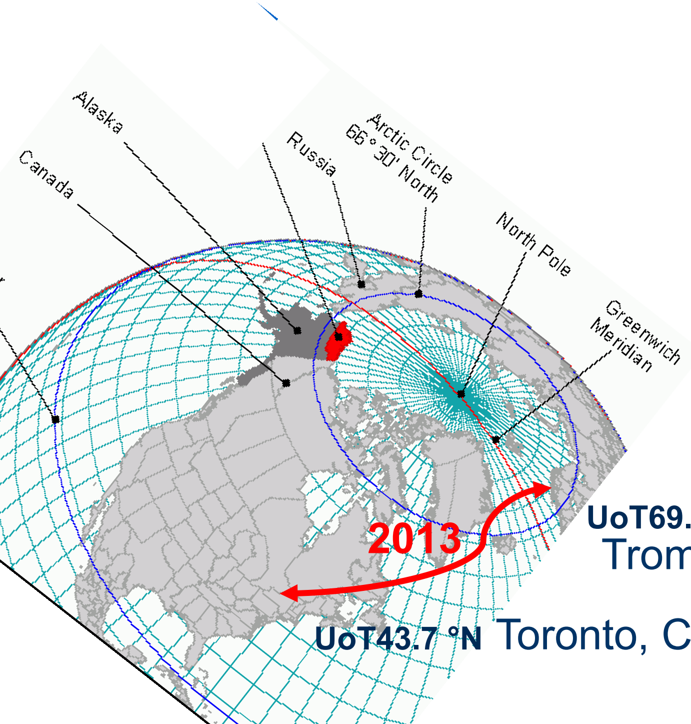
Adopting computer-assisted technologies in patient care – to be or not to be a prosthodontist of the future

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

LOOKING WEST: Kvaløy island

LOOKING EAST: The Mainland

THE ISLAND OF TROMSØ



UoT69.7°N
Tromsø, Norway

UoT43.7 °N Toronto, Canada

Innovations in digital technologies has influenced the career decisions of many

Dentistry student
U. of Oslo

→

Military dentist
North Norway

1974-1979

1979-1982

Professor
Jon Ørstavik
(1937-†2003)

One of the co-founders of EPA in 1977

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1982-

ND

NORSK DATA 1967 to 1992

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

ND-100 32-bit minicomputer

"The Norwegian version of the NOKIA cell phone adventure"

Object-Oriented Programming - "O.O.P.-language": SIMULA
(Today: Java, C++, etc.)

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1984 -

University of Oslo
Faculty of Dentistry
Anatomy Department

~1980: Electron microscopy went digital

→ 1984 Department of Anatomy, U of Oslo

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1982-1984

↓

1984 -
Oslo Dental Faculty, Anatomy Dept.
SEM / TEM microscopy

Jeol 1200 EXII

Transmission Electron Microscope

Philips SEM 515

Scanning Electron Microscope

Then:
8” → 5.25” → 3.5” floppy disks (250Kb→9Mb)

Today:
USB sticks (Gb) / External harddisk (Tb)

Photo: Wikipedia

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Transmission
Electron
Microscope

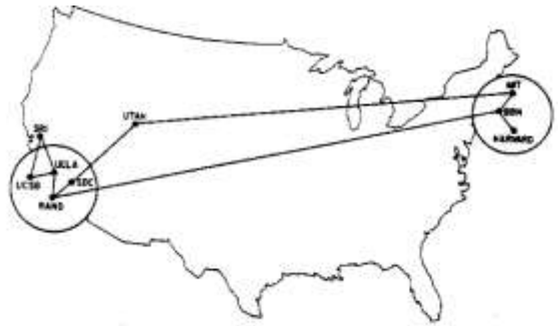
Philips SEM 515

Scanning
Electron
Microscope

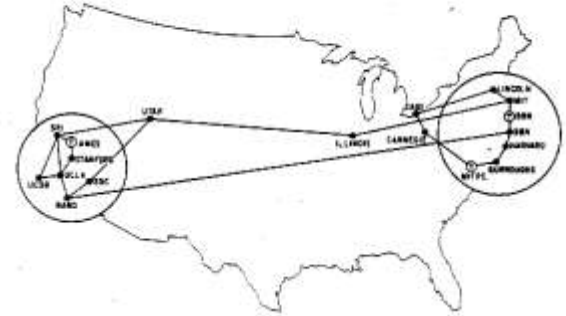
Arpanet

1969

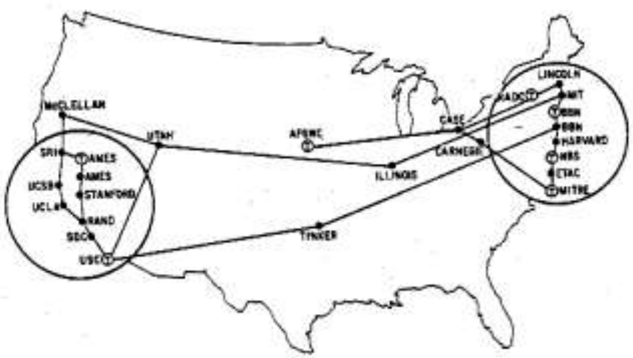
1970



1971



1972



1973

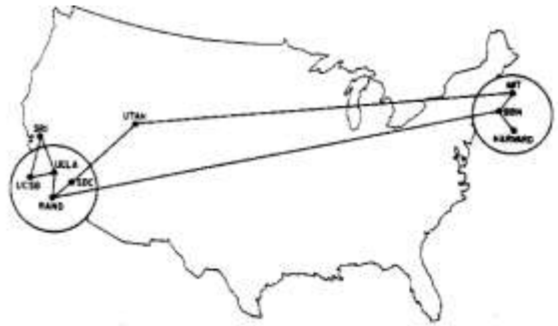
An early packet switching network (FTP)

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

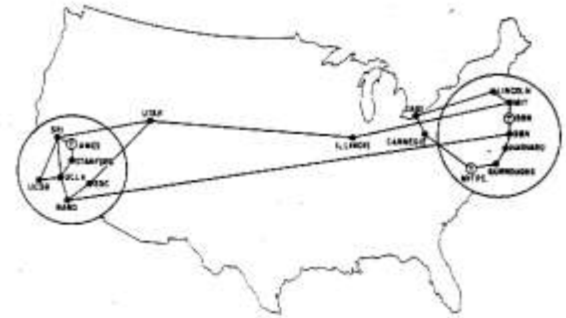
Arpanet

1969

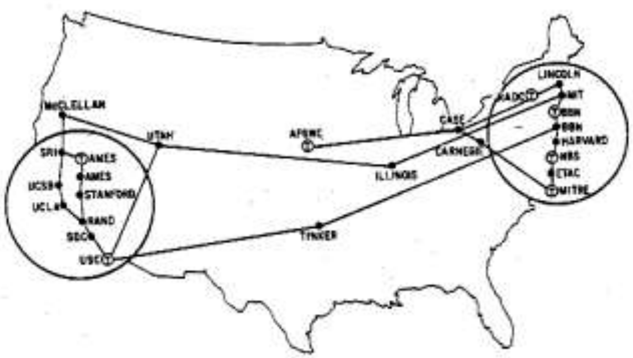
1970



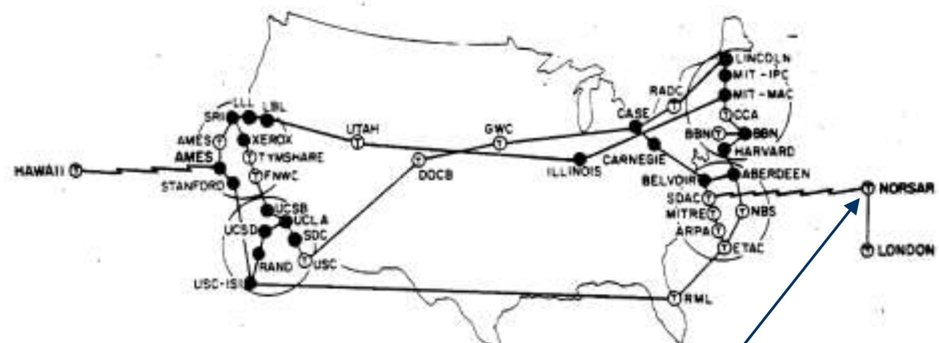
1971



1972



1973



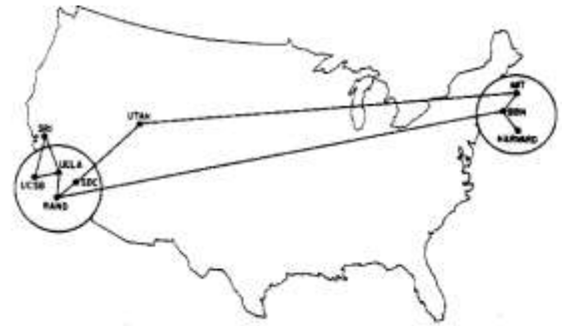
An early packet switching network (FTP)

Norway - of all places!?

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

1969

1970



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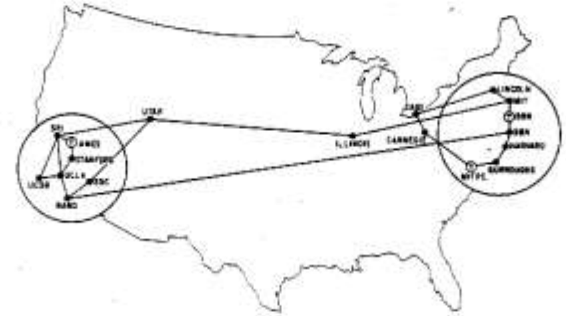
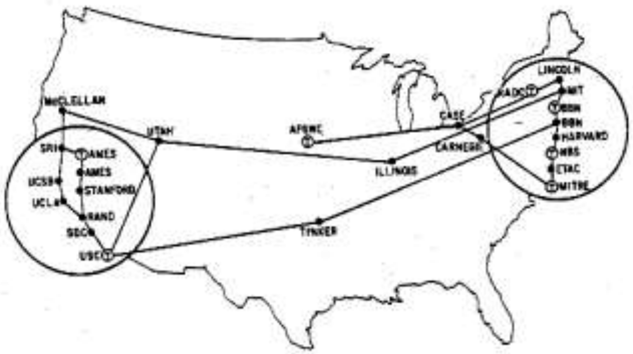
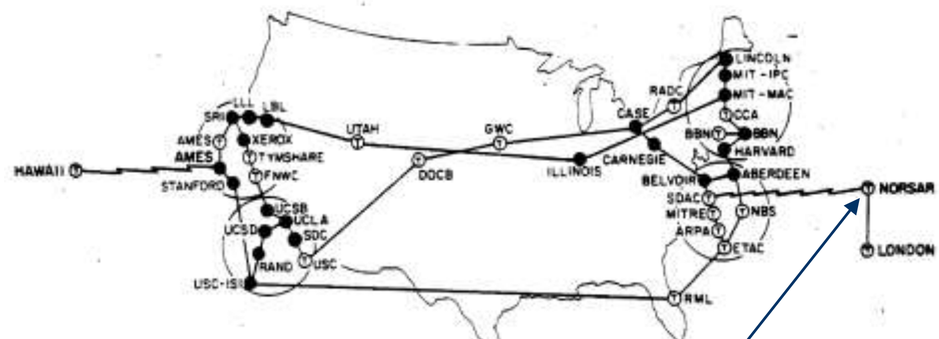


1972



1973



Michael Caine as spy in the film "Billion Dollar Brain"

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1984- Oslo Dental Faculty, Anatomy Dept.
SEM / TEM
Computer-Network infrastructure
&
1985- Nordic Institute of Dental Materials

NIOM
Nordic Institute of Dental Materials

Professor Ivar A. Mjör
1st NIOM Director
On leave from the
Department of Anatomy

DEC Vax

October 1985:

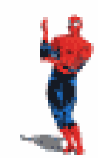
- The computer collapsed!

- All datafiles were corrupted and required tedious reconstruction!!

- All clinical data accumulated over 10 years since the inception of NIOM were in a disarray!!!

(….backup routines are only for the cowards..)

URGENT need for a computer geek with a dentistry background!!!



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SEM / TEM
Computer-Network infrastructure
&

1985-

Nordic Institute of Dental Materials
Clinical trials
Restorative materials
(Amalgam-)Toxicology

Electron Microscopy

Clinical studies program

Thesis. 1986:

How will a restoration perform as a function of the qualities of the cavity prepared by the dentist?

NOT FEASIBLE IN 1986
Stereo-photogrammetry
Computer Stereo Vision

Cavity designs for class II amalgam restorations

A literature review and a suggested system for evaluation

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

Jokstad A, Mjör IA. Cavity designs for class II amalgam restorations. A literature review and a suggested system for evaluation. Acta Odontol Scand 1987;45:257–273. Oslo. ISSN 0001-6357.

A classification system for variations in cavity design and finish has been developed for application on models of teeth with class II cavities for amalgam restorations. The system was based on a review of the literature, on principles for clinical studies, and on examination of models of 623 teeth in which routine class II cavity preparations had been made. Preliminary data on the agreement of rating of evaluators indicated that the classification system can be used with good consistency for assessment of variations in cavity preparations. Longitudinal clinical studies on the performance of restorations will be decisive for the validity of the selected criteria and for a relevant differentiation between acceptable and unacceptable preparation features. ☐ *Conservative dentistry; failure of restorations; longevity of restorations; operative dentistry*

Asbjörn Jokstad, Department of Anatomy, Dental Faculty, P.O. Box 1052 Blindern, University of Oslo, N-0316 Oslo 3, Norway

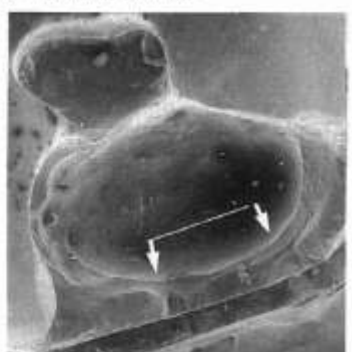
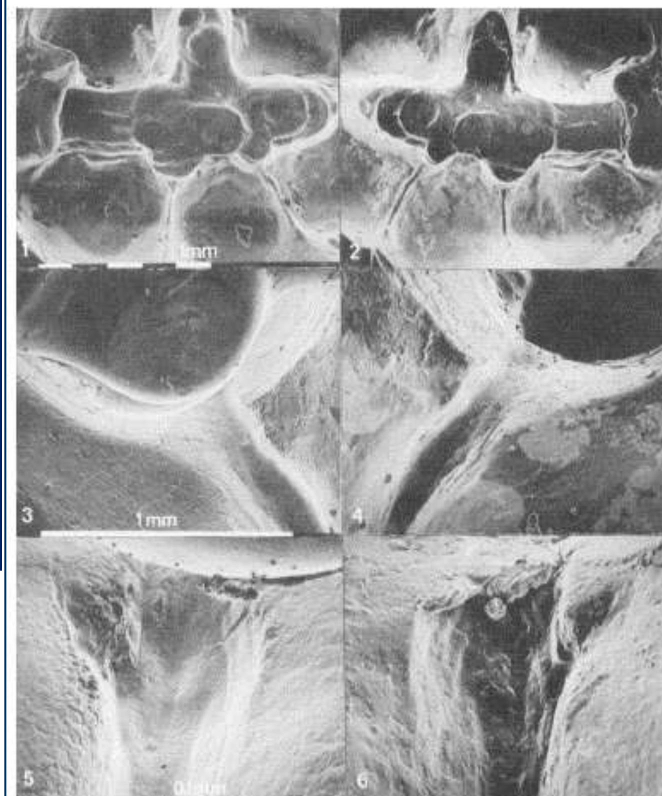


Fig. 5. Example of a cavity preparation with unsupported enamel along the gingival margin (arrows), at the mesial surface in an upper first premolar.

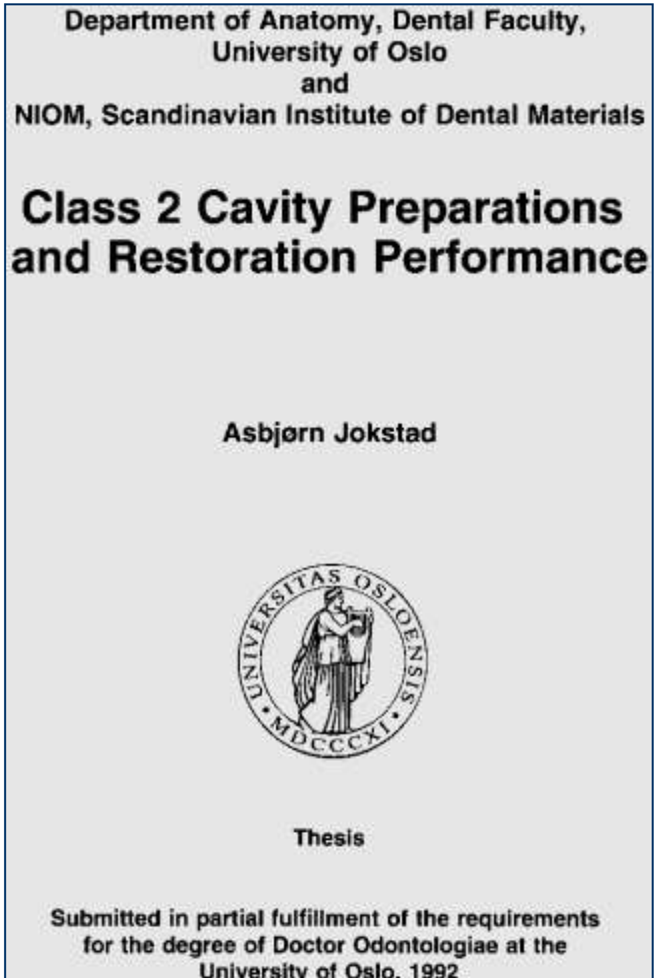
Fig. 7. Example of a cavity preparation with irregular margin on the lingual wall (arrow), at the distal surface in an upper second premolar.



