implant-sup. meso-structure
Implant-sup. super-structure



Innovations in CA additive / subtractive manufacturing methods ~2016 and beyond



Fabrication process
Manufacturing
Subtractive
Additive
Device
Prosthesis
Tissue-engineering



Surface or volume rendering

Designing software

Manufacturing software

Fabrication process- parameters

Manufacturing
Subtractive
3 / 3.5 / 4 / 5 / 6-axes –milling --- +/- Sintering-furnace
Additive
Solid freeform fabrication, stereolithography, powder-fusion printing, bioprinting

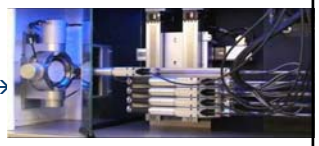
Device
Prosthesis
- In-/Onlay/Veneer
- Single-unit coping
- Crown
- Monolithic Crown
- 3 →16unit(/4 →7cm)-FDP
- Implant abutment
- Implant bars / Meso-structure
- (Endosseous dental implant)
- Surgical guidance stent
- Partial / Full Removable Prosthesis
- Wax-up / Provisional / Splint



Tissue-engineering
- Scaffolds +/- cells

Milling in dentistry – From 3→5→5+5 axes






Milling machines have moved from manually operated to mechanically to digitally automated via computer numerical control (CNC) re. e.g., torques, feed-rate, nature of cutters, etc..

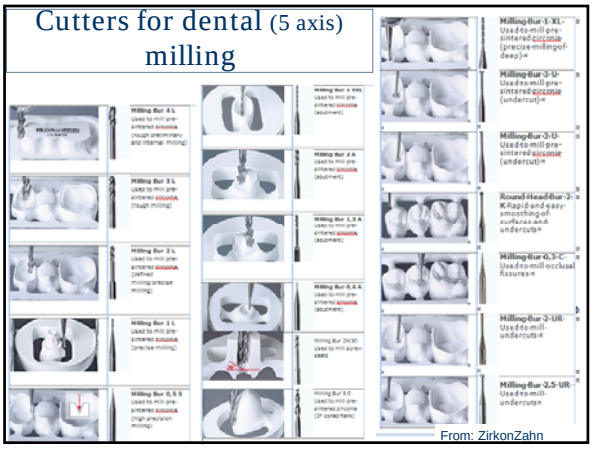
Software algorithm compensation for errors introduced during milling processes

- Geometrical compensation
- Force compensation
- Thermal compensation

torque
feed-rate
cooling

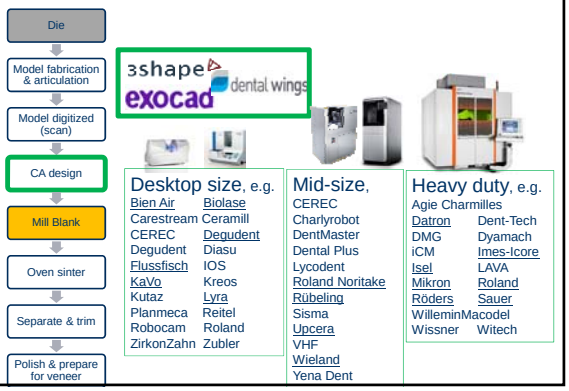
- Errors in the final dimensions of the machined part are determined by the accuracy with which the commanded tool trajectory is followed, combined with any deflections of the tool, parts/fixture, or machine caused by the cutting forces
- The effect of geometric errors in the machine structure is determined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

Cutters for dental (5 axis) milling



From: ZirkonZahn

CAM – subtractive manufacturing



Desktop size, e.g.

Bien Air	Biolase
Carestream	Ceramill
CEREC	Degudent
Degudent	Diasu
Flussfisch	IOS
KaVo	Kreos
Kutaz	Lyra
Planmeca	Reitel
Robocam	Roland
ZirkonZahn	Zubler

Mid-size,
CEREC
Charlyrobot
DentMaster
Dental Plus
Lycodent
Roland Noritake
Rübeling
Sisma
Upcera
VHF
Wieland
Yena Dent

Heavy duty, e.g.
Agie Charmilles

Datron	Dent-Tech
DMG	Dyamach
iCM	Imes-Icore
Isel	LAVA
Mikron	Roland
Röders	Sauer
WilleminMacodel	
Wissner	Witech

Additive manufacturing technologies

Multiple ambiguous terms: 3D printing / Additive (freeform) fabrication / Layered manufacturing / Rapid prototyping /-manufacturing, etc.

