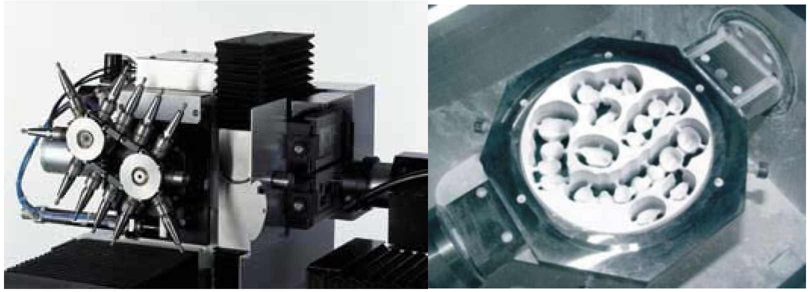
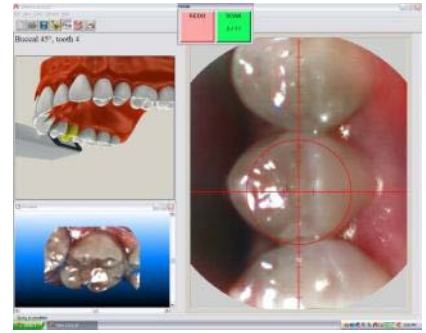
The benefits and caveats of using computer technologies in the fabrication process to make supra-constructions

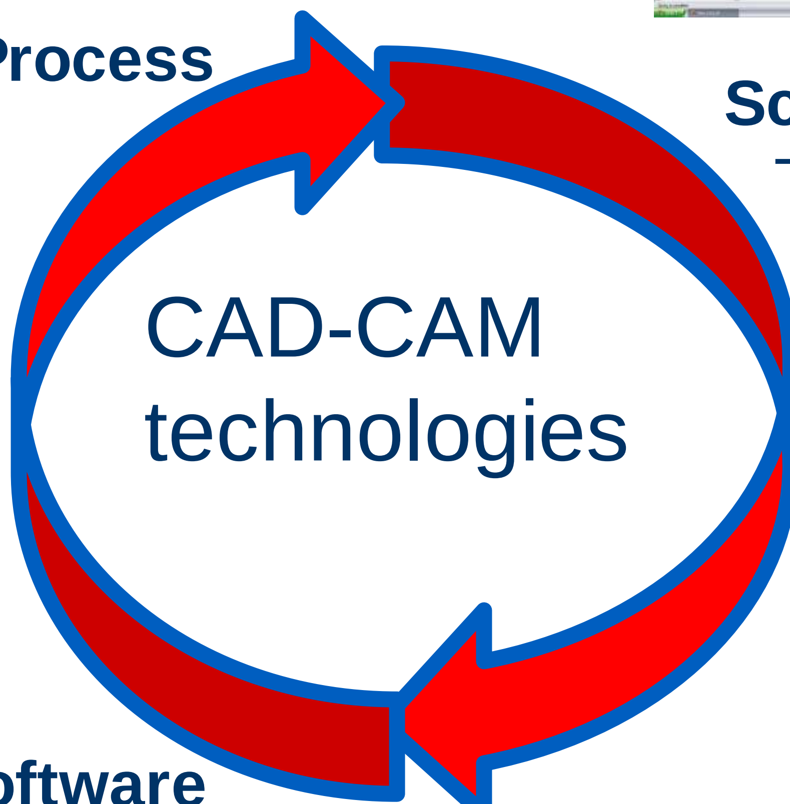
Asbjørn Jokstad
University of Toronto, Canada

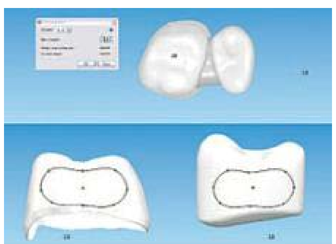


Manufacture Process
Device
Applications
Materials

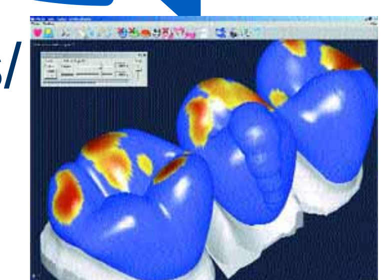


Scanning
Technology
Acquisition
Scan Items
Data export format(s)