Figs. 1–6. SEM micrographs of a class-II cavity preparation made in 1979. Figs. 1, 3, and 5 are 10-year-old negative replicas made of a condensation silicone elastomer, while Figs. 2, 5, and 6 are 10-year-old positive replicas made of epoxy. Magnification: Figs. 1 and 2, ×10; Figs. 3 and 4, distobuccal fissure on Fig. 1, ×75; Figs. 5 and 6, mesiobuccal fissure on Fig. 1, ×200. The light gray zones on the surface on the epoxy replicas are presumably caused by a chemical interaction between the impression material and the epoxy material at the time of casting.

Philips SEM 515 Scanning Electron Microscope

Restoration performance followed 10 years


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

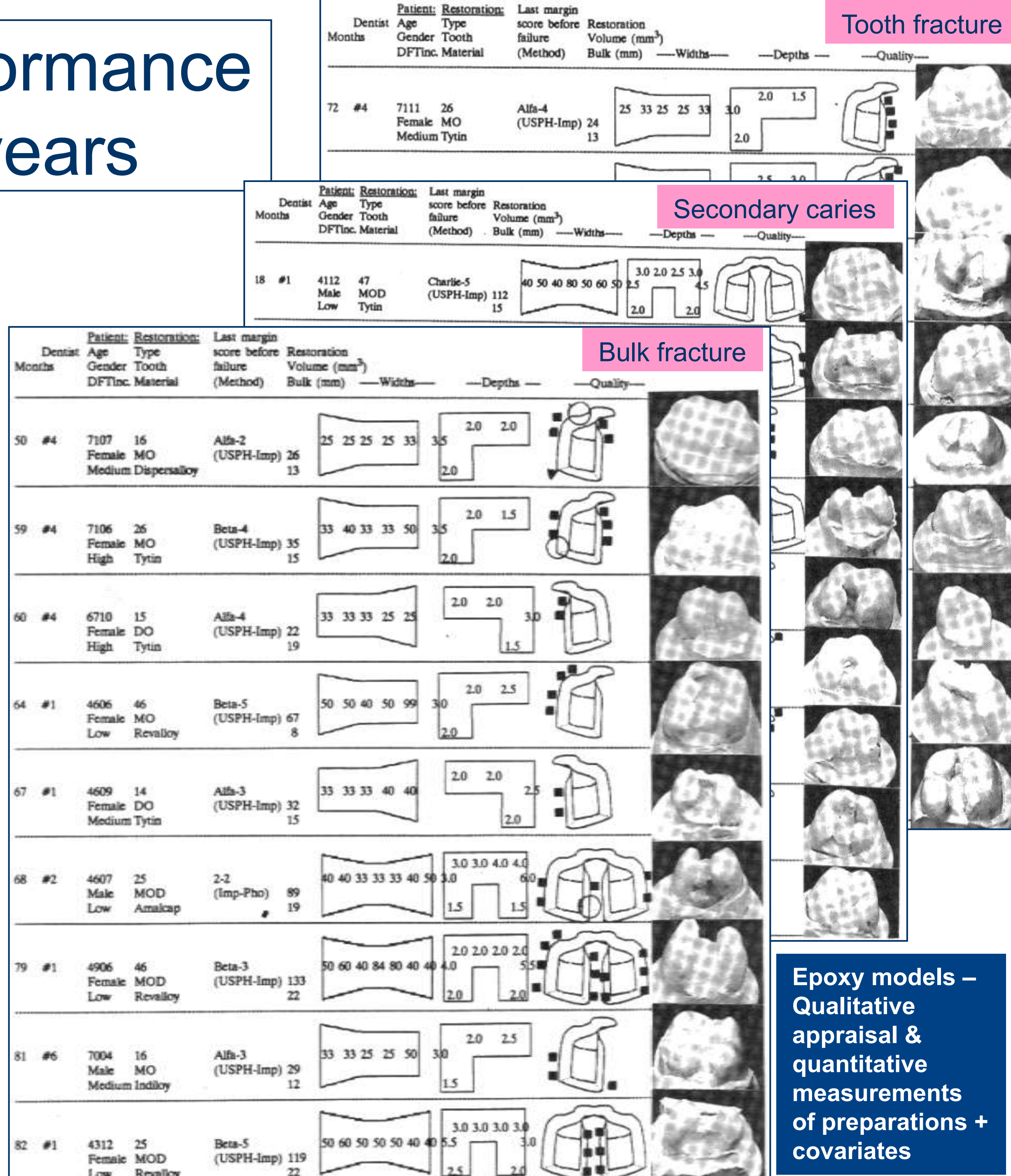
Class 2 Cavity Preparations and Restoration Performance

Asbjørn Jokstad

Thesis

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

COST-PROHIBITIVE IN 1992:
Stereo-photogrammetry
Computer stereo vision



Months	Dentist	Patient: Age / Gender / DFTinc.	Restoration: Type / Tooth / Material	Last margin score before failure (Method)	Restoration Volume (mm³) / Bulk (mm)	Widths	Depths	Quality
50	#4	7107 / Female / Medium	16 / MO / Dispersalloy	Alfa-2 (USPH-Imp)	26 / 13	25 25 25 25 33	2.0 2.0 3.5 2.0	
59	#4	7106 / Female / High	26 / MO / Tytin	Beta-4 (USPH-Imp)	35 / 15	33 40 33 33 50	2.0 1.5 3.5 2.0	
60	#4	6710 / Female / High	15 / DO / Tytin	Alfa-4 (USPH-Imp)	22 / 19	33 33 33 25 25	2.0 2.0 3.0 1.5	
64	#1	4606 / Female / Low	46 / MO / Revalloy	Beta-5 (USPH-Imp)	67 / 8	50 50 40 50 99	2.0 2.5 3.0 2.0	
67	#1	4609 / Female / Medium	14 / DO / Tytin	Alfa-3 (USPH-Imp)	32 / 15	33 33 33 40 40	2.0 2.0 2.5 2.0	
68	#2	4607 / Male / Low	25 / MOD / Amalcap	2-2 (Imp-Pho)	89 / 19	40 40 33 33 33 40 50	3.0 3.0 4.0 4.0 3.0 6.0 1.5 1.5	
79	#1	4906 / Female / Low	46 / MOD / Revalloy	Beta-3 (USPH-Imp)	133 / 22	50 60 40 84 80 40 40	2.0 2.0 2.0 2.0 4.0 5.5 2.0 2.0	
81	#6	7004 / Male / Medium	16 / MO / Indiloy	Alfa-3 (USPH-Imp)	29 / 12	33 33 25 25 50	2.0 2.5 3.0 1.5	
82	#1	4312 / Female / Low	25 / MOD / Revalloy	Beta-5 (USPH-Imp)	119 / 22	50 60 50 50 50 40 40	3.0 3.0 3.0 3.0 5.5 3.0 2.5 2.0	

Epoxy models – Qualitative appraisal & quantitative measurements of preparations + covariates

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SEM / TEM
Computer /Network infrastructure
&
<u>Nordic Institute of Dental Materials</u>
Clinical trials
Restorative materials
(Amalgam-)Toxicology

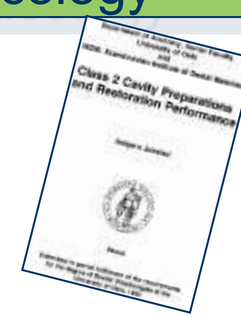
1984-1992

Prosthodontics
Graduate
Program
&
Private
Practice

Dept. Prosthodontics and
Stomatognathic Function

1995-

Professor
Jon Ørstavik
(1937-†2003)
EPA President, 1988-1989
EPA meeting organizer, Oslo, 1988



Department of Prosthodontics and Stomatognathic Function

Digital Motion Capture System + ElectroMyoGraphy (EMG)

QUALISYS Motion Capture Systems

BIOPAC® Systems, Inc.

Meeting surplus 1988 EPA Oslo
→
Purchase of $$$ equipment

Professor Stig Karlsson
Interim Department Head

Journal of Oral Rehabilitation, 1982, Volume 9, pages 317-326

Computer-analysed movements in three dimensions recorded by light-emitting diodes

A study of methodological errors and of evaluation of chewing behaviour in a group of young adults

TORSTEN JEMT and STIG KARLSSON Department of Prosthetic Dentistry, University of Göteborg

Summary

Journal of Oral Rehabilitation 1996 23; 121-128

Movement and signal analysis by means of a computer-assisted system

R. HAMBORG & S. KARLSSON* Department of Prosthetic Dentistry and Stomatognathic Physiology, University of Oslo, Oslo, Norway and *Department of Prosthetic Dentistry, Göteborg University, Göteborg, Sweden

SUMMARY The aim of this study was to evaluate the suitability of an optoelectronic system for recording ... also reflected external vibrations. A clinical pilot study was performed to find a feasible site for attaching the

Department of Prosthodontics and Stomatognathic Function

Digital Motion Capture System + ElectroMyoGraphy (EMG)

QUALISYS Motion Capture Systems

BIOPAC Systems, Inc.

Meeting surplus 1988 EPA Oslo
→
Purchase of $$$ equipment

HOWEVER - The user complexity was too high
Need for a computer geek with a background in prosthodontics!!!

Digital Motion Capture System + ElectroMyoGraphy (EMG)

QUALISYS Motion Capture Systems

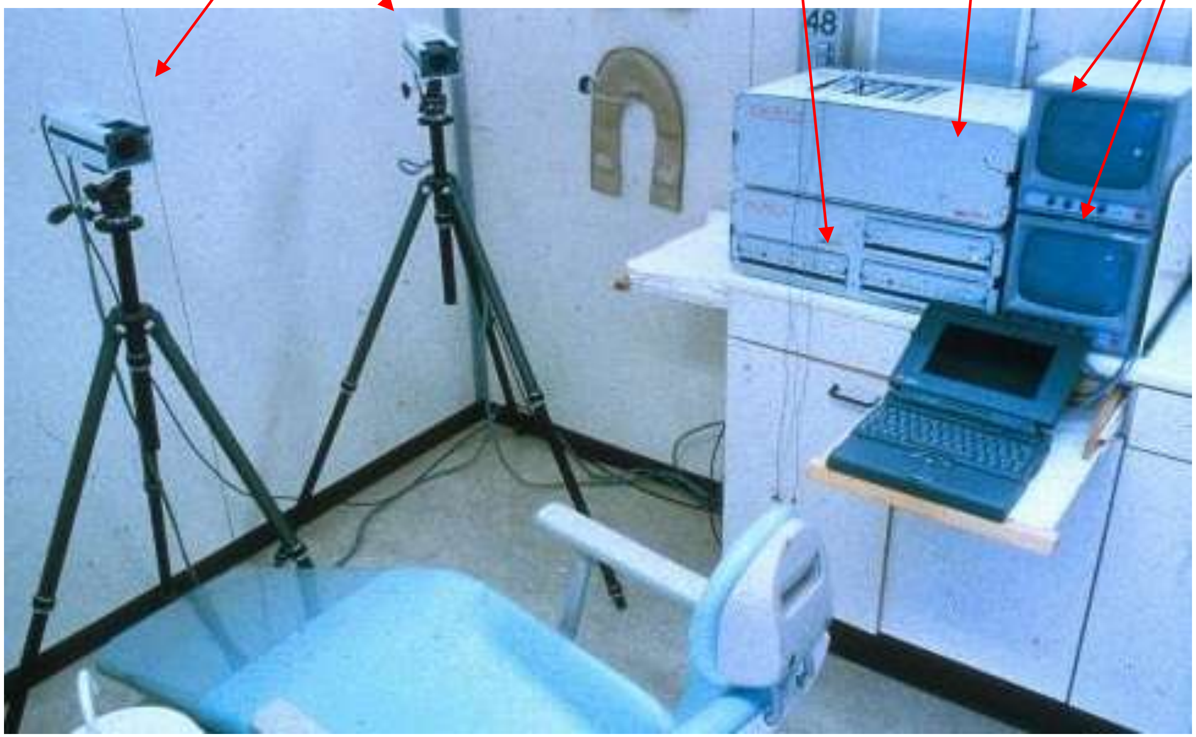
BIOPAC Systems, Inc.

2xIR cameras - 40Hz

Graphic controller

EMG

Analogue x-y & y-z video screens



Calibration frame for 3D recording

Fiducial markers (IR reflectors)

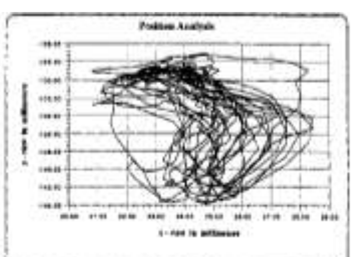
MacReflex software:
Triangulation of centre points (40 Hz)
MacIntosh computer

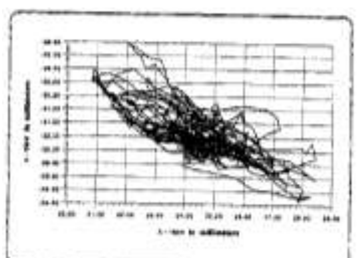
Digital Motion Capture System - chewing

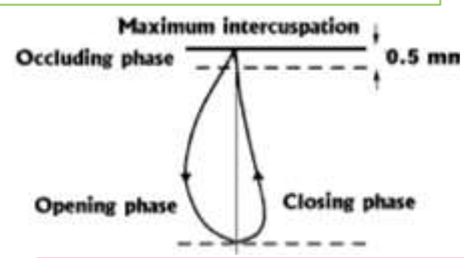
Chewing Movements in TMD Patients and a Control Group Before and After Use of a Stabilization Splint

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

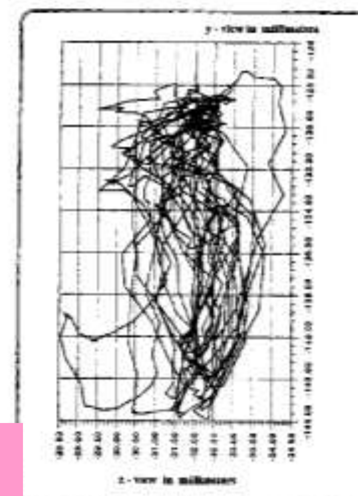
Purpose: This study assessed the effect of using an occlusal stabilization splint in the maxilla for 6 weeks on certain parameters of chewing movements in subjects with and without temporomandibular disorder symptoms. **Materials and Methods:** Twelve male and 30 female temporomandibular disorder patients 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.*



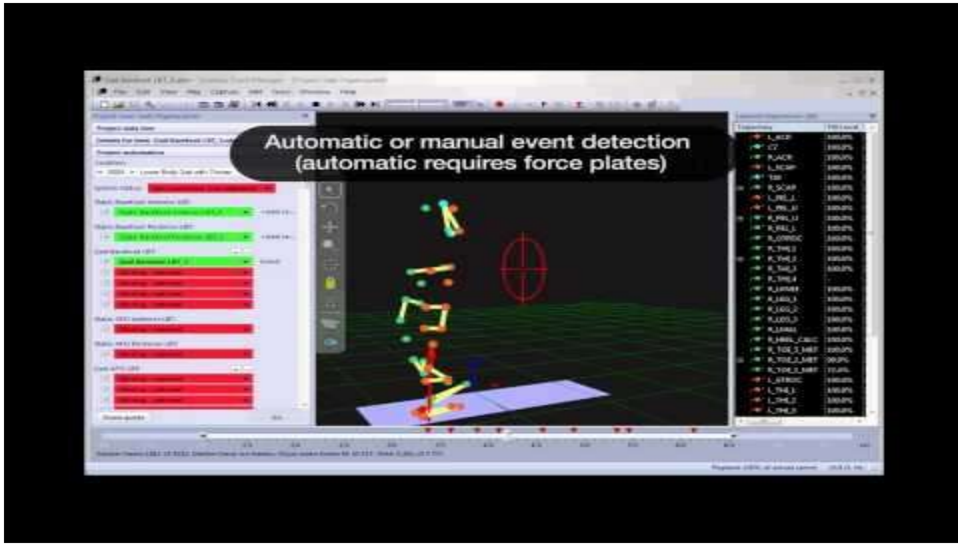


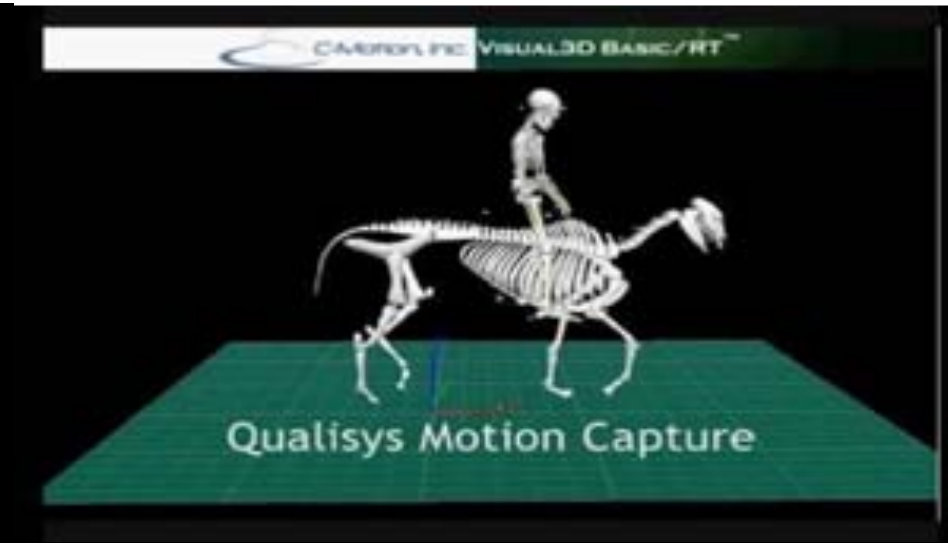


ideal versus reality:



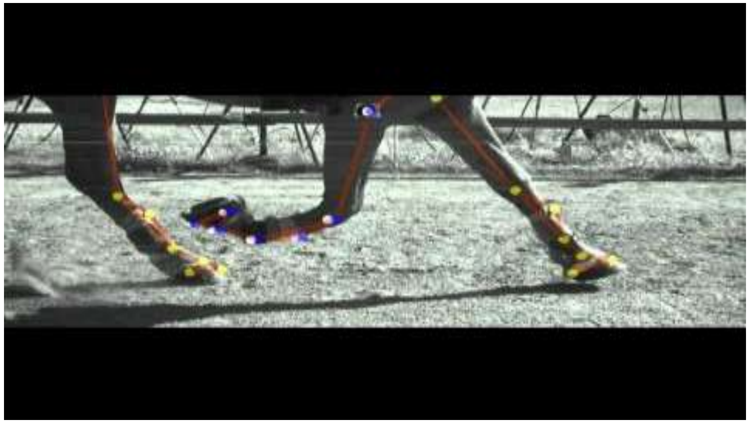
Digital Motion Capture Systems in the 90'ies





40 Hz

QUALISYS
Motion Capture Systems



...a few years later...
200 Hz

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	Intel 4004 / 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: www.old-computers.com/museum

Computer performance in 1996 and innovations in digital technologies in dentistry

Clock speed (MHz)

<1 1971 Intel4004/ Texas Instrument TMS100

...