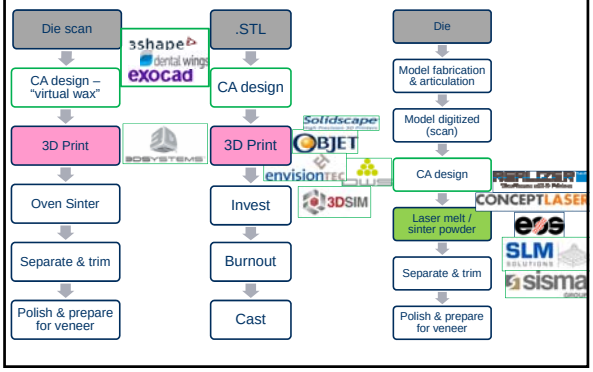
	Tissue-engineering	Prosthodontics
Solid freeform fabrication (SFF)*	Anisotropic scaffolds	Extensive
Stereolithography (SLA)	Precision scaffolds	Semi-permanent
Powder-fusion printing (PFP)	Rigid scaffolds	Experimental
Bioprinting (Laser/Inkjet/Extrusion)	Cellularized constructs	Soft-tissues

3D geometries are physically constructed directly from 3D CAD.

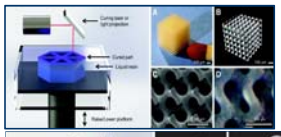
Introduced in the mid-1980s. Original term *rapid prototyping* alluded to making prototypes of parts without having to invest the time and resources to develop tooling or other traditional methods.

*"Fused deposition modelling", "Laminated object modelling", "Direct Metal Printing", "Selective laser sintering", "Solid ground curing", "Robocasting"

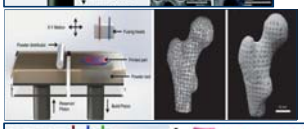
CAM – additive manufacturing



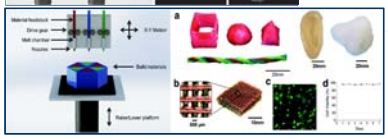
Additive manufacturing in Tissue Engineering



Stereolithographic printing technique and exemplary tissue engineering scaffold composed of poly(d-l lactic acid)



Powder-fusion printing technique and exemplary tissue engineering scaffolds composed of calcium phosphate–poly(hydroxybutyrate-cohydroxyvalerate,



Solid freeform fabrication and exemplary tissue engineering scaffold composed of poly(ethylene glycol) diacrylate;, nanosilicates, and alginate

From: Sears ea. *Tissue Engineering, 2015*

Solid freeform fabrication in prosthodontics

- A high power laser (e.g., CO_2) 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.
- Does not require support structures due to the fact that the part being constructed is surrounded by unsintered powder at all times

Crowns/Coping/FDPs

RPDs

Implants

From: Traini ea Dent Mater 2008

World's first individualized jaw implant made by SLS - 2012

Ti6Al4V ELI (extra-low interstitial) powder
Coated with hydroxylapatite

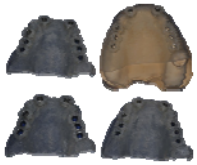
University Hasselt, Xios Hogeschool, University Leuven , Orbis Medisch Centrum Sittard-Geleen, Belgium & Xilloc Medical BV, Cam Bioceramics BV, Netherlands

Liz Nickels, Metal Powders Report, 2012

Stereolithography in prosthodontics

- 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.

Surgical guides for implant placement

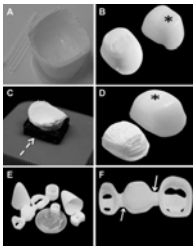


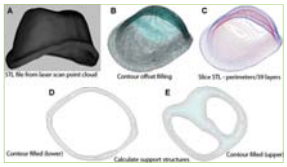
Simplant Surgiguide

Nobelguide

Powder-fusion printing in prosthodontics

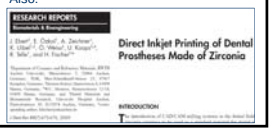
A material is deposited at room-temperature material -- in the form of a viscous gel or ceramic slurry -- from a robotically controlled syringe or extrusion head. The material is hardened / cured after deposition





From: Silva ea. J Prosthodont 2011

Also:



Innovations in CA additive / subtractive manufacturing methods ~2016 and beyond

Fabrication process
Subtractive
Additive

Materials
Prosthesis
Tissue-engineering

Innovations in CAD-CAM technologies

Surface or volume rendering

Manufacturing software

Designing software

Manufacturing methods - parameters

Additive fabrication
Laser sintering
Printing
Subtractive fabrication
3 / 3.5 / 4 / 5 / 6-axes -milling
with / without
Sintering-furnace

Device
In-/Onlays/Veneers
Single-unit copings
Crowns
Monolithic Crowns
3 →16unit(/4 →7cm)-FDPs
Implant abutments
Implant bars / Meso-structures
(Endossous dental implants)
Surgical guidance stents
Partial / Full Removable Prosthesis
Wax-ups / Provisionals / Splints

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

Composite resins
Casting Resins / Wax
Polymers (PEEK, PMMA)

Hi/low-glass content ceramics
Feldspathic
Glass-ceramics, e.g., $Li_2Si_2O_5$
In-Ceram (Porous Alumina)
No glass content
Alumina (sintered)
Zirconia (porous/green state)
Zirconia (pre-sintered state)
Zirconia (sintered)
Zirconia (sintered & HIP-ed state)

Zirconia milling substrates are not all alike!