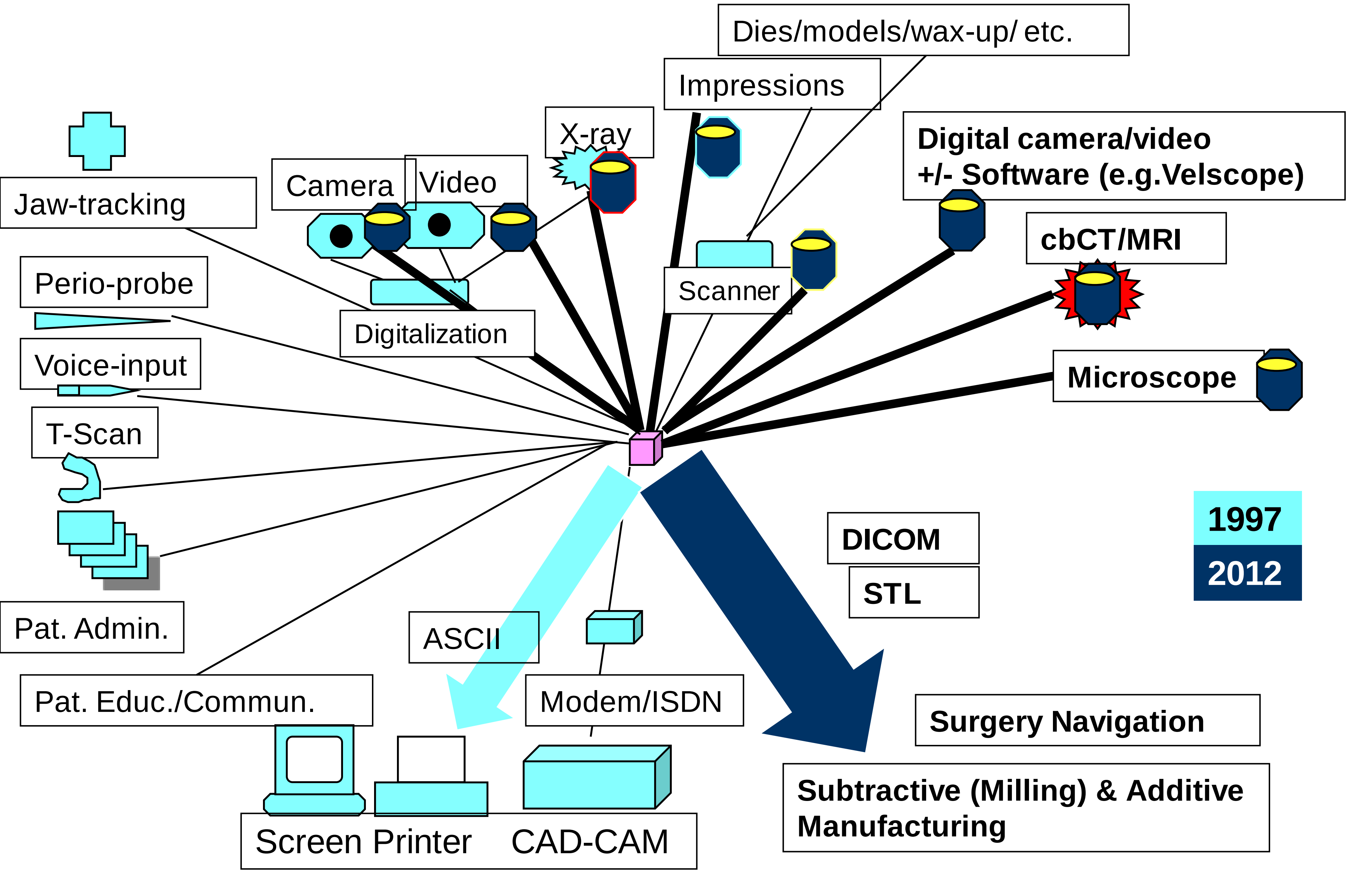


Manufacture Software
Data import/export formats/ formatting
Manufacturing applications



Design Software
Data import/export formats / formatting
Design applications

Microprosessor uses in the dental clinic



Microprocessor performance

Clock speed (MHz)

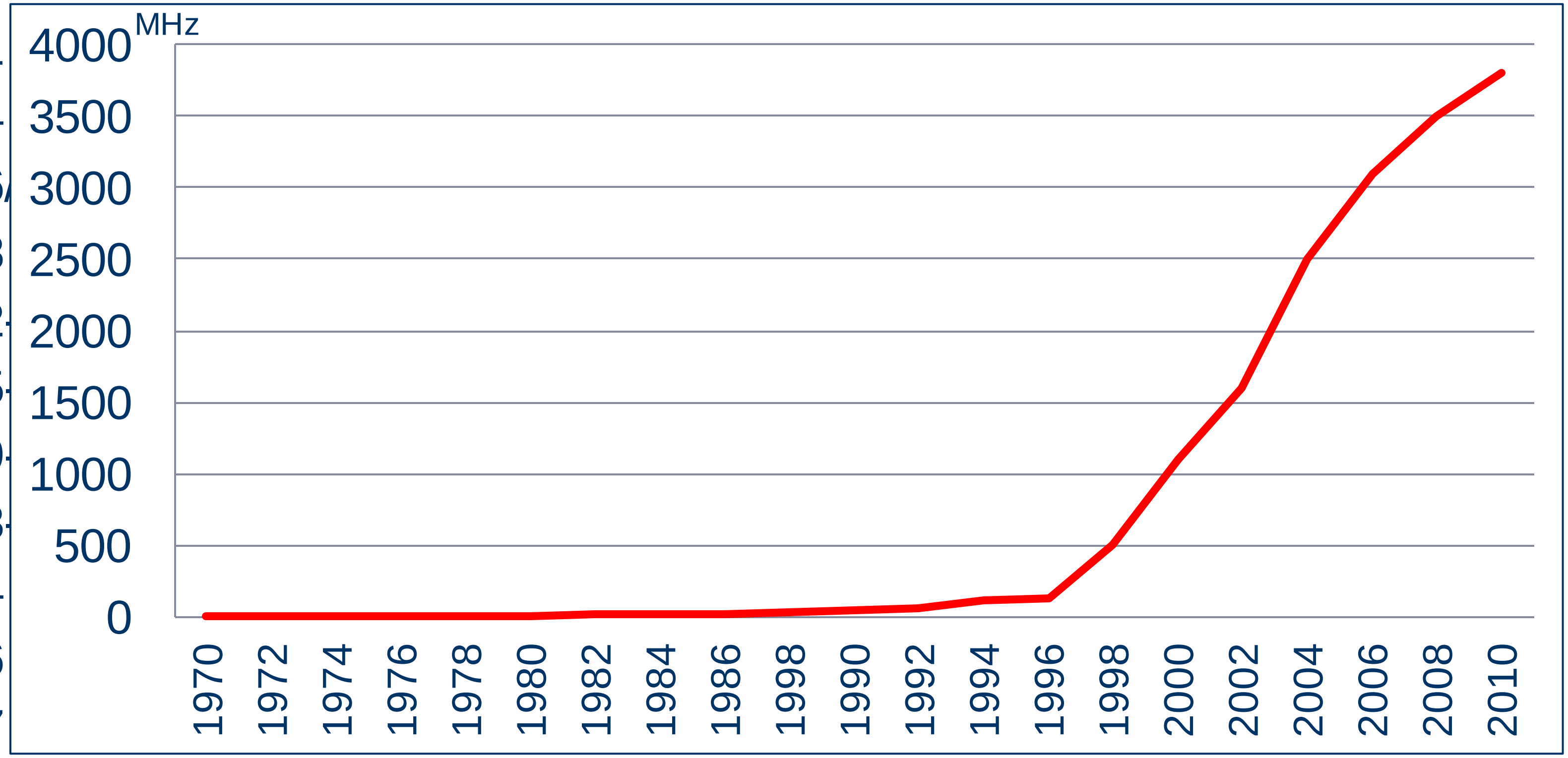
<1	1971	Intel4004/ Texas Instrument TMS100
1	1974	Motorola/Intel8008/ZilogZ80 8bit.Cp/M (Commodore 64, Apple II)
4.77	1976/8	Intel 8086 16bit; (Compaq, IBM PC); Intel 8088 (IBM (1981))
8	1978	Motorola 68000 (Macintosh128k, Amiga1000)
6 – 25	1982-85	Intel 80286 DOS(1981); (IBM-AT (1984))
12 – 40	1985-90	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)
133	1996	AMD K5
500	1997	IBM PowerPC 750 (iMac)