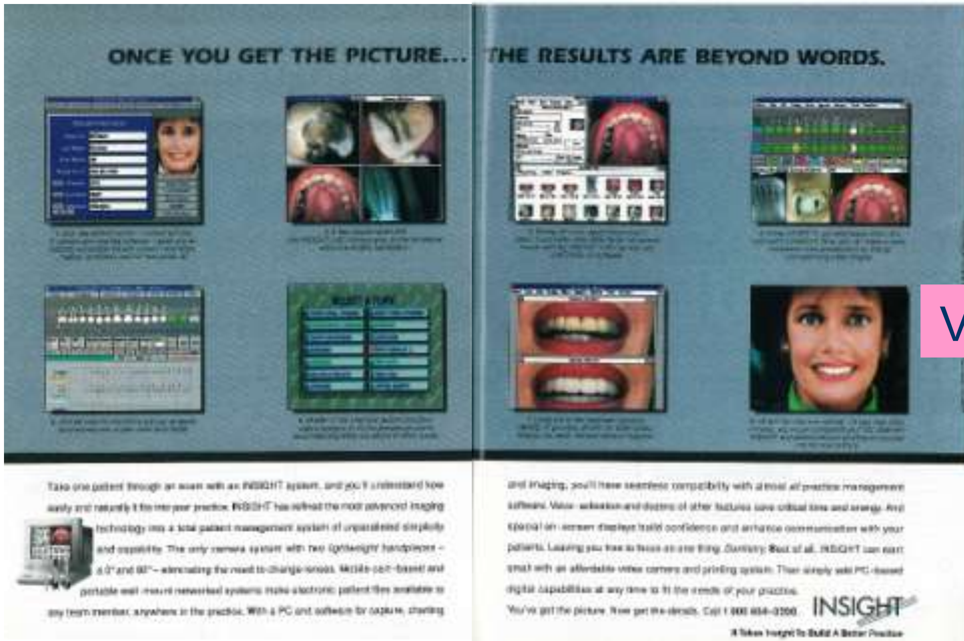
...

...

...

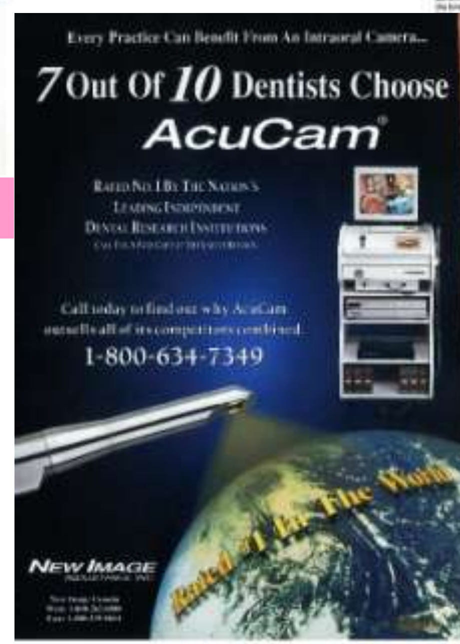
110 1994 IBM PowerPC 601 (Power Macintosh 8100)

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

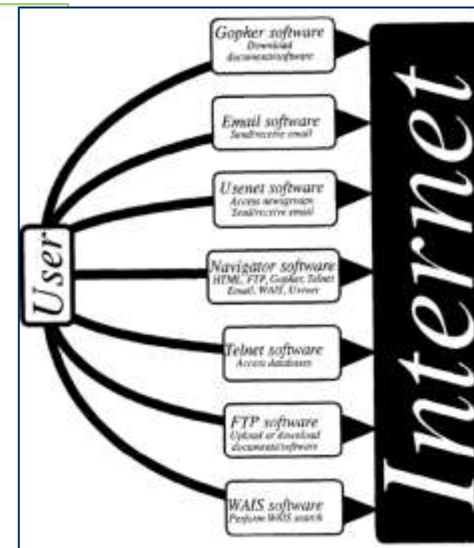
Meade C. van Putten, Jr., DDS, MS[a]
The Ohio State University, College of Dentistry, Columbus, Ohio

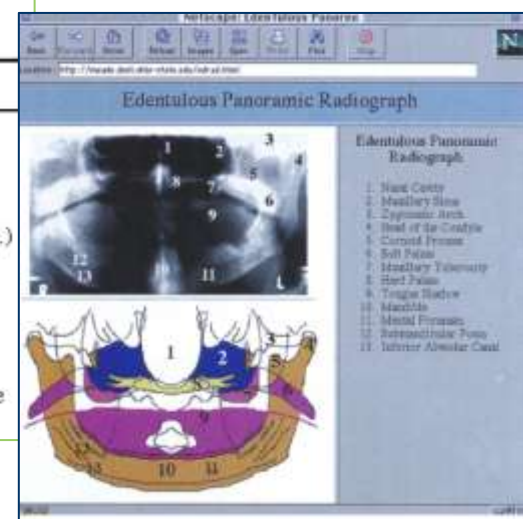
Internet is the common term for the information superhighway. The Internet has become a major information resource for educational, governmental, and business institutions. This article reviews the current operation of the Internet as a background for discussing educational opportunities for instruction 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

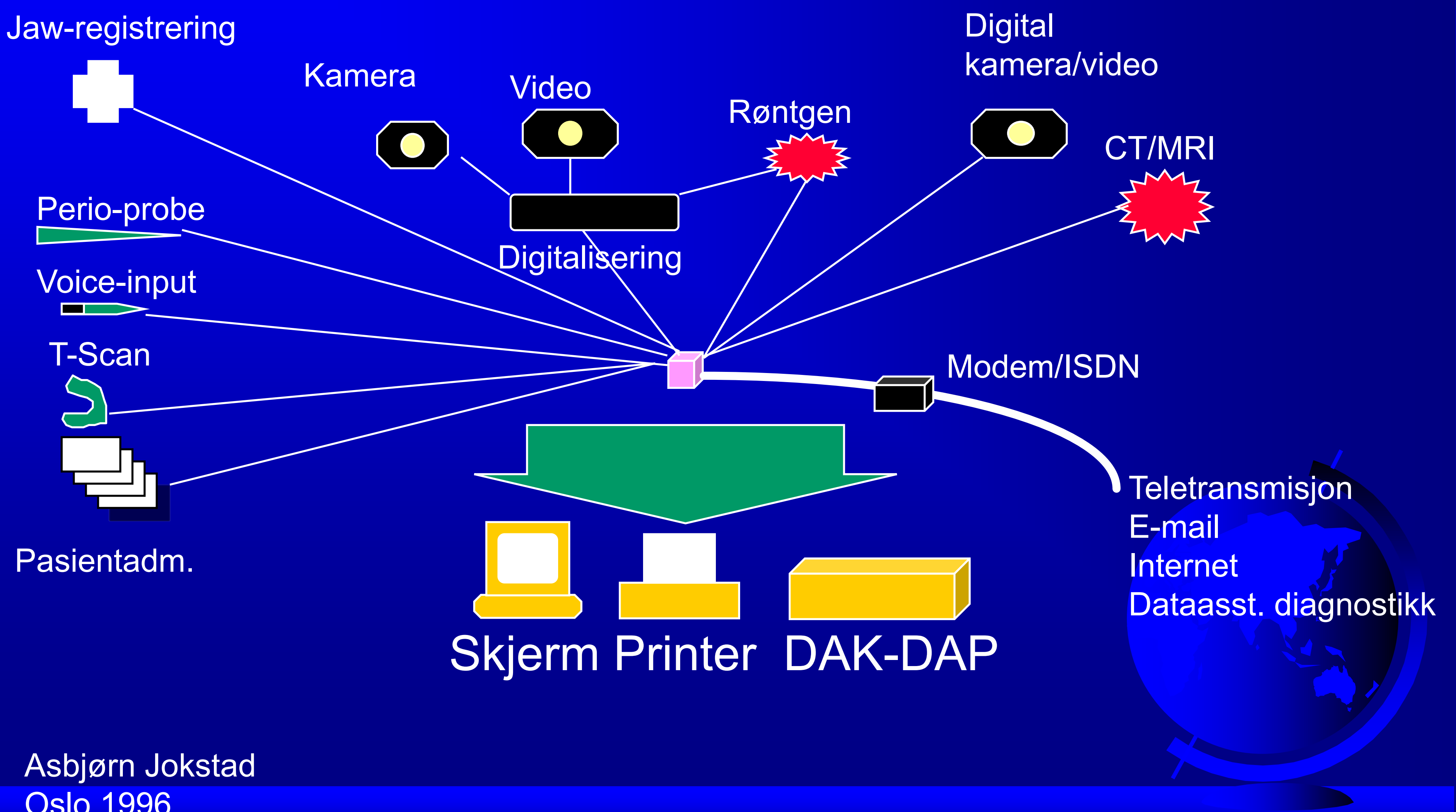
Table I. Computer equipment and software requirements for Internet access

Hardware	Software
Computer (486, Pentium, Mac II, PowerPC.)	Windows, Windows 95, UNIX, MacOS 7.0+
RAM 8 metabytes 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)





Mikroprosessoren i tannklinikken

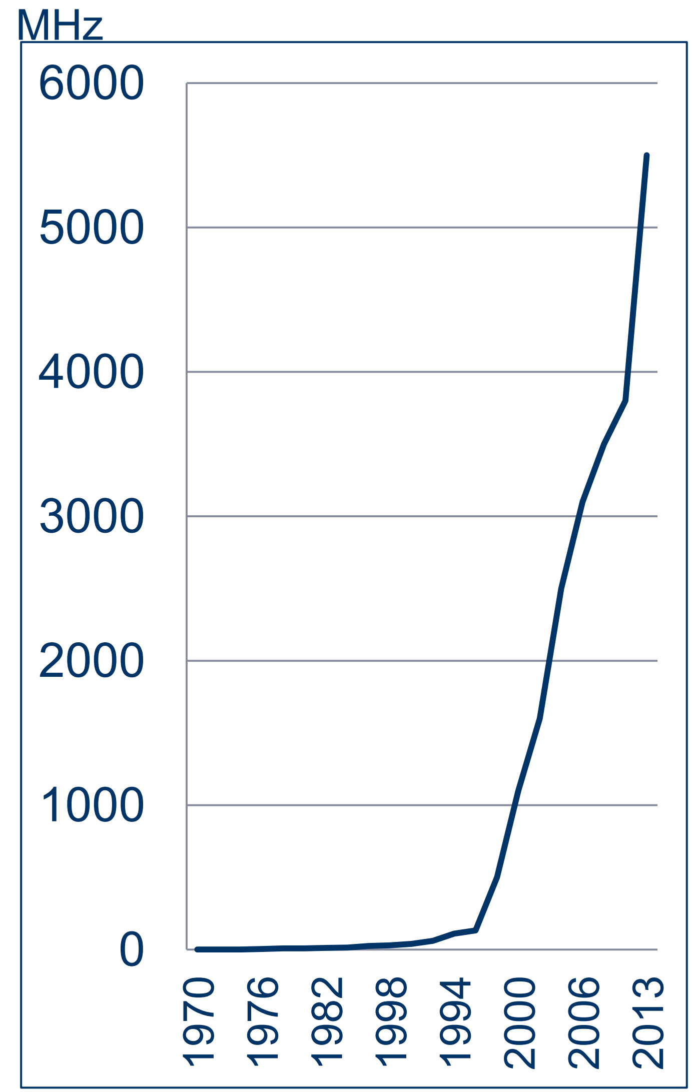


Asbjørn Jokstad
Oslo 1996

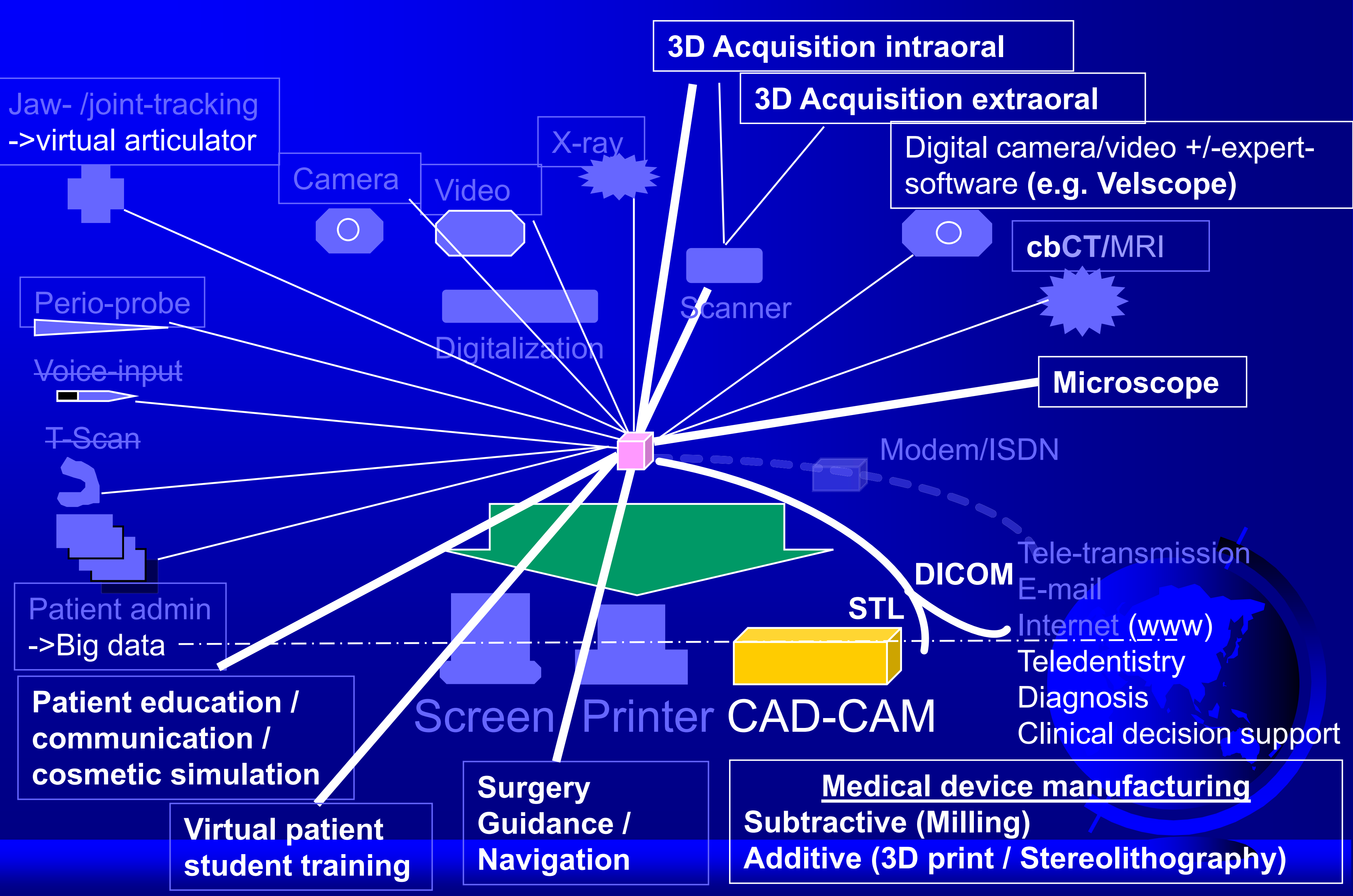
Computer performance today

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 4 bit	
	1974 8bit	
4.77	1976 16bit	
12 – 40	1985 32bit	
20 – 100	1989-94	→ 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