		%
TZP*	ZrO_2 / Y_2O_3	95 / 5
TZP-A	ZrO_2 / Y_2O_3 / Al_2O_3	~95 / ~5 / 0.25
FSZ	ZrO_2 / Y_2O_3	90 / 10
PSZ	ZrO_2 / MgO	96.5 / 3.5
ATZ	ZrO_2 / Al_2O_3 / Y_2O_3	76 / 20 / 4
Ce-TZP	ZrO_2+CeO_2	98

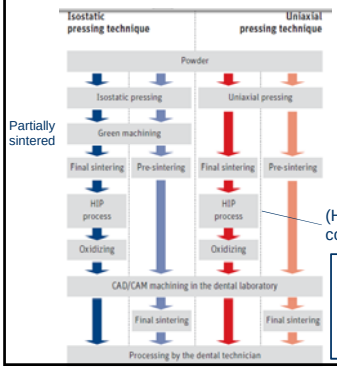
Great variations regarding:

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

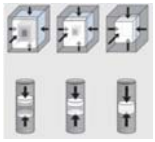
Who do you believe checks:
Veneering ceramic compatibility?
Optimal core-veneer layering thickness?

*TZP=(tetragonal zirconia polycrystals)

Zirconia milling substrates are not all alike!



Partially sintered



Isostatic

Uniaxial

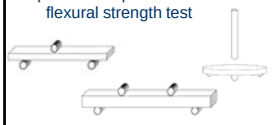
(HIP process: hot isostatic post compaction

Final sintering: ~1350°C (cercon) -1500°C (lava) -1530°C (vita)

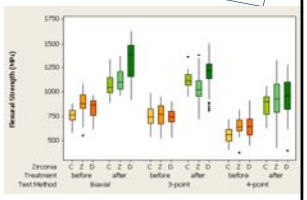
affects grain sizes → translucency (& clinical performance?)

Zirconia milling substrates are not all alike!

3 point 4 point biaxial flexural strength test



Beware when comparing strength data



Fracture toughness may be a better predictor

* dry polishing before sintering or wet polishing after sintering

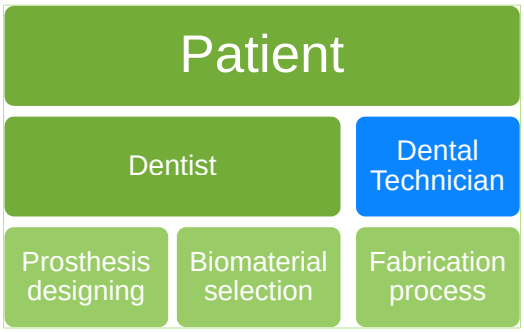
From: Schatz ea Materials 2016

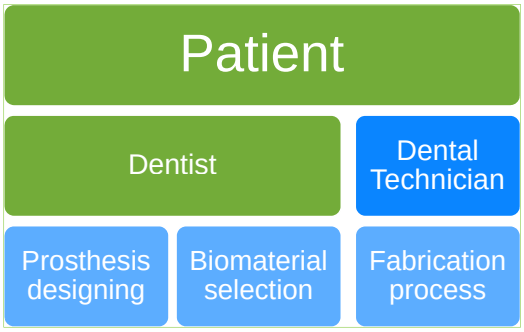
FUTURE TRENDS IN PROSTHODONTICS?

The pace of technological developments compress the learning curve time for

- operating new devices for surface or volumetric rendering
- mastering CA Designing 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

→ **A rise of a "bundle package industry"**





Customised medical devices for your patients

ESSENTIALS:

1. It is always a **responsibility of a doctor** to maintain the control of, and overview of the chain of materials and fabrication methods
2. Materials and fabrication methods may be incompatible
3. Stay with a validated concept or upgrade your knowledge about new material properties, as well as new additive & subtractive manufacturing methods

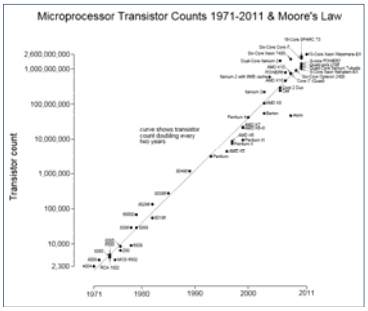
Customised implant abutments – the interface in ceramic or metal – your decision or the technician's?