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

Microprocessor performance

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



<1	1971	
1	1974	
4.77	1976/	
8	1978	
6 – 25	1982-	
12 – 40	1985-	
20 – 100	1989-	
	1993-	
110	1994	
133	1996	
500	1997	
0.6→1400	1997-2002	Intel Pentium III (Celeron/Zeon)
0.8→3000	2001	IBM PowerPC950 (PowerPC G5)
1.3→3800	2000-2008	Intel Pentium 4 (Pentium M/D)
1→3000	2003	AMD Athlon 64 → 64X2
3300	2011	Intel Core i7

Computer- aid/-assistance in dentistry

Engineering & Production

Computer-aided design "CAD"

Computer-aided drafting

Computer-aided engineering

Computer-aided manufacturing "CAM"

Computer-aided quality

Computer-aided maintenance

Health Care

Computer-assisted detection

Computer-aided diagnosis

Computer-aided tomography

Computer-assisted / -guided surgery

Teaching

Computer assisted instruction

Computer assisted/based learning

Computer-assisted assessment

Communication

Computer-assisted personal interviewing

Computer-assisted telephone interviewing

Computer-assisted reporting

Dental Clinic

Computer-aided shade-matching

CURRENT STATUS AND CHALLENGES OF SCANNING DEVICES

Scanning - Parameters

Technology

Optical-white light

Optical-blue light

Optical-stripe light

Optical-laser/video

Optical-laser-triangulate

Optical-laser-confocal

Mechanico-electric (laser-adjusted)

Conoscopic Holography

Acquisition

Intra-oral

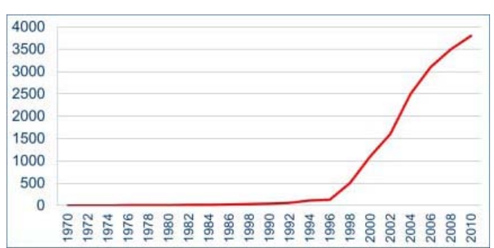
Extra-oral

Intra-& extra-oral

Scan export format

Open format (STL, DICOM)

Closed



Scan Items

Antagonist

Bite registration

Die

Full arch

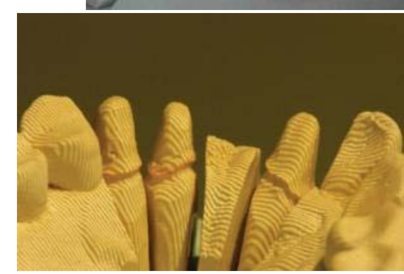
Implant Abutment

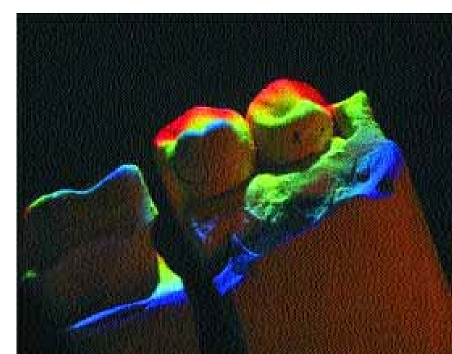
Model

Prostheses

Wax-up

ISO-standard(?)





Intra oral scanning

CEREC BlueCam / AC

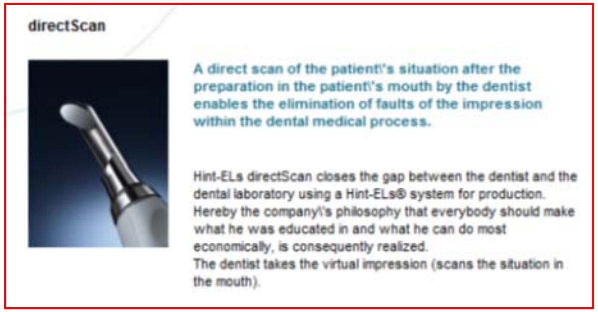
Laser Triangulation

Confocal light

Per 2010;
4 systems
(+E4D)