Computer-assisted technologies in dentistry



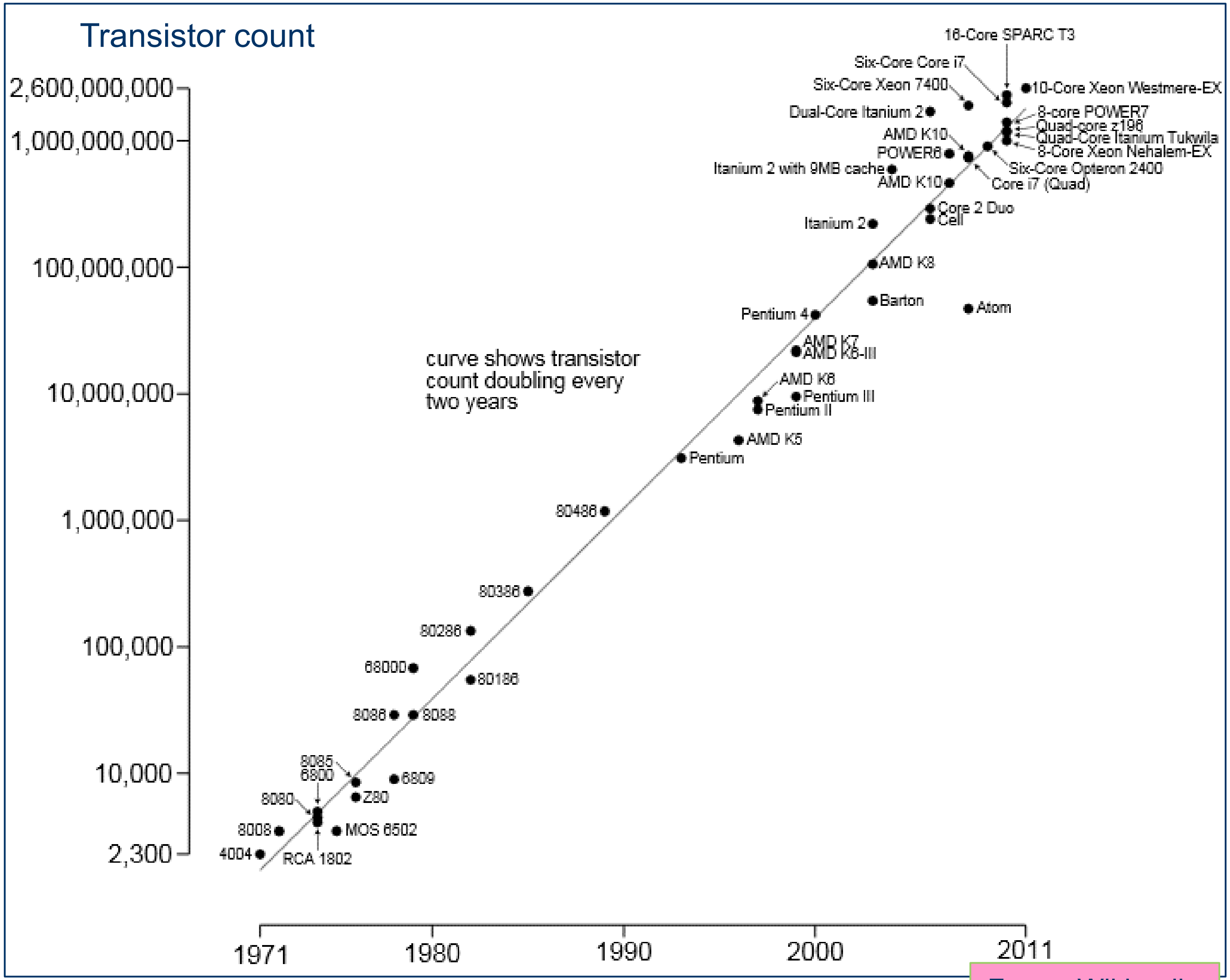
Computer performance today

Moore's* law: *The number of <u>transistors</u> in a dense <u>integrated circuit</u> doubles approximately every two years* (*Gordon Moore, co-founder of Intel)

1. New microchips are **<u>faster and have lower cost</u>** per performance unit

2. Innovative software programs that may harness the improvements in performance

→ Digital devices with better performance at a lower price



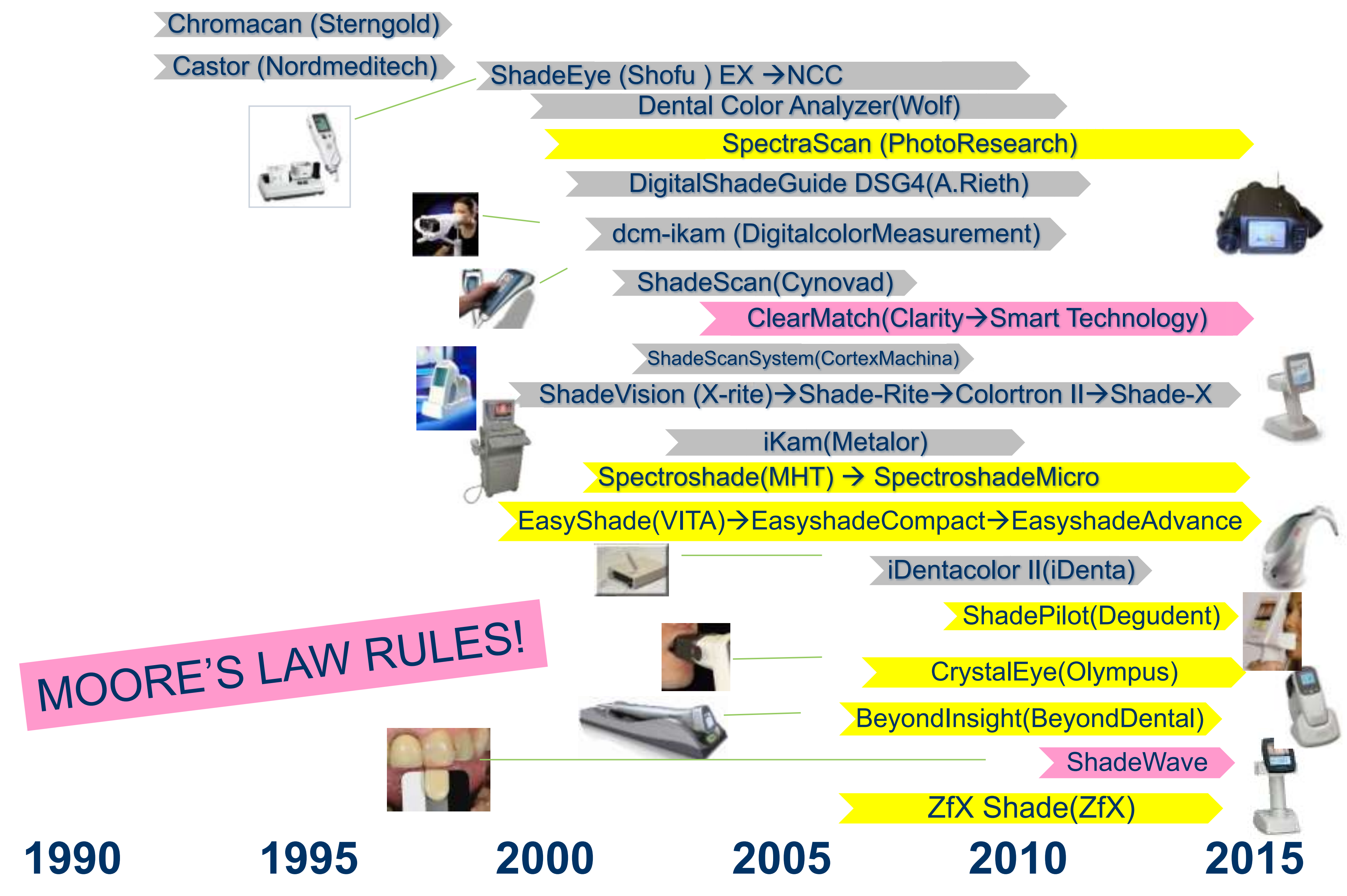
From: Wikipedia

Digital Electron Microscopes life range

MOORE'S LAW RULES!

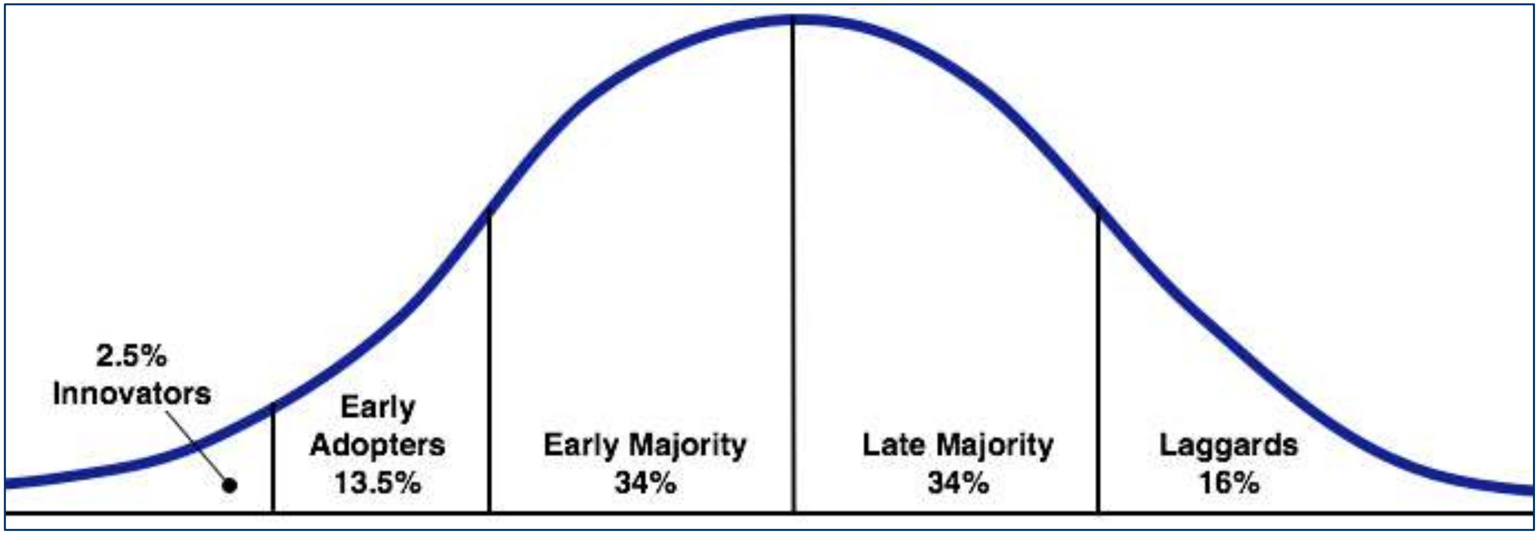
DEPRECIATION TIME DECREASES!

Moore’s law & digital tooth shade acquisition



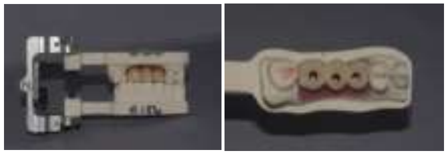
The diffusion of innovations

- 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)

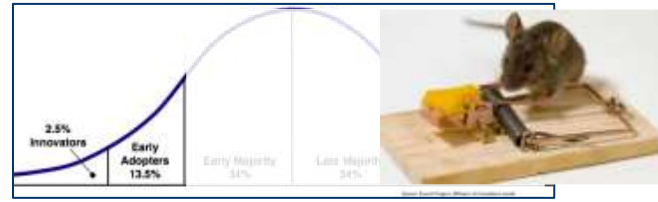
Are the early adopters like the first mouse that try to eat the cheese in the trap? -1



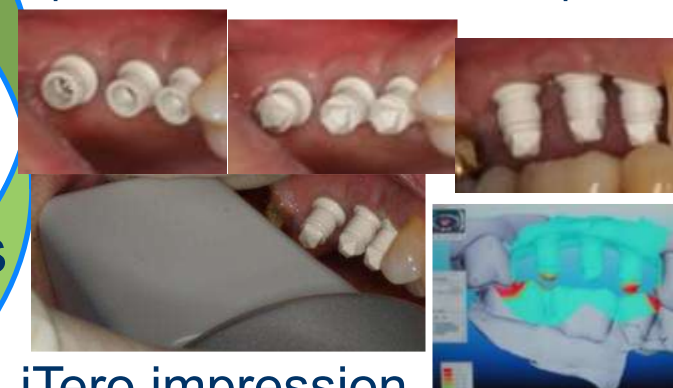
2nd clinical check for intraoral fit

Verification jig for checking accuracy intraorally

2008/2009: Objective: Develop a protocol for digital impression of implants



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

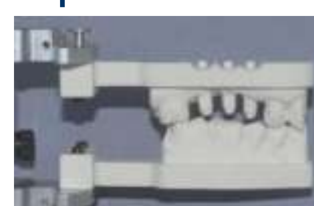


iTero impression

Forced to retrofitting the implant analogues

Lab.photos: S Bilko LHM, Toronto

RETURNED: Polyurethane model – with no implant analogues!



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

CLINICAL ORAL IMPLANTS RESEARCH 2015

Eszter Somogyi-Ganss
Howard I. Holmes
Asbjørn Jokstad

Accuracy of a novel prototype dynamic computer-assisted surgery system

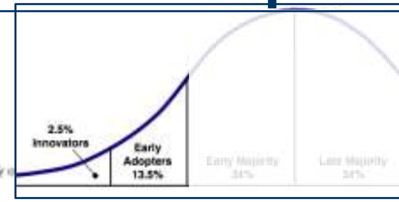
Authors' affiliations:
Eszter Somogyi-Ganss, Discipline of Prosthodontics, Faculty of Dentistry, University of Toronto, Toronto, ON, Canada
Howard I. Holmes, Discipline of Oral and Maxillofacial Surgery, Faculty of Dentistry, University of Toronto, Toronto, ON, Canada
Asbjørn Jokstad, Discipline of Prosthodontics, Faculty of Dentistry, University of Toronto, Toronto, ON, Canada
Faculty of Health Sciences, UiT The Arctic University of Norway, Tromsø, Norway

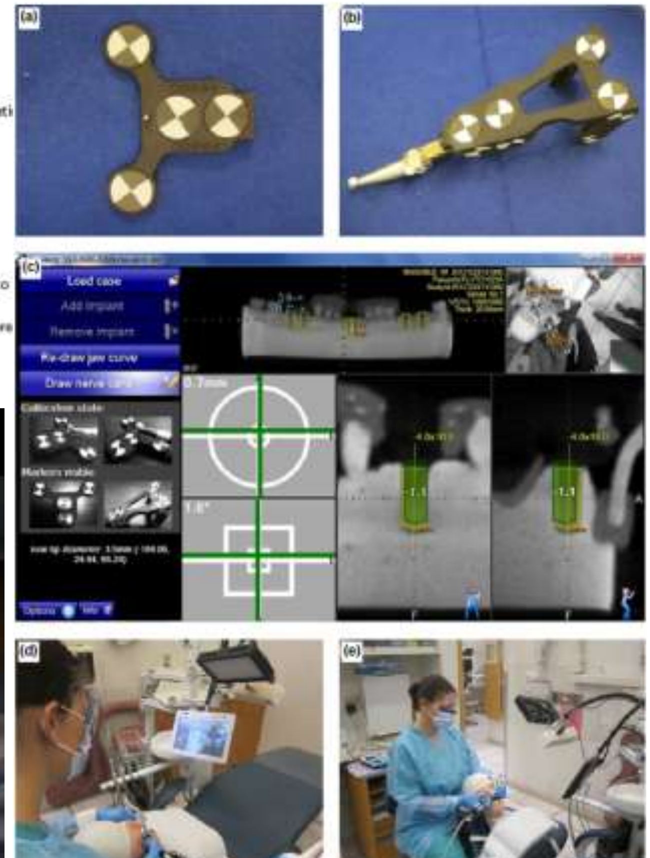
Corresponding author:
Asbjørn Jokstad

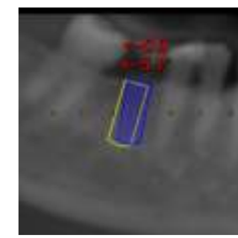
Key words: accuracy, computer aided, computer guided, dental implant, navigation, stati guide, stereolithographic guide

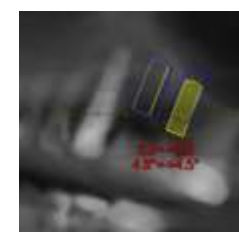
Abstract
Objectives: To implement and evaluate the accuracy of a prototype dynamic computer-assisted surgery (CAS) system for implant osteotomy preparation and compare its accuracy vs. three commercial static CAS systems and the use of an acrylic stent.
Material and methods: Eight osteotomies were prepared in radiopaque partially edentulous mandible and maxilla typodonts. After cone-beam CT acquisition, DICOM files were imported into a prototype dynamic, and three static CAS systems (NobelClinician, Simplant, and CoDiagnostiX). Implant placements were planned to replicate the existing osteotomies and respective guides were

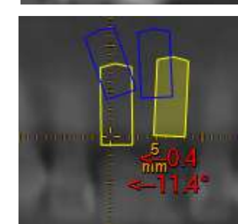
Somogyi-Ganss et al · Accuracy o











In-vitro accuracy =/= in-vivo accuracy

Dynamic Navigation market 2017: 10 products

Intro	Brand name	Company	FDA
2017	Adens-NAVI	U&I Adens Dental Clinic, Taiwan	-
2014	AQ Navi Surgical Navigation System	Taiwan Implant Technology Company, Taiwan	-
2016	DENACAM	Mininavident AG, Swtizerland	-
2001	IGI-System (AKA DenX)	DenX Advanced Dental systems, Israel	Yes
2016	ImplaNav	BresMedical, Australia	-
2015	Inliant	Navigate Surgical Technologies Technologies, Canada	-
2015	IRIS-100 Implant Real-time Imaging System	EPED Incorporated, Taiwan	-
2014	Navident	ClaroNav Inc., Canada	Yes
2014	X-Guide Dynamic 3D Navigation	X-Nav Technologies, PA, USA	yes

MOORE'S LAW RULES!