Computer performance today & in the future

1. Computers will continue to be **faster and with lower cost** per performance unit.

2. Innovative software programs will harness these improvements in performance.

3. The www of Internet will likely continue to be commercialized, driving other services to VPN-like solutions.

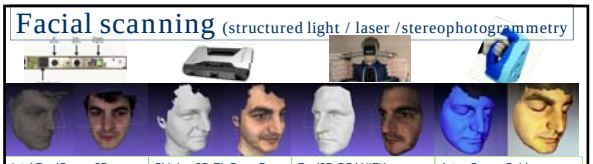


Moore's law: the number of transistors in a dense integrated circuit doubles approximately every two years

Virtual patients – already feasible today

	Planmeca	Cerec4.2(Sirona)	3dMDvultus
Conebeam Rx	√	√	√
Facial scan	√		√

Facial scanning (structured light / laser /stereophotogrammetry



Intel RealSense 3D $99	Shining 3D EinScan-Pro $3,999	Fuel3D SCANIFY $1,500	Artec Space Spider – $27,600
•Mesh Quality – 4/5: The mesh quality is really good. Dense and detailed. •Texture Quality – 2/5: Texture quality is quite poor, the resolution of the sensor being limited to 640 x 480. Synthesis: The 3D scans took a very long time to obtain. A decent result at an affordable price, however necessitates a lot of practice to get good results	•Mesh Quality – 4/5: High mesh quality, hair tends to degrade the performance. •Texture Quality – 4/5: Good sensor quality. However the color module is in option and costs an extra $700. Synthesis: the scan process takes some time. The Einscan-pro is not specifically designed for face scanning but is a very versatile portable scanner.	• Mesh Quality – 3/5: The mesh is really good in the center, the cheeks have less details and are more approximate. • Texture Quality – 5/5: Excellent quality of the textures due to the technology and high resolution of the cameras. Synthesis: Fuel3D SCANIFY delivers an excellent performance. The capture is instantaneous and the user can even keep his eyes open. The marker is the only constraint	•Mesh Quality – 5/5: Excellent mesh resolution and accuracy. •Texture Quality – 5/5: Texture is very detailed and high resolution. Colors are less realistic compared to the SCANIFY. (Example is not very good as it is a picture of t computer screen.) Synthesis: A product made for metrology and reverse engineering but capable of producing amazing face 3D scans. Its price puts it in an entirely different category.
Intel on Amazon			Source: aniwaa.com

Management of patients with oral dyskinesia with digital motion capture systems?

Past: 2 dim.

1990'ies: 3 dim., 40 Hz

Today: Multi-dimensional → 4000Hz

"MoCap": is extensively used in the film and entertainment industry, e.g.,
Avatar,
Planet of the apes, etc.

Virtual patients – already feasible today

	Planmeca	Cerec4.2(Sirona)	3dMDvultus
Conebeam Rx	√	√	√
Facial scan	√		√
Jaw tracking	√	√	

CA jaw recording → (Virtual) articulator

WinJaw (Zebris) JMA20

Myotronics

ARCUSdigma II (KaVo) **Ultrasound**

Axioquick Recorder (SAM)

Opto-electronic

Cadiax

Freecorder BlueFox (DDI-Group)

A virtual articulator may replace the mechanical in complex treatment cases

From 3 df to 6 df


Sirona Scicat

Planmeca Romexis

Virtual patients – already feasible today

	Planmeca	Cerec4.2(Sirona)	3dMDvultus
Conebeam Rx	√	√	√
Facial scan	√		√
Jaw tracking	√	√	
Smile design	√	√	√

Application of innovations in 2016 vz. 1996?

Great visual impact by use of the state-of-the-art technology in 1996

Virtual smile designing in 2016- an even more impressive visual impact

Digital Smile Design (DSD) Smile composer, 3Shape

CEREC 4.2, Sirona Romexis, Planmeca

Also,

- Digital smile system
- Envisionasmile
- GDesign (Hack Dent.)
- GPS Digital Smile Design (Dental GPS)
- Insignia Advanced Smile Design
- Smile Designer Pro (Tast Tech)
- SNAP instant Dental imaging

but,

...carries also a potential to be misused by catering to Barbie doll syndrome patient demands

from: sdcdentist.com

Thank you for your kind attention

asbjorn.jokstad@uit.no