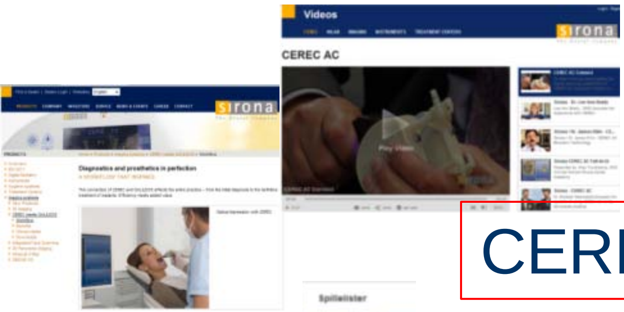
LAVA COS
(2008)

Cadent Itero
(2006)

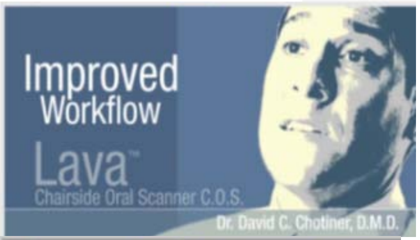


Hint-Els GmbH (2009)

Intra oral scanning

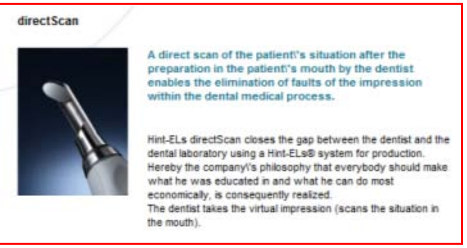


CEREC



LAVA COS

Cadent Itero



Hint-Els GmbH

Per 2010/2011:
4 additional systems introduced

Densys3D: MIA3d

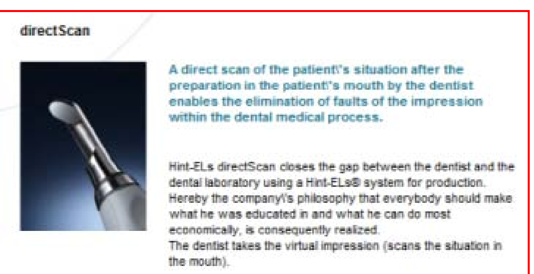
Intellidenta/ Clõn3D: IODIS

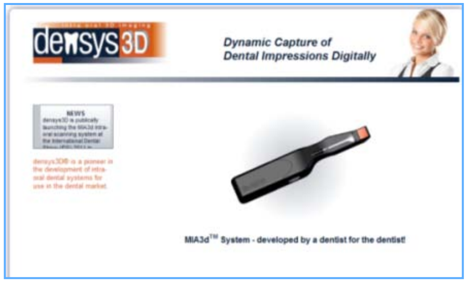
MHT: Cyrtina/3DProgress

3Shape: TRIOS /(Dentaswiss)

Intra oral scanning

Per 2012: 3 additional systems introduced

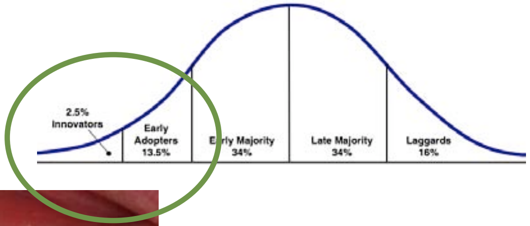




Zfx / Intrascan

Bluescan /a.tron3D

IOS: Fastscan

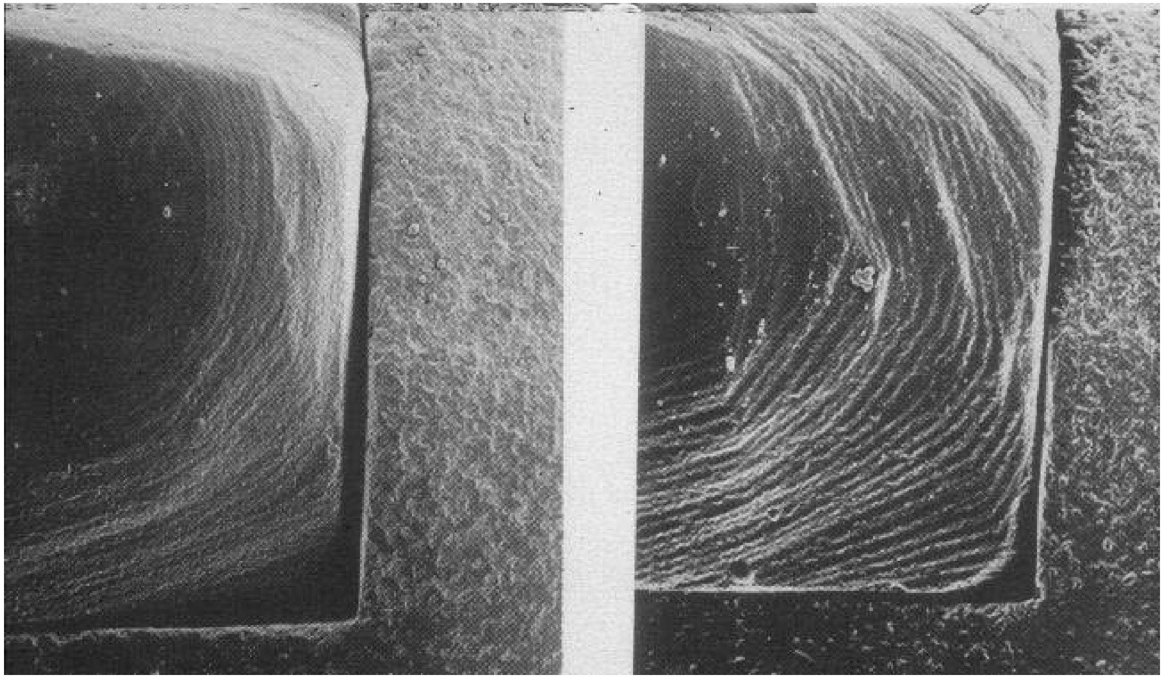


Digital Impression with the Itero device of Straumann Implants

(Lab. photos: Slawek Bilko, RDT)