Dynamic Navigation market 2017: 10 products

Launched Sep 19, 2017

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

CLINICAL ORAL IMPLANTS RESEARCH

2015

Asbjørn Jokstad
Babak Shokati

New 3D technologies applied to assess the long-term clinical effects of misfit of the full jaw fixed prosthesis on dental implants

Authors' affiliations:
Asbjørn Jokstad, Faculty of Dentistry, Discipline of Prosthodontics, University of Toronto, Toronto, ON, Canada
Asbjørn Jokstad, Faculty of Health Sciences, UiT The Arctic University of Norway, Tromsø, Norway
Babak Shokati, Faculty of Dentistry, Discipline of Prosthodontics, University of Toronto, Toronto, ON, Canada

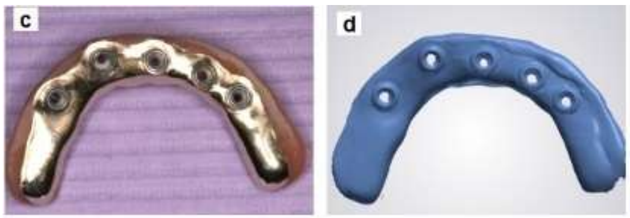
Corresponding author:
Asbjørn Jokstad
Department of Clinical Dentistry, Faculty of

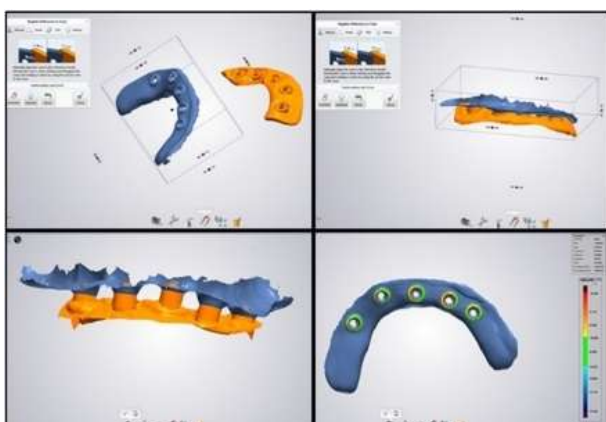
Key words: 3D measurement, 3D scanner, intra-oral digital optical impression

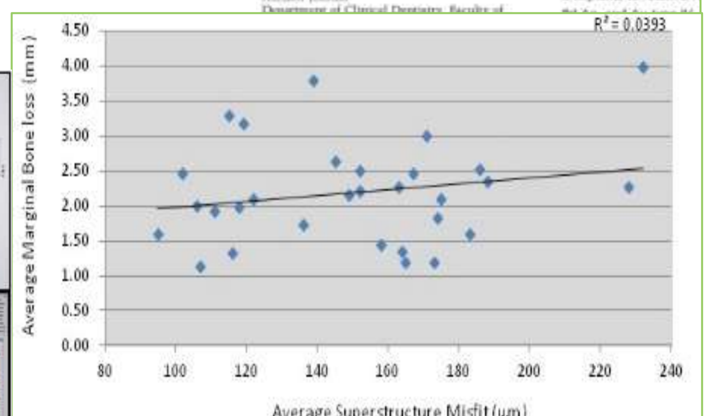
Abstract
Objectives: To assess implant:suprastructure misfit in patients with an edentulous jaw restored by an implant-retained fixed dental prosthesis (FDP) and its association with biologic and mechanical adverse events over an extensive period.
Material and methods: supported prosthetics ... 6 implants to retain a F...

Perforated PMMA stent on original stone model → Intraoral scan (iTero) →STL-file
+
Desktop scan (D810, 3Shape) of a cleaned FDP →STL-file

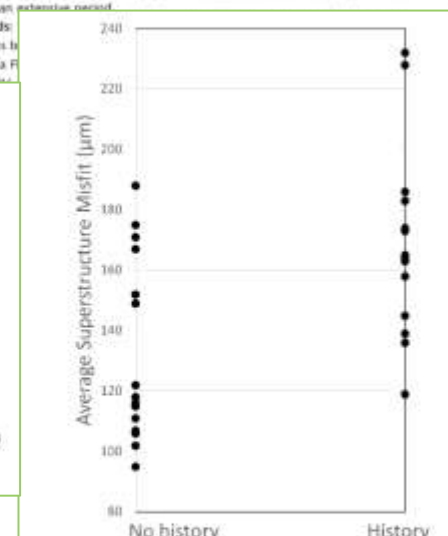
= STL-files compared by use of an industrial metrological software (Convince Premium, 3Shape)







FDPs 12-32 years (mean 19 yrs)



History of screw issues

Current computer- aided/-assisted tools and concepts in 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

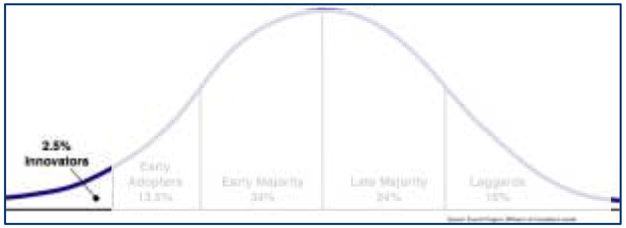
Tissue-engineering constructs

Other applications

Quality assurance "Registration"

Tele-dentistry

Innovations in CA additive / subtractive manufacturing methods ~1987



W. Mörmann / M. Brandestini
University of Zurich

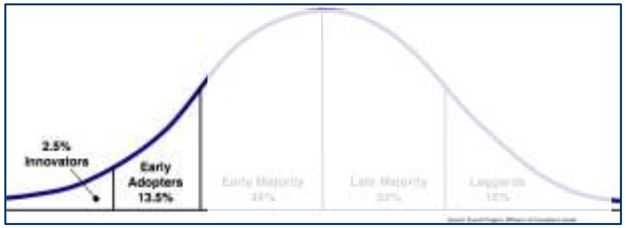
Prototype 1985

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

Product commercialized as:
CEREC by Siemens, Germany

First generation
CEREC from 1987

Innovations in CA additive / subtractive manufacturing methods ~1997



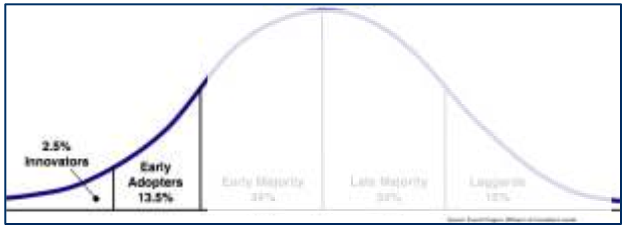
Cerec 2, Siemens→Sirona, Germany (1994)
Cicero, Elephant, Netherlands
DENStech, Dens, Germany
Decsy, Media Corp., Japan
Precident-DCS, DCS-Dental, Switzerland (1989)
Procera, Nobel Biocare, Sweden (1993)

"Closed systems"

"Milling centres"

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

Innovations in CA additive / subtractive manufacturing methods ~2007



“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 ~2017 and beyond

Fabrication process

New methods
New materials
New designs

<u>Restorative dentistry:</u>
Zirconia
Hybrids
<u>Tissue-engineering</u>
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

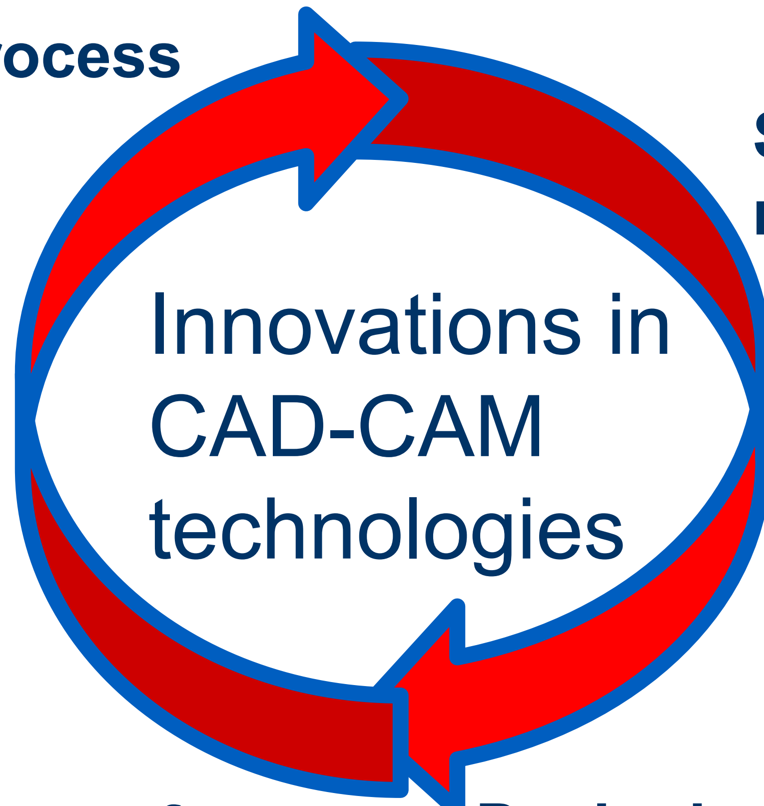
"Open systems"

Manufacturing software

Designing software

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

Fabrication process



Surface / volume rendering

Technology

Acquisition

Data export format(s)

Scan items

Manufacturing software

Designing software

Surface/volume rendering - parameters

Technology

<u>Surface:</u>

Mechanical-electric +/- laser-adjusted

Optical-structural light

Optical-laser/video

Optical-laser-triangulate/confocal

Optical conoscopic holography

<u>Volumetric:</u>

X-ray Tomography

Magnetic res. Tomo.

Optical coher. 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

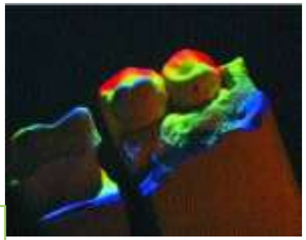
Prostheses

Wax-up

Reflex/Opacity

Surface preparation

Surface coating



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

REMEMBER MOORE'S LAW

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

REMEMBER
MOORE'S LAW

Zfx / Intrascan

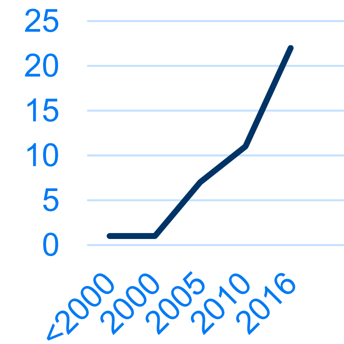
Bluescan /a.tron3D

IOS: Fastscan

Intraoral surface scanning

2017: 22 products+

Product name	Manufacturer	Refs
3D Progress MHT	MHT (Medical High Technologies, Italy / Switzerland	#
Aadva IOS ← Bluescan-I ← a.tron 3D	GC, Belgium ← 2016 a.tron 3D, Klagenfurt, Austria	0
Apollo DI	Sirona Dental Systems, Germany	#
CEREC OmniCam / BlueCam	Sirona Dental Systems, Germany	2
Condor	Condor International, Belgium	0
CS3500 / CS3600	Carestream Dental, USA	0
Dentium rainbow iOS	Dentium, Korea	0
Detection Eye	Zirkonzahn, Italy	0
directScan	Hint-Els, Germany	0
DWIO ← DigImprint Steinbichler	Dental Wings, Canada ←2013 Steinbichler	#
IntraScan Zfx	zfx, Germany	0
i/s/canoral	Goldquadrat, Germany	0
IOS Fastscan	Glidewell Laboratories, USA ← 2015 IOS technologies, USA	0
Itero Element / Itero	Align Technology, USA ← 2011 Cadent, Israel	3
KaVo Lythos	KaVo, Germany ← 2015 Ormco Corp.	0
MIA3D	Densys, Israel	0
Organical Scan Oral	R+K CAD/CAM Technologie, Germany	0
PlanScan ← E4D	PlanMeca, Finland ← 2015 E4D Tech, USA	1
Progress IODIS	Clon 3D / IODIS / Intellidenta (USA?)	0
TRIOS 3 / TRIOS Color / Standard	3Shape, Denmark	3
True Definition Scanner ← Lava COS (Chairside Oral Scanner)	3M ESPE, USA ← 2006 Brontes Technology	4



MOORE'S LAW RULES!

Intraoral surface scanning

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Progress IODIS	Clon 3D / IODIS / Intellidenta (USA?)	0
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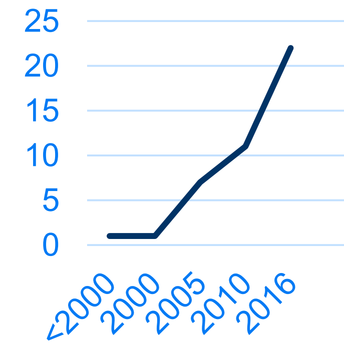
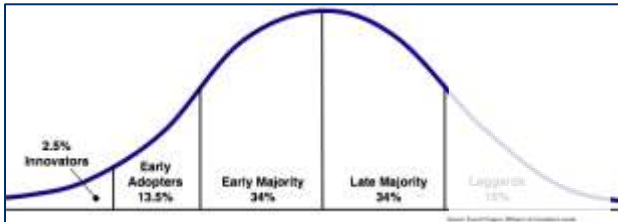


MOORE'S LAW RULES!

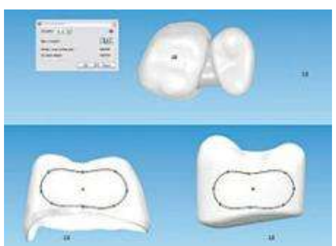
Innovations in CA additive / subtractive manufacturing methods ~2016 and beyond

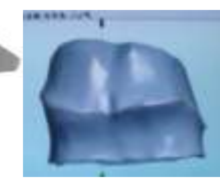


Fabrication process

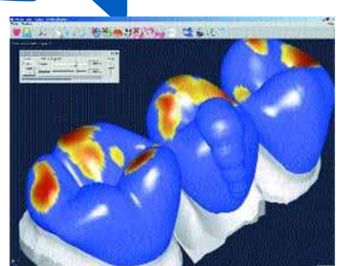
Surface or volume rendering

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
- widely used for rapid prototyping and CAM
- only surface geometry - no representation of color, texture or other common CAD model attributes
- describes a raw unstructured triangulated surface by the unit normal and vertices of triangles using a three-dimensional Cartesian coordinate system

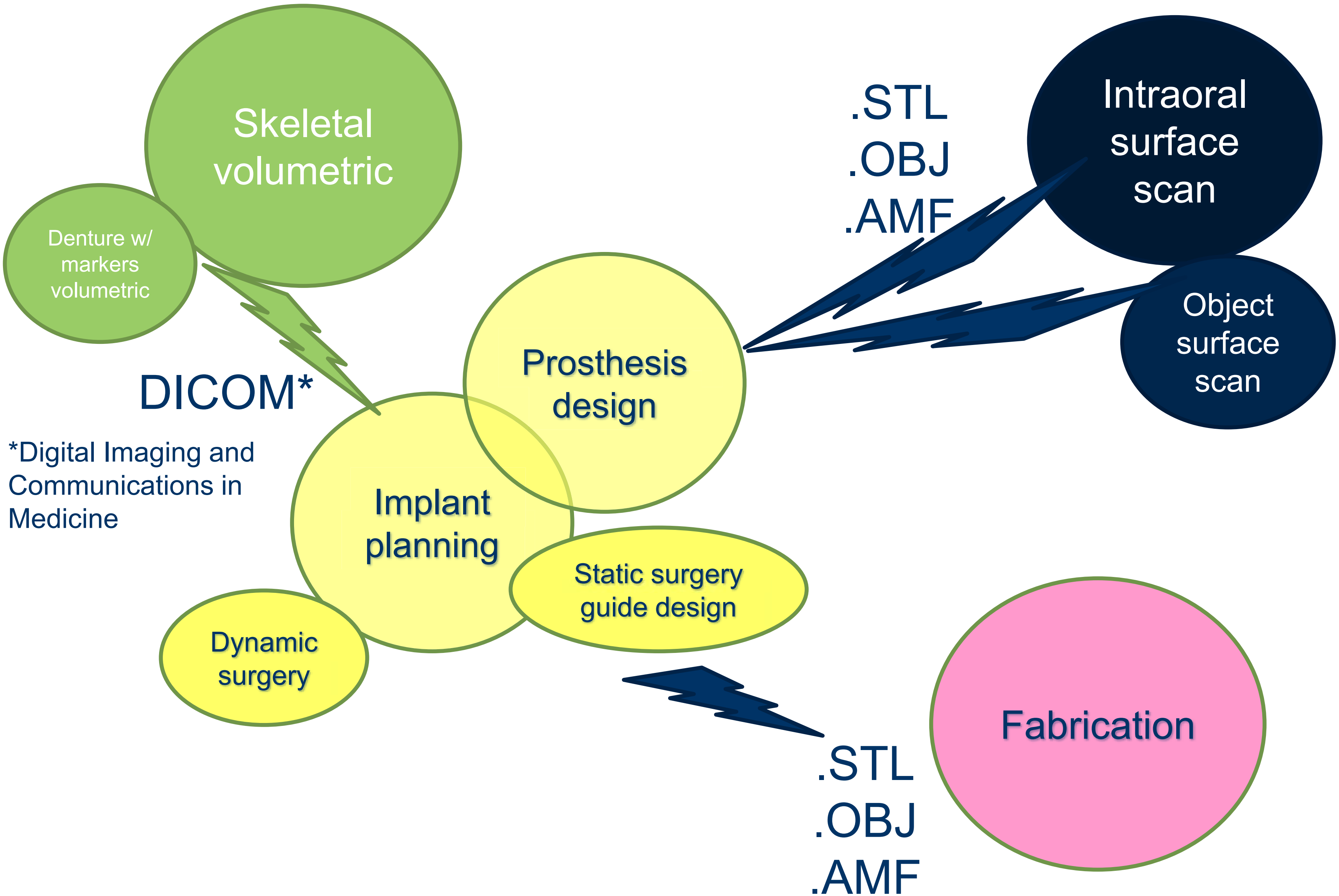
.
OBJ (Object files)