CURRENT STATUS AND CHALLENGES OF DESIGN & MANUFACTURER SOFTWARE

The sum of Hardware + Software Improvements



CEREC 1 (~1986)

CEREC 2 (~1992)

Design / Manufacturer Software Parameters

Import format(s)

Open

Scanner-CAD bundled (Closed)

Export format(s)

Open (e.g. STL)

CAD-CAM bundled (Closed)

Applications

Wax-ups / temporaries

Inlays / Onlays

Single-unit copings

Crowns / monolithic crowns

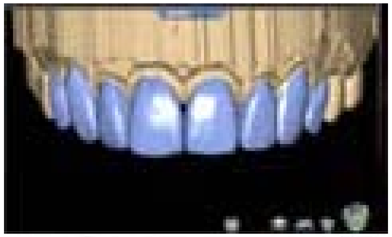
3 → 16u / 4 →7cm –FDPs

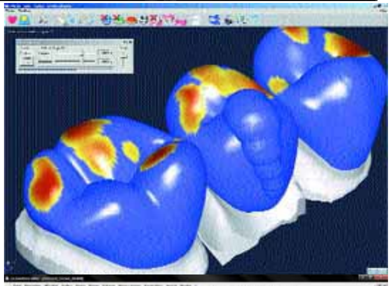
Removable Dental Prosthesis (Partial / Full)

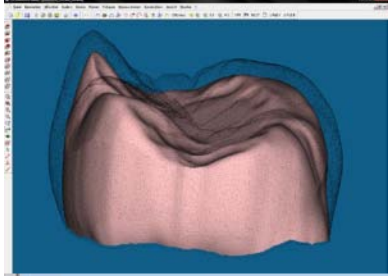
Implant “customised” abutments

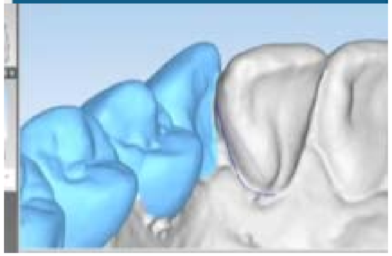
Implant meso-structures

Implant-Bars









CURRENT STATUS AND CHALLENGES OF ADDITIVE AND SUBTRACTIVE MANUFACTURING CONCEPTS

Manufacturing Parameters

Device - additive
3D Laser sintering
3D Printing
Device - subtractive
3/3.5/4/5/6-axis-milling

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

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

Composite resins
Cast Resins / Wax
PMMA

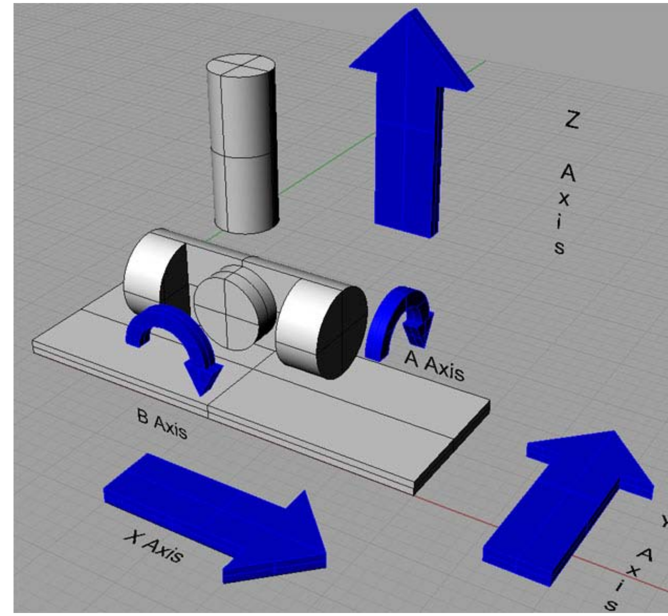
In-Ceram (Porous Al_2O_3)
Al_2O_3 (sintered)
Feldtspathic
$Li_2Si_2O_5$
ZrO_2 (porous/green state)
ZrO_2 (pre-sintered state)
ZrO_2 (sintered)
ZrO_2 (sintered & HIP-ed state)

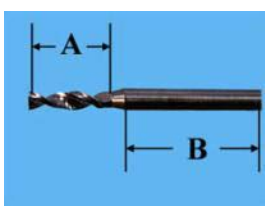
with / without
Sintering-furnace

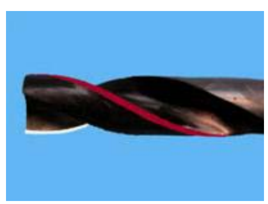



Milling in Dentistry – From 3 axes → 5 → 5+5 milling axes

↘







↘

Milling machines today are manually operated, mechanically automated, or digitally automated via computer numerical control (CNC) re. e.g. torques, feed-rate, nature of cutters, etc..

Software algorithm compensatation for errors introduced during milling processes

Often based on finite-element-modeling calculations

- Geometrical compensation
- Force compensation
- Thermal compensation
- Errors in the final dimensions of the machined part are determined by the accuracy with which the commanded tool trajectory is followed, combined with any deflections of the tool, parts/ fixture, or machine caused by the cutting forces
- The effect of geometric errors in the machine structure is determined by the sophistication of the error compensation algorithms
- The cutting tools' trajectories are subject to performance of the axis drives and the quality of the control algorithms

Submarine's propellers

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

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

State-of-the-art manufacturing of propellers

1. Bronze continuous/industrial casting
2. Quenching
3. Milling
4. Berillium layer on the bronze
5. Repeat milling

"Акула”

CoCom

CoCom is an acronym for *Coordinating Committee for Multilateral Export Controls*. CoCom was established by Western bloc powers in the first five years[1] after the end of World War II, during the Cold War, to put an arms embargo on COMECON (Warsaw Pact) countries.

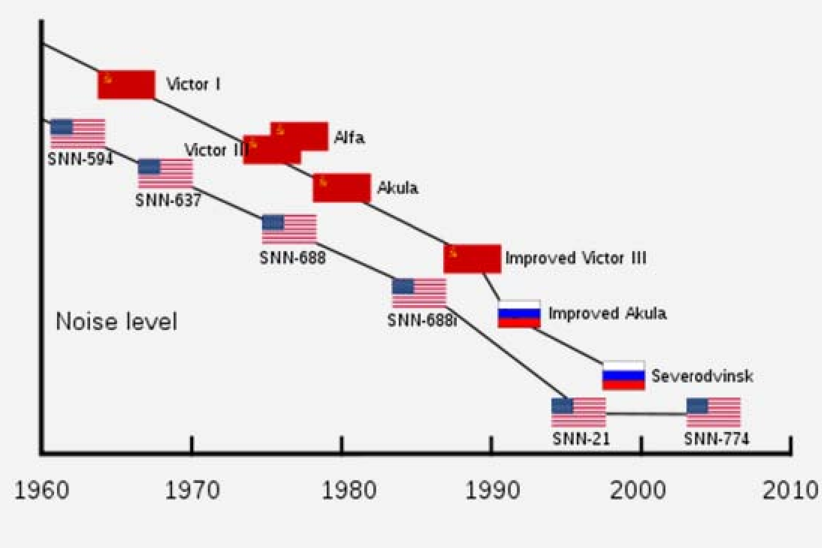
CoCom ceased to function on March 31, 1994

Magyar vontatkozású COCOM-listás termékek [szerkesztés]

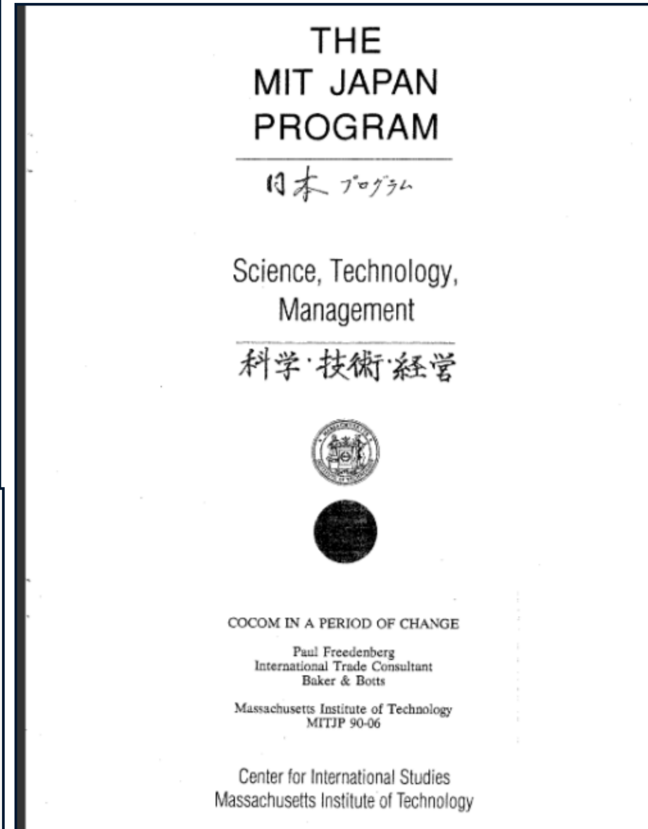
- Informatika (A "turista importban" bejutó termékekre pedig a magyar kormány vetett ki magas vámot)
  - Hardver
    - Commodore 64
    - Ethernet hálózati eszközök (1990-ig)
    - IBM számítógépek
      - IBM PC XT és AT
        - A Magyarországra került gépeket általában alkatrészként szétszerelve hozták be, és rakták össze [7]
      - Mainframe-ek
        - 9221 Model 150 [8]
        - 5110 (BASIC és APL nyelven programozható, 8" floppy disk, 64 kB memória [9]
    - Apple Macintosh [10]
    - Digital Equipment Corporation termékek kilencven százaléka [11][12]
      - PDP, VAX (a KFKI-n visszafejtették a gép működését, ebből lett a TPA - Tárolt Programú Analizátor. Ritka esetekben a TPA átcímkézett és becsempészett PDP és VAX gépeket is jelentett)
    - Amiga
    - 4 GB-ot meghaladó kapacitású merevlemez [13]
  - Szoftver

A Commodore 64 az 1980-as évek közepén került le a COCOM-listáról

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



Submarine and noise level. US vs Russians



THE
MIT JAPAN
PROGRAM

日本プログラム

Science, Technology,
Management

科学·技術·経営

COCOM IN A PERIOD OF CHANGE

Paul Freedenberg
International Trade Consultant
Baker & Botts

Massachusetts Institute of Technology
MITJP 90-06

Center for International Studies
Massachusetts Institute of Technology

Cutters for dental (5 axis) milling

Milling Bur 4 L
Used to mill pre-sintered zirconia (rough preliminary and internal milling)