- include surface texture/color - 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)

Data / file / system formats



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

Prosthodontic applications

Wax-up / temporary

Inlay / Onlay

Single-unit coping

Crown / monolithic crown

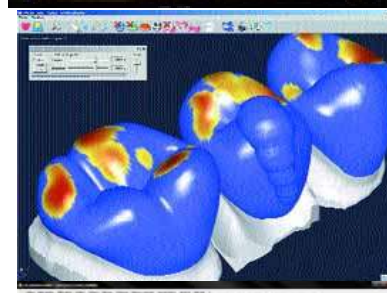
3 → 16unit / (4 →7cm) FDP

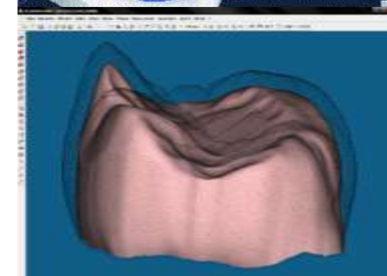
Removable Dental Prosthesis
(Partial / Full)

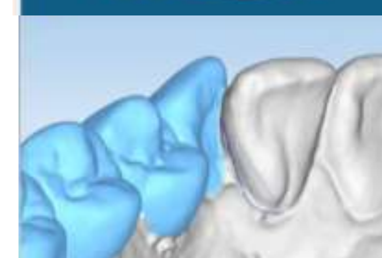
Implant “customised” abutment

Implant-suport. meso-structure

Implant-suport. super-structure





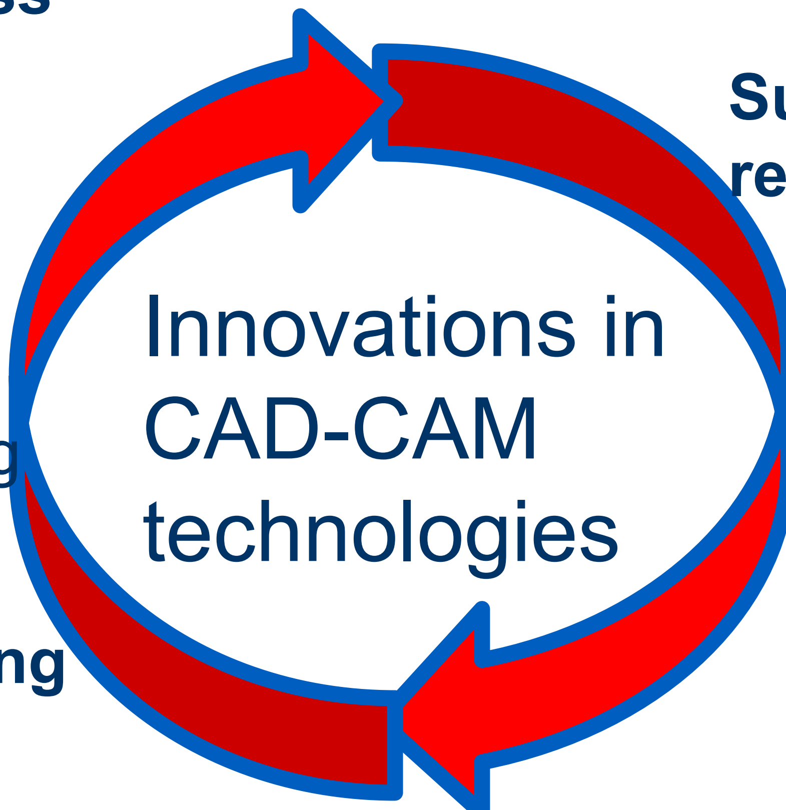


Innovations in CA additive / subtractive manufacturing methods ~2016 and beyond

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

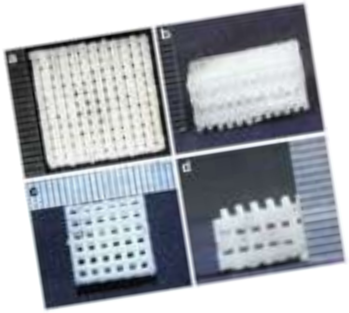
Device

Prosthesis

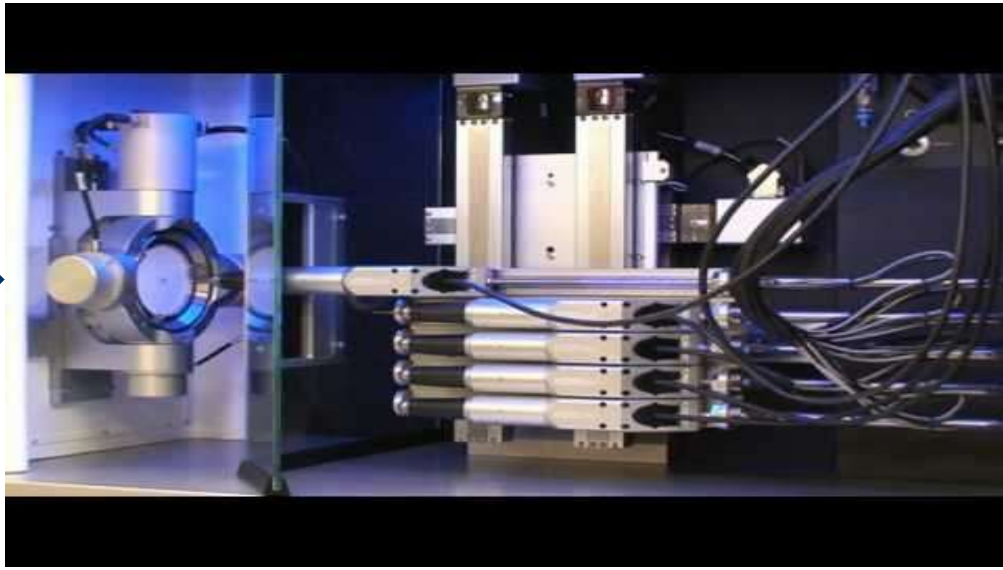
- In-/Onlay/Veneer
- Single-unit coping
- Crown
- Monolithic Crown
- 3 → 16unit(/4 → 7cm)-FDP
- Implant abutment
- Implant bars / Meso-structure
- (Endosseous dental implant)
- Surgical guidance stent
- Partial / Full Removable Prosthesis
- Wax-up / Provisional / Splint

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

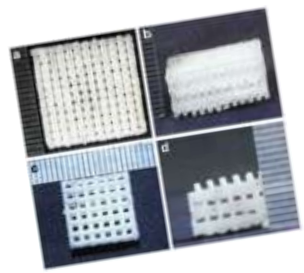
torque
feed-rate
cooling

- 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

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 physically constructed directly from 3D CAD.

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

CAM – subtractive manufacturing

Die

Model fabrication & articulation

Model digitized (scan)

CA design

Mill Blank

Oven sinter

Separate & trim

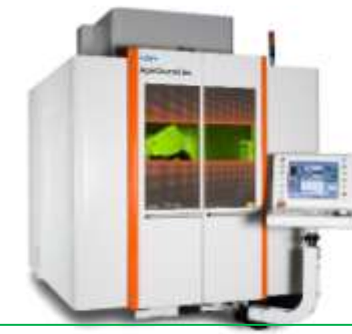
Polish & prepare for veneer

3shape

exocad

dental wings

MOORE'S LAW RULES!



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 in prosthodontics

CA design – “virtual wax” → 3D Print → Oven Sinter → Separate & trim → Polish & prepare for veneer

3shape
dental wings
exocad

3DSYSTEMS

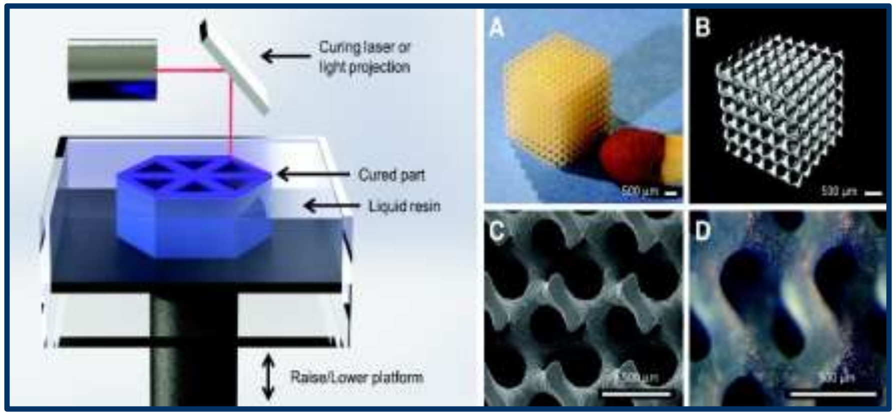
CA design → 3D Print → Invest → Burnout → Cast

Solidscape High Precision 3D Printers
OBJET
EnvisionTEC
DWS
3DSIM

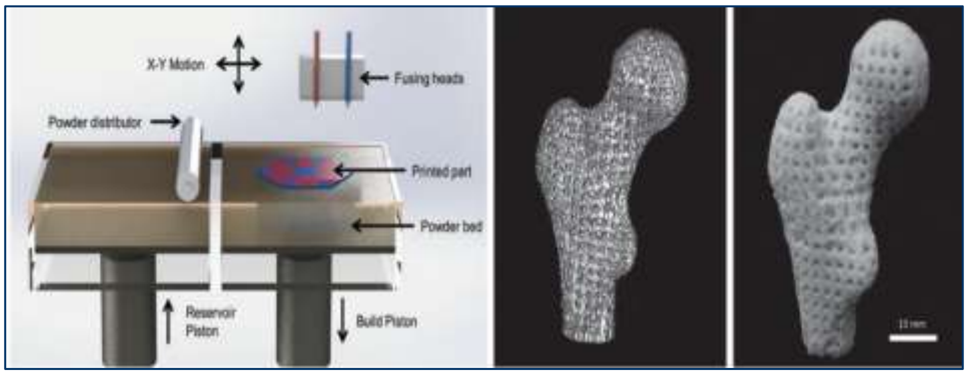
CA design → Laser melt / sinter powder → Separate & trim → Polish & prepare for veneer

REALIZER SLM The Pioneer of 3-D Printers
CONCEPTLASER
eos
SLM SOLUTIONS
sisma GROUP

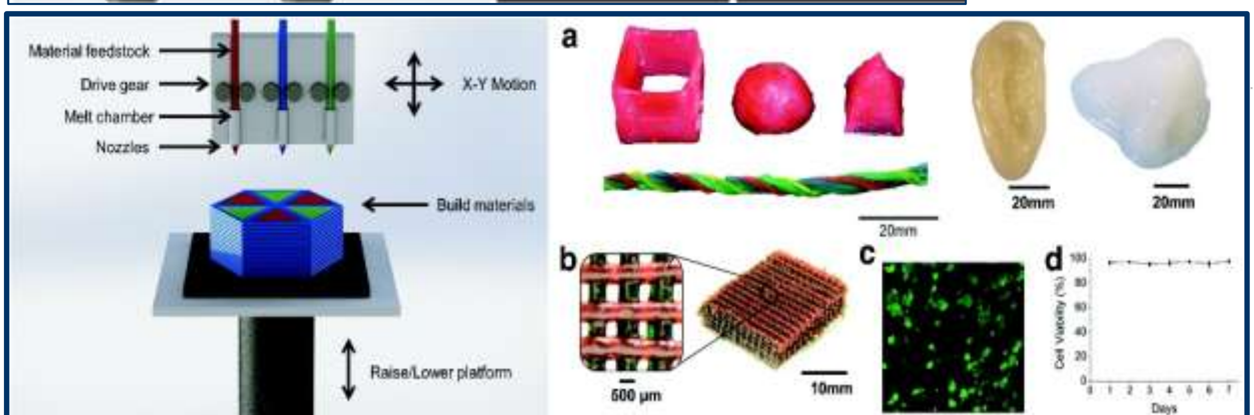
Additive manufacturing in Tissue Engineering



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



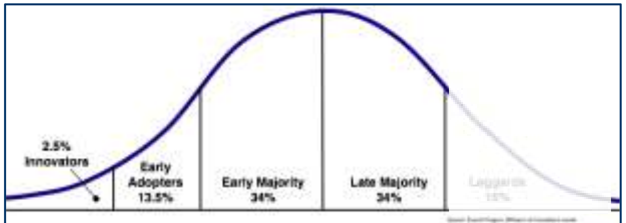
Powder-fusion printing technique and exemplary tissue engineering scaffolds composed of calcium phosphate–poly(hydroxybutyrate-cohydroxyvalerate,



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

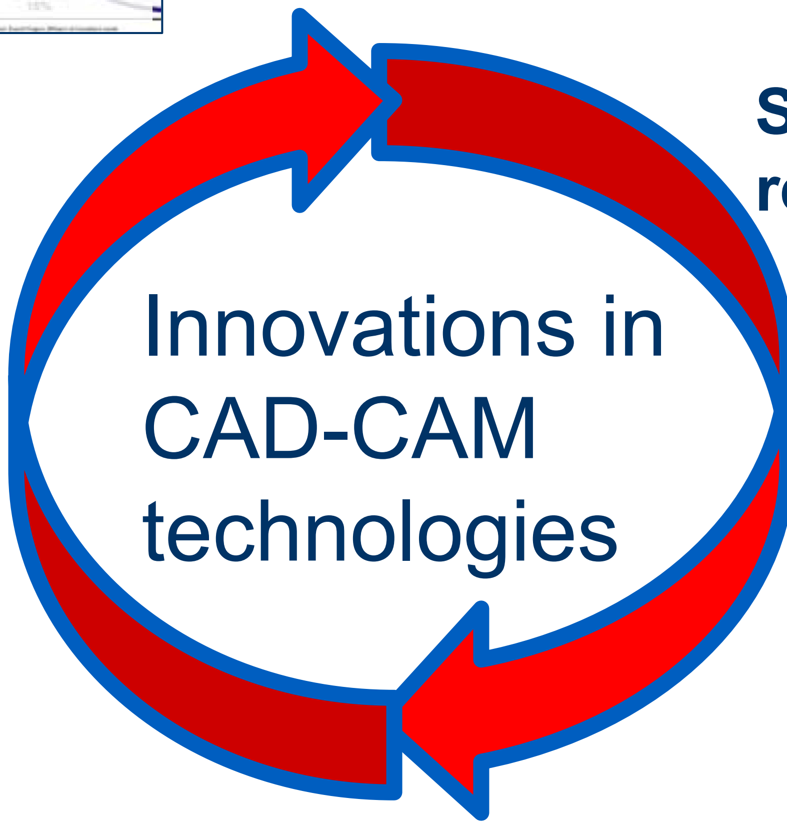
From: Sears ea. *Tissue Engineering, 2015*

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



Fabrication process
Subtractive
Additive

Materials
Prosthesis
Tissue-engineering



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

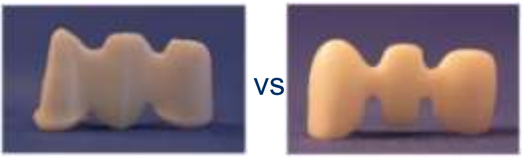
Materials - Restorative
Base alloys
Gold alloys
Non-precious alloys
Titanium / - alloys

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)

Restorative materials for CAM

Photos: Song et al. (2013)



Photos: Mahmood et al. (2015)

FPD substructure dimensions?

Monolithic

Veneer

High Temperature

Lava Ultimate

Cerasmart

Shofu block-HC

Light cured

Paradigm MZ100

VITA Enamic

Feldspatic

Mica

Leucite

Li-Ox

Al/Zr-Infiltrate

Aluminium

PSZ Ce Mg Yt

3Y-TZP Zirconia

Polymers

Polymer-infiltrated Ceramic Network (PICN)

Glassy Ceramics

Poly-crystalline

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

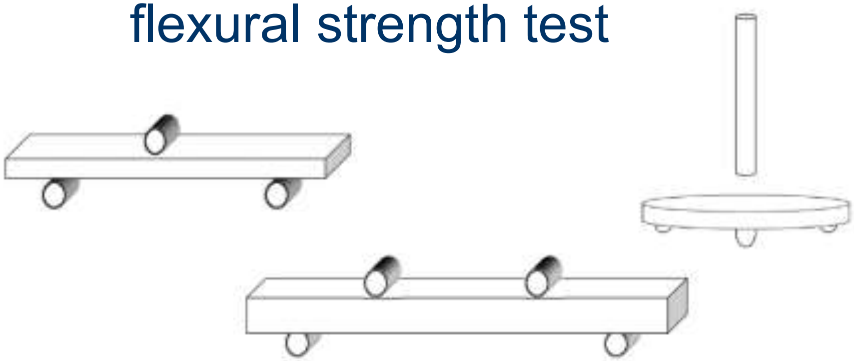
Who do you believe checks:
Veneering ceramic compatibility?
Optimal core-veneer layering thickness?