Milling Bur 3 L
Used to mill pre-sintered zirconia (rough milling)

Milling Bur 2 L
Used to mill pre-sintered zirconia (defined milling/precise milling)

Milling Bur 1 L
Used to mill pre-sintered zirconia (precise milling)

Milling Bur 0,5 S
Used to mill pre-sintered zirconia (high precision milling)

Milling Bur 1 XXL
Used to mill pre-sintered zirconia (abutment)

Milling Bur 2 A
Used to mill pre-sintered zirconia (abutment)

Milling Bur 1,5 A
Used to mill pre-sintered zirconia (abutment)

Milling Bur 0,6 A
Used to mill pre-sintered zirconia (abutment)

Milling Bur 2W30
Used to mill screw seats

Milling Bur 3 C
Used to mill pre-sintered zirconia (2° coned flank)

Milling Bur 1 XL
Used to mill pre-sintered zirconia (precise milling of deep)

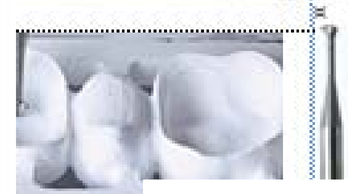
Milling Bur 3 U
Used to mill pre-sintered zirconia (undercut)

Milling Bur 2 U
Used to mill pre-sintered zirconia (undercut)

Round Head Bur 2 K Rapid and easy smoothing of surfaces and undercuts

Milling Bur 0,3 C
Used to mill occlusal fissures

Milling Bur 2 UR
Used to mill undercuts



Milling Bur 2,5 UR
Used to mill undercuts

From: ZirconZahn

Emerging Additive manufacturing technologies

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

3D geometries physically constructed directly from 3D CAD.

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

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

Comparison of solid freeform fabrications methods

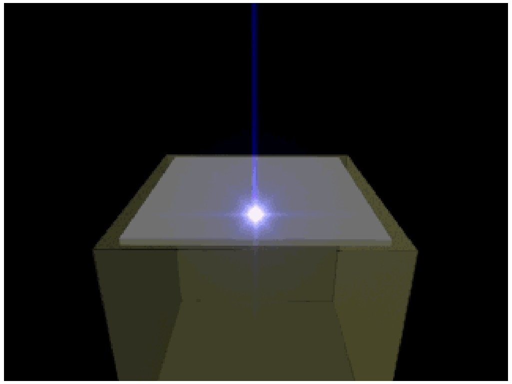
Method	Accuracy (mm/mm)[6]	Maximum part size (mm)[7]	Process time (hh:mm)[8]
Fused deposition modelling	0.005	254 x 254 x 254 (Stratasys)[9]	12:39
Laminated object modeling	0.01	812 x 558 x 508 (Cubic Technologies)	11:02
Selective laser sintering	0.005	381 x 330 x 457 (3D Systems)	4:55
Solid ground curing	0.006	508 x 355 x 508 (Cubital)	11:21
Stereolithography	0.003	990 x 787 x 508 (Sony)	7:03
Robocasting	0.1 (Fab@Home)	240 x 240 X 240 (Fab@Home)	TBD

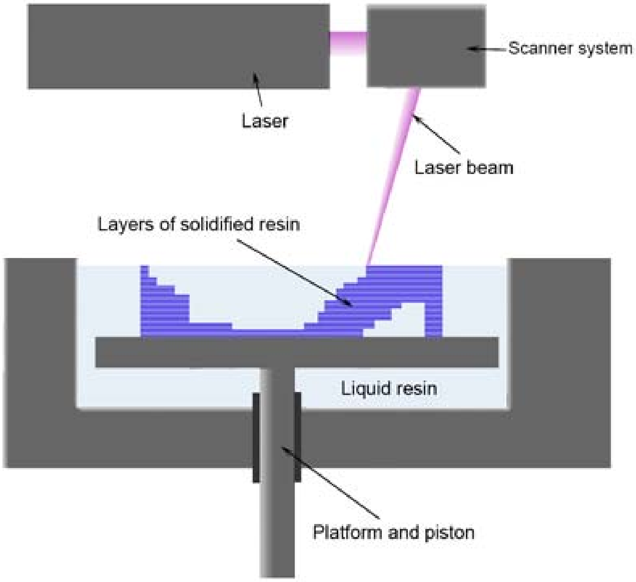
From: wikipedia.com

Additive manufacturing: Stereolithography (SL / SLA)

The method and apparatus make solid objects by successively "printing" thin layers of an UV-curable material one on top of the other.

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





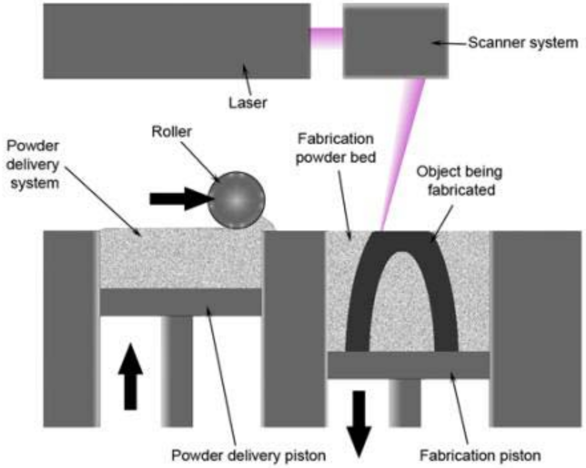
Additive manufacturing: Selective Laser Sintering (SLS)

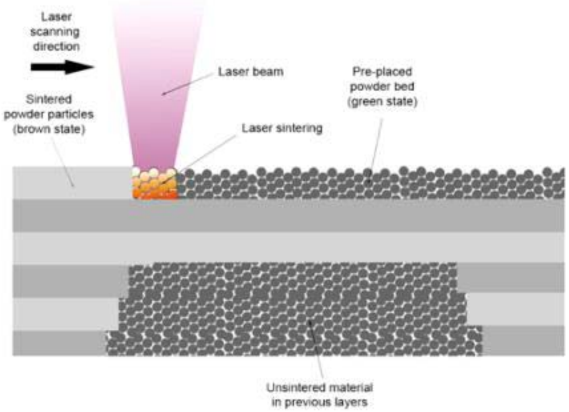
A high power laser (e.g., CO_2) fuse small particles of plastic, metal, ceramic, or glass powders into a desired 3-dimensional shape.