*TZP=(tetragonal zirconia polycrystals)

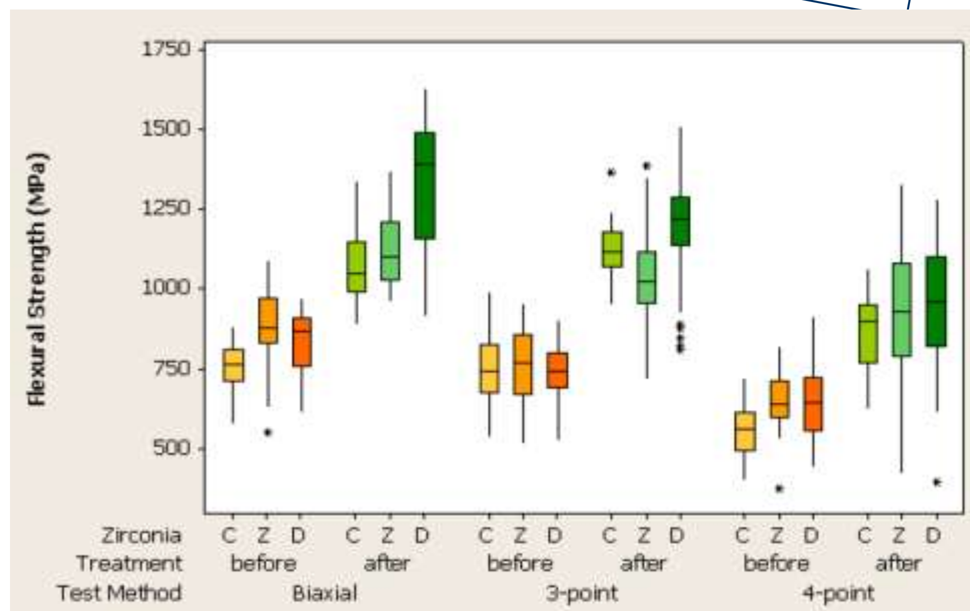
Zirconia milling substrates are not all alike!

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

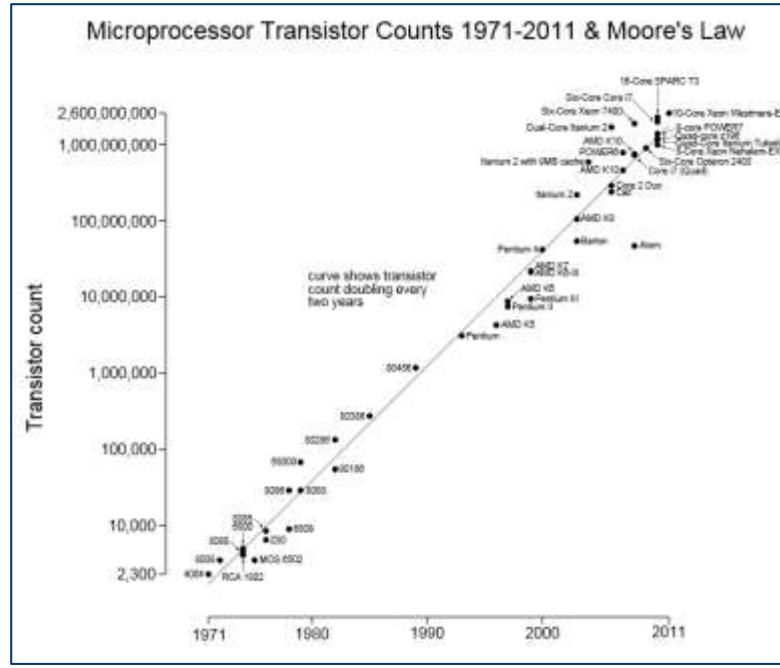
FUTURE TRENDS IN PROSTHODONTICS?

Computer performance in the future

MOORE'S LAW RULES!

Digital devices will likely continue to be **faster and with lower cost** per performance unit; and Innovative software programs will harness these improvements in performance.

The www of Internet will likely continue to be commercialized, driving oth vices to VPN-like solutions.

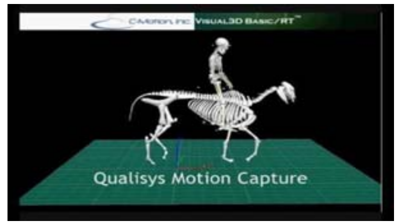


Moore's law: the number of transistors in a dense integrated circuit doubles approximately every two years

Digital motion capture systems to appraise and manage patients with oral dyskinesia

Past: 2 dim.

→



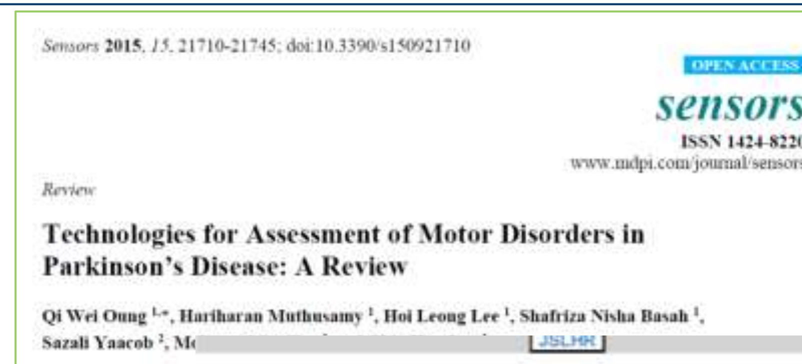
1990'ies: 3 dim., 40 Hz

→

Today: Multi-dimensional → 4000Hz

"MoCap": is used extensively in films and cartoons; e.g., Avatar, Planet of the apes, etc.

but increasingly also in neuromedicine



Sensors **2015**, *15*, 21710-21745; doi:10.3390/s150921710

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sensors

ISSN 1424-8220

www.mdpi.com/journal/sensors

Review

Technologies for Assessment of Motor Disorders in Parkinson's Disease: A Review

Qi Wei Oung [1,*], Hariharan Muthusamy [1], Hoi Leong Lee [1], Shafriza Nisha Basah [1], Sazali Yaacob [2], Mc

JSLHR

Research Article

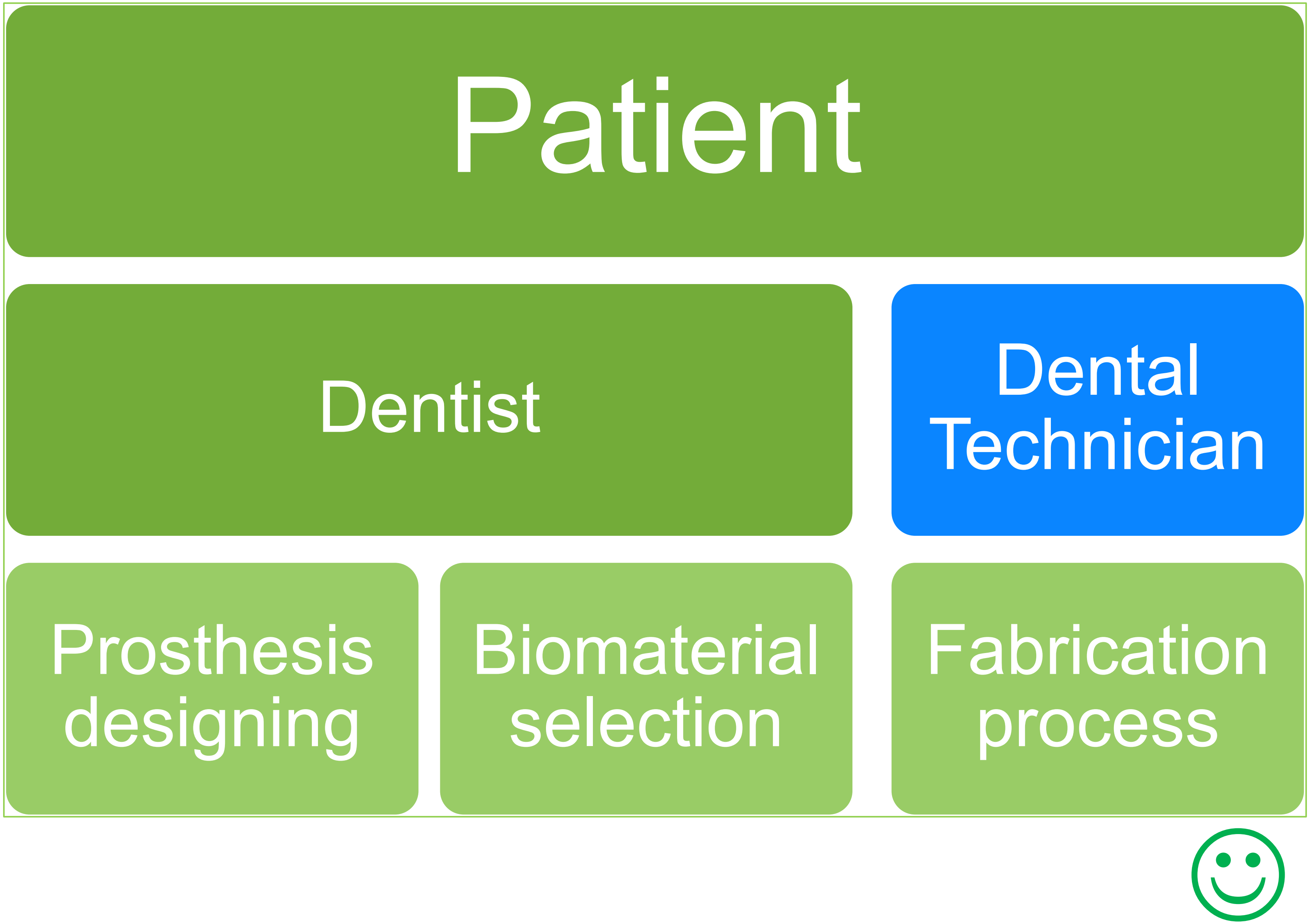
Face-Referenced Measurement of Perioral Stiffness and Speech Kinematics in Parkinson's Disease

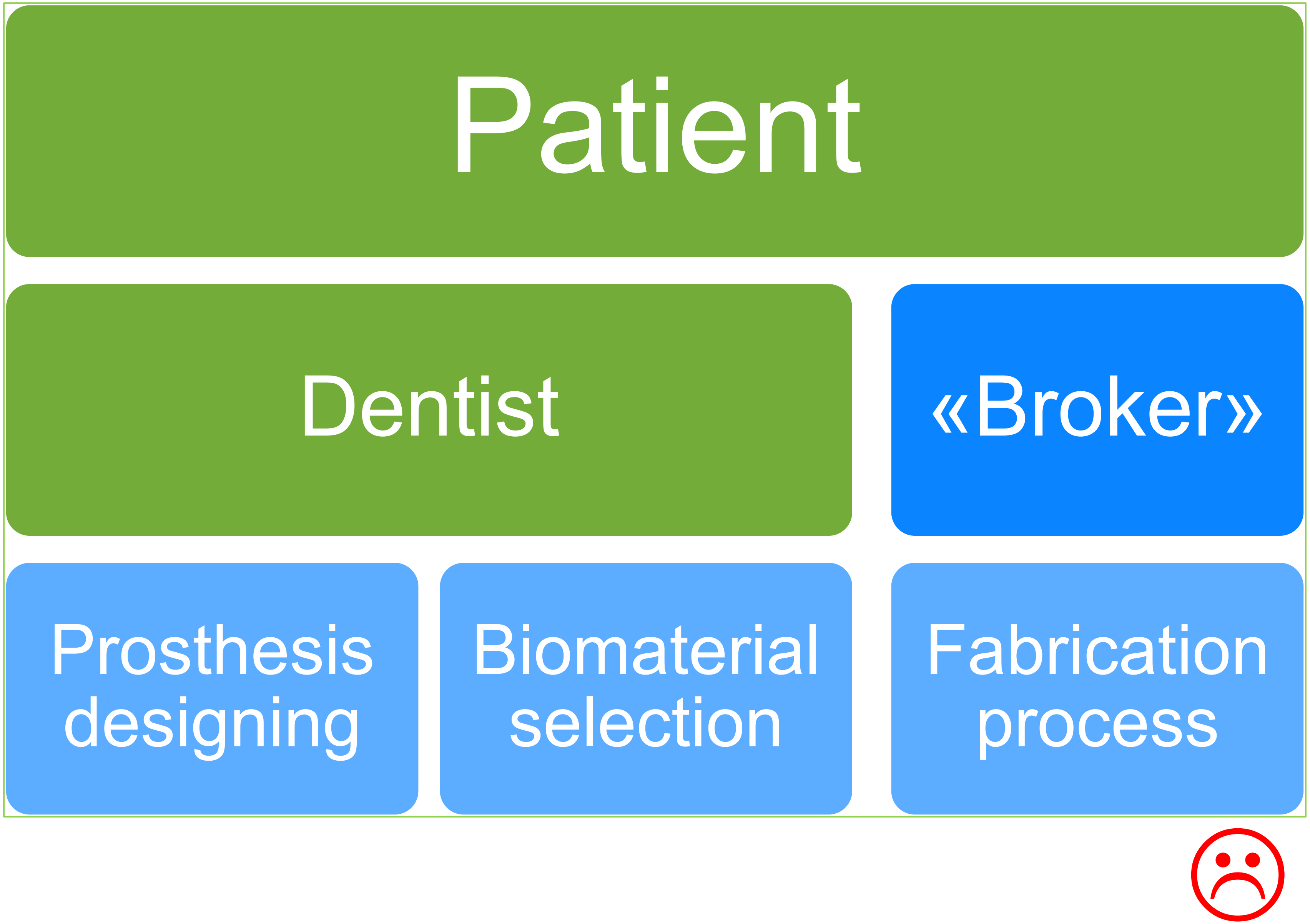
Shin Ying Chu,[a] Steven M. Barlow,[b] and Jaehoon Lee[c]

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 and subtractive manufacturing technologies
- optimal handling of new CAD-CAM-biomaterials

→ **Brokers & “bundle package industries”** ☹


Patient
Dentist
Dental Technician
Prosthesis designing
Biomaterial selection
Fabrication process


Patient
Dentist
«Broker»
Prosthesis designing
Biomaterial selection
Fabrication process

Medical device customised for your patient

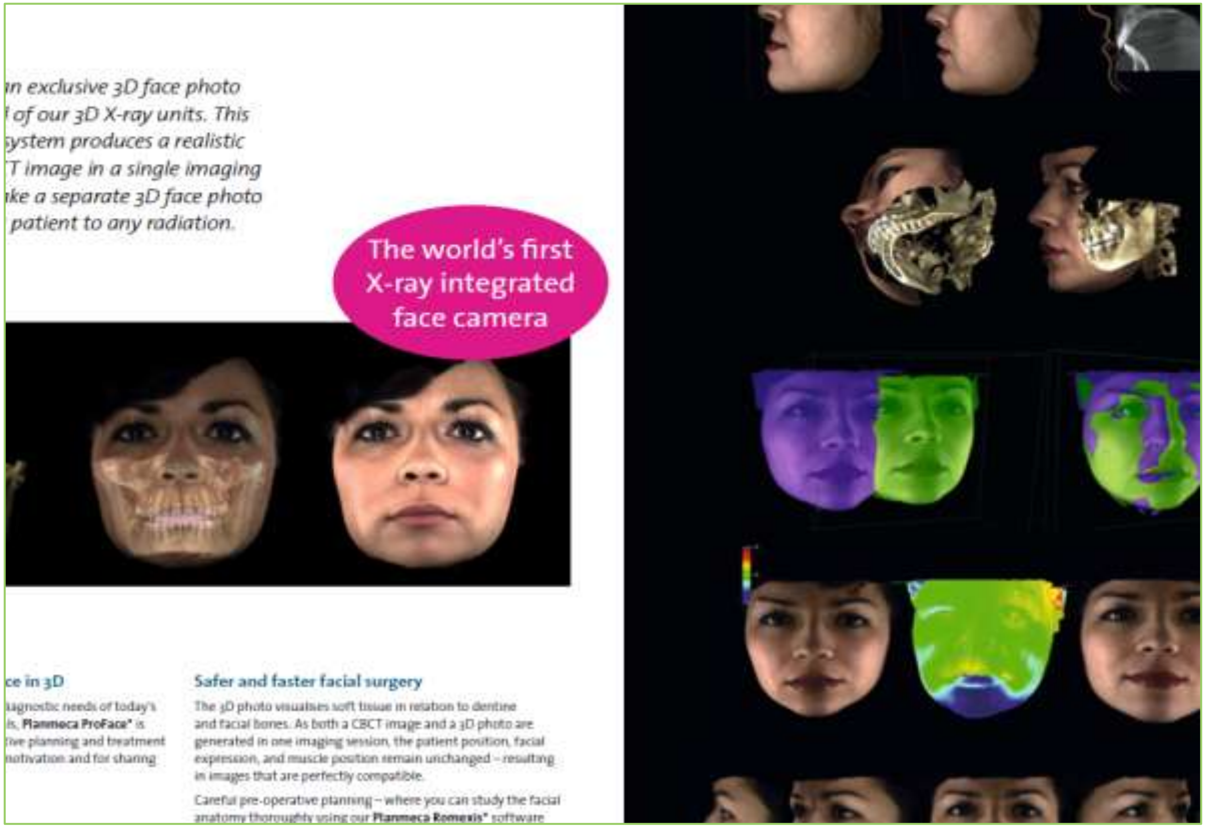
ESSENTIAL:

1. It is always a **responsibility of a doctor** to maintain the control of the choice of biomaterial and chain of fabrication method
2. The choice of biomaterial and CAM method may not be compatible – time will tell
3. Stay with a validated concept or upgrade your knowledge about properties of new material & new CAM methods

Example, Customized abutments with CAM

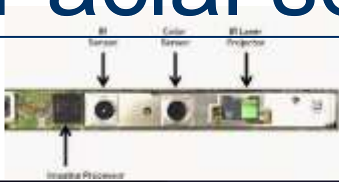
Who decides whether the interface is in ceramic or metal? The clinician or the CAM owner?

Virtual patients – already feasible today



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

Facial scanning (structured light / laser /stereophotogrammetry





Intel RealSense 3D
$99
•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

[Intel on Amazon]

Shining 3D EinScan-Pro
$3,999
•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.

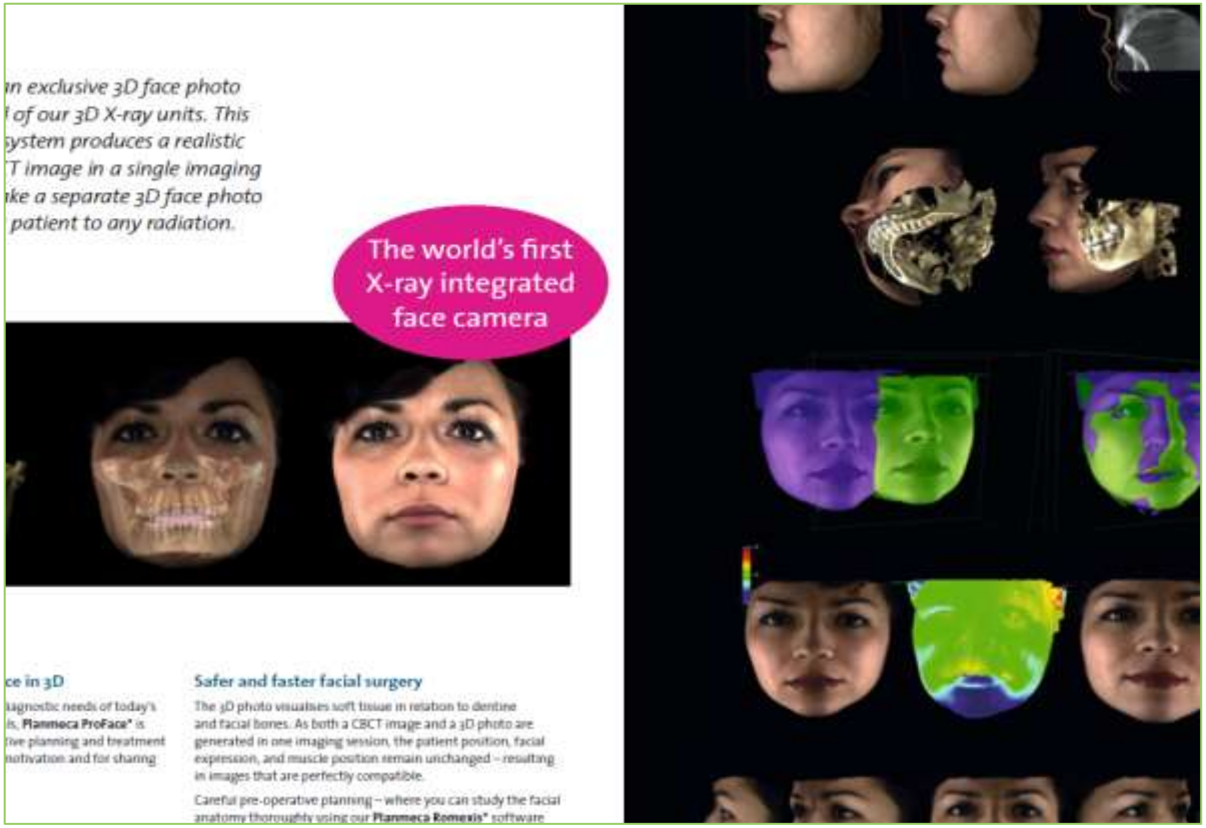
Synthesis: the scan process takes some time. The Einscan-pro is not specifically designed for face scanning but is a very versatile portable scanner.

Fuel3D SCANIFY
$1,500
• 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

Artec Space Spider –
$27,600
•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.

From: aniwaa.com

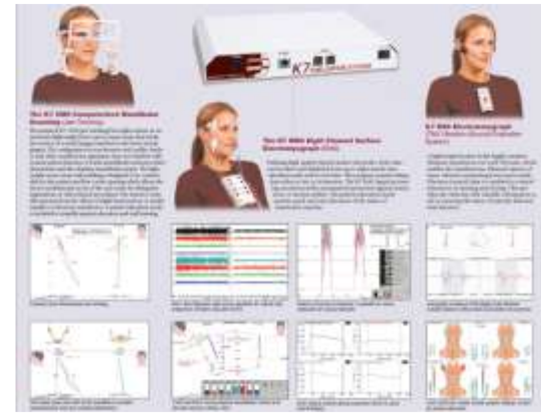
Virtual patients – already feasible today



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

CA jaw recording → (Virtual) articulator

WinJaw (Zebris) JMA20



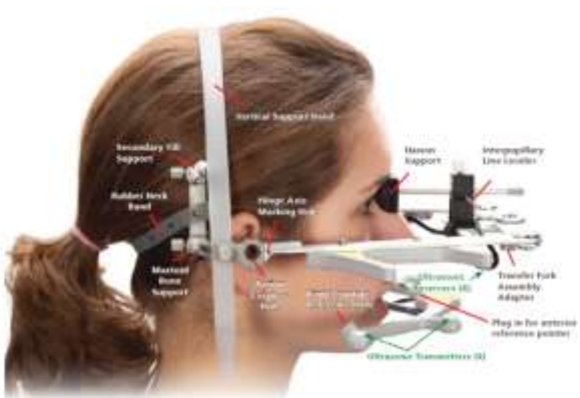
Myotronics

ARCUSdigma II (KaVo)

Ultrasound

Axioquick Recorder (SAM)

Opto-electronic

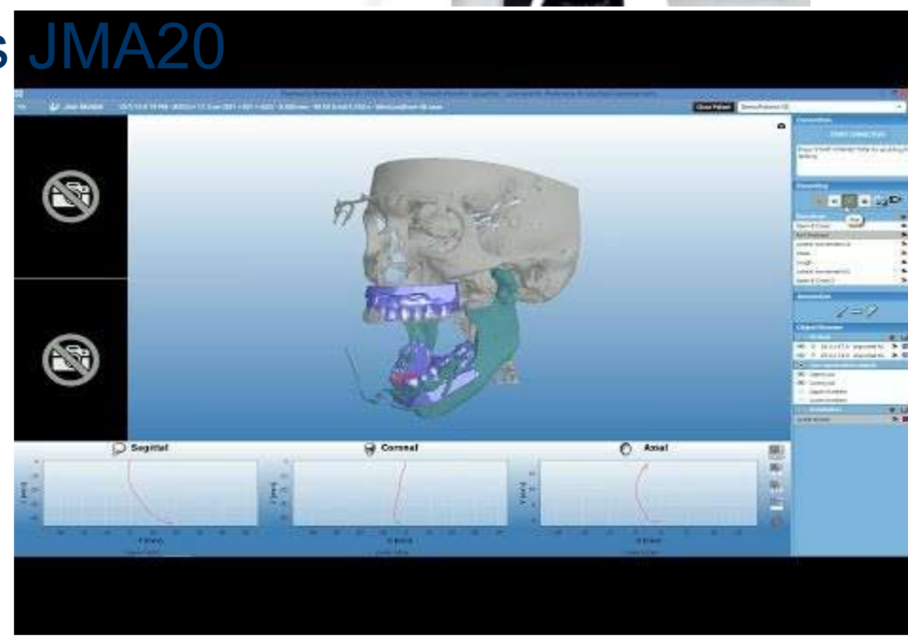


Cadiax

Freecorder BlueFox (DDI-Group)

A virtual articulator may replace the mechanical in complex treatment cases

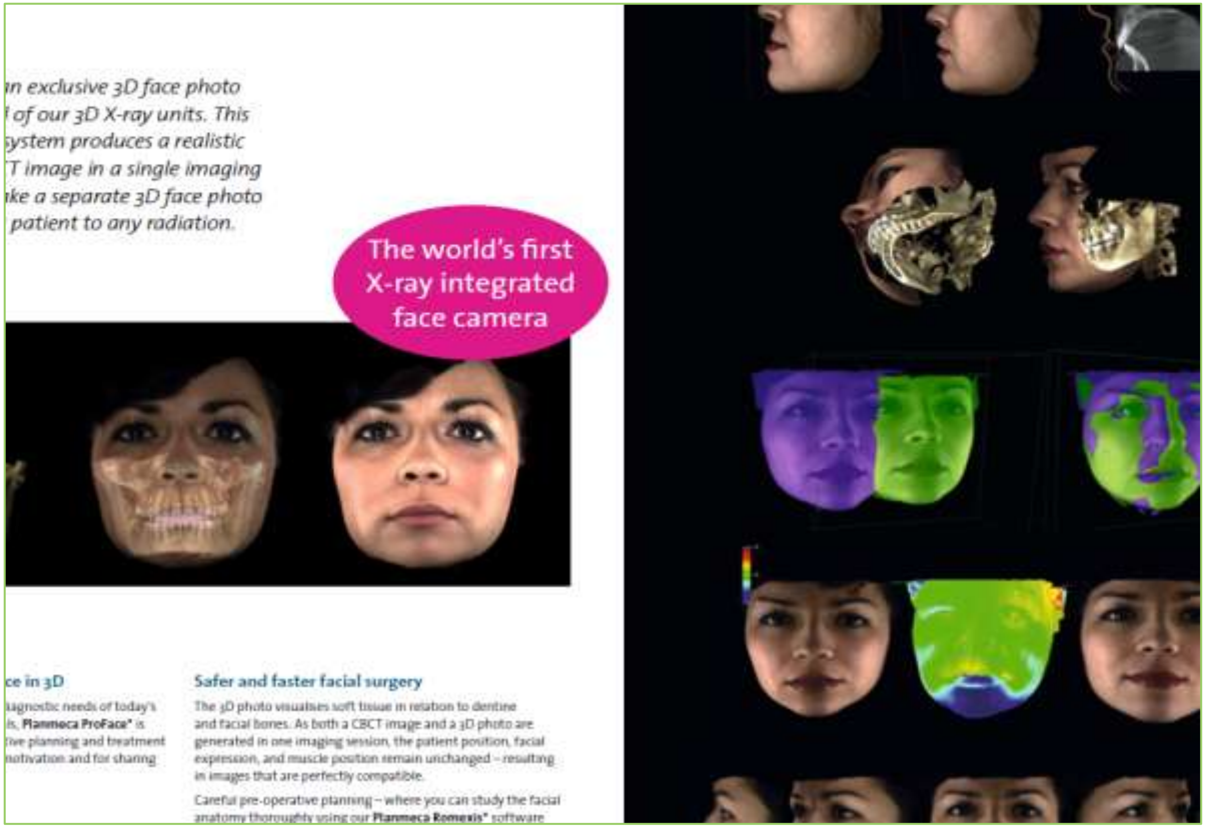
zebris JMA20



Sirona Scicat

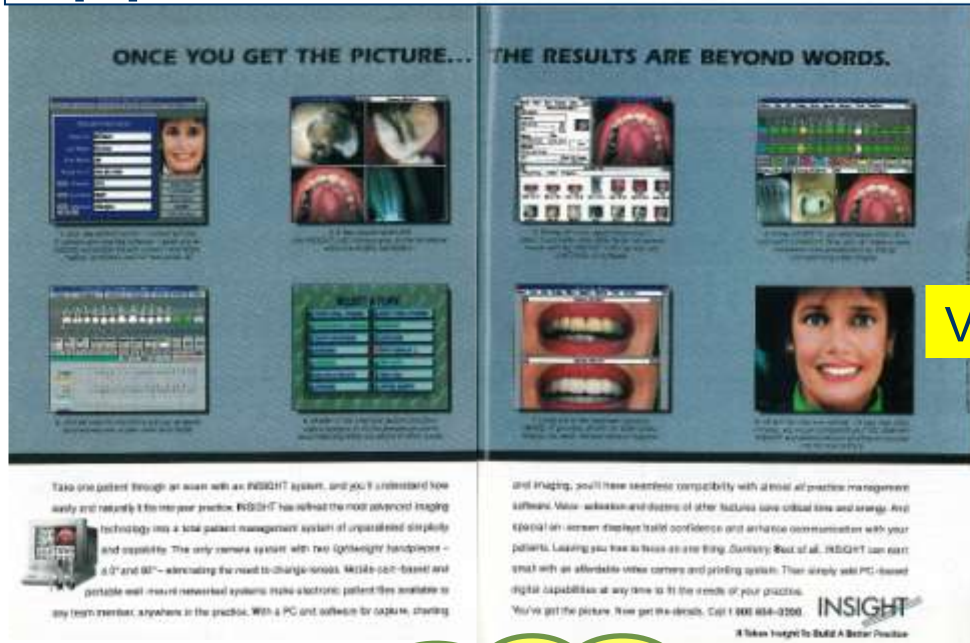
Planmeca Romexis

Virtual patients – already feasible today



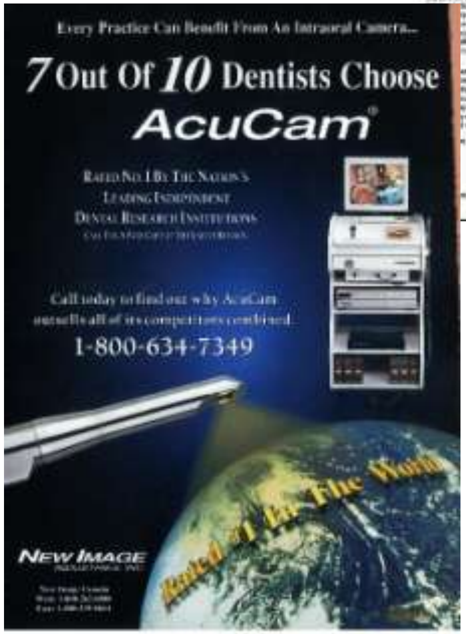
	Planmeca	Cerec4.2(Sirona)	3dMDvultus
Conebeam Rx	√	√	√
Facial scan	√		√
Jaw tracking	√	√	
Smile design	√	√	√

Application of innovations in 2017 vz. 1996?



Virtual smile

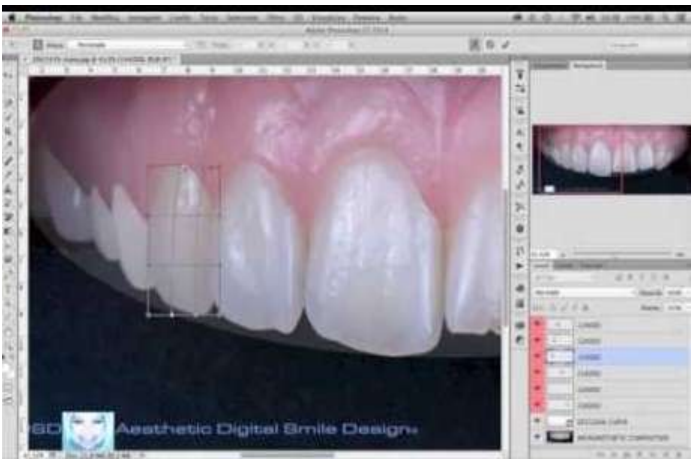
Digitized intraoral camera



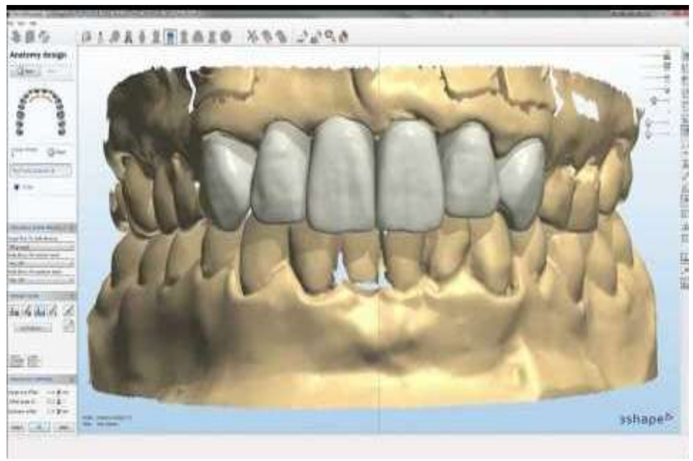
WOW!

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

Virtual smile designing in 2017- an even more impressive visual impact



Digital Smile Design



Smile composer

CEREC Smile Design

Romexis Smile Design

Product name	Manufacturer
CEREC Smile Design	Sirona, Germany
Digital Dentist	Digident, USA
Digital Smile Design	DSD, Spain
Digital Smile System	DSS, Italy
Envisionasmile	EnvisionASmile , USA
G Design / D Pack	HackDental, Romania
GPS Digital Smile Design	Dental GPS, Canada
Insignia Advanced Smile Design	Ormco, USA
Romexis Smile Design	Planmeca, Finland
Smile Composer	3Shape, Denmark
Smile Designer Pro	Tasty Tech, Canada
Smile-Vision System	Smile-Vision, USA
SNAP Instant Dental Imaging	SNAP Imaging Systems, USA

Thank you for your kind attention

asbjorn.jokstad@uit.no