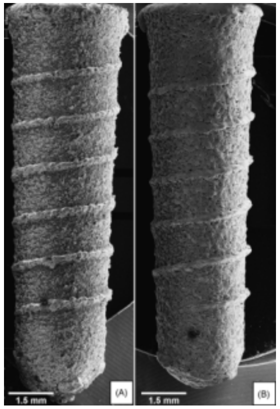
The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part on the surface of a powder bed.

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.

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





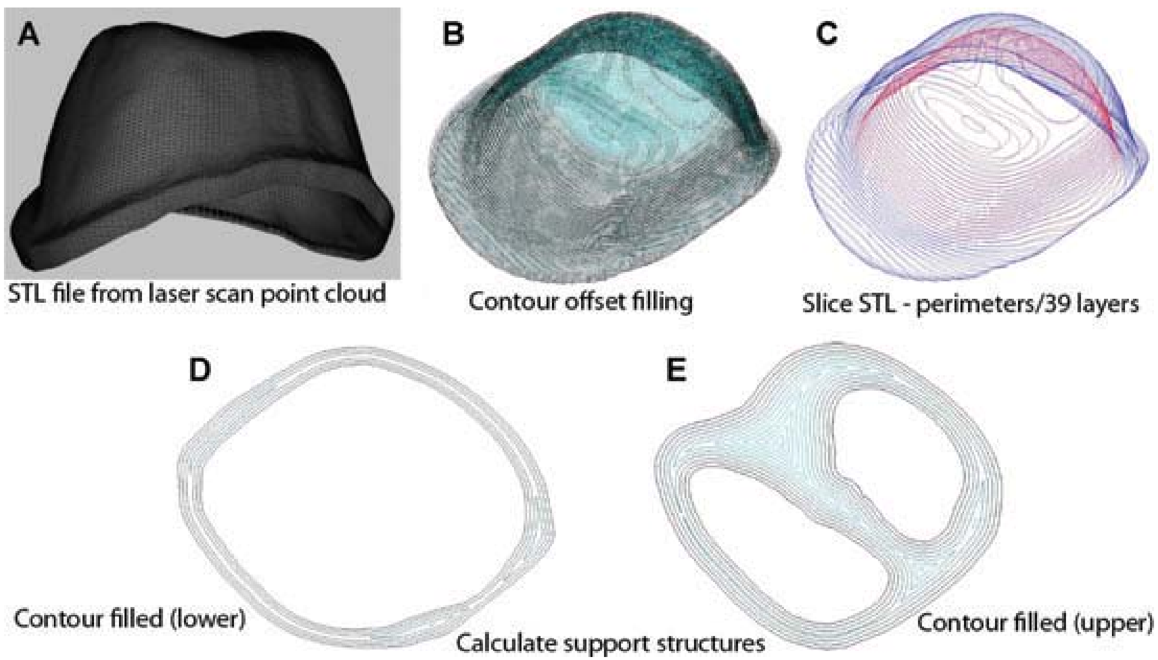


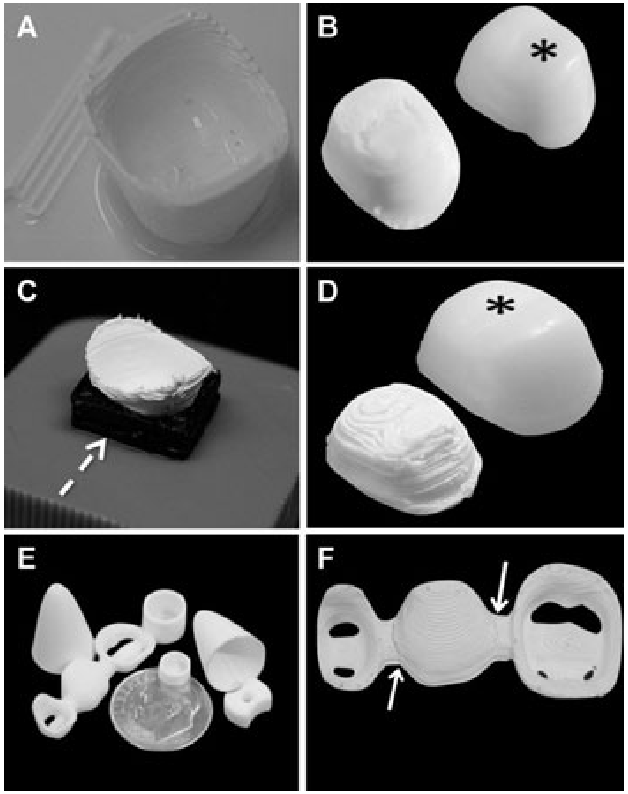
From: Traini ea Dent Mater 2008

Additive manufacturing: Robocasting

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

The material hardens or cures after deposition





From: Silva ea. NYU J Prosthodont 2011

CURRENT STATUS AND CHALLENGES OF RESTORATIVE MATERIALS

Zirconia milling substrates are not all alike!

		%
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

Great variations regarding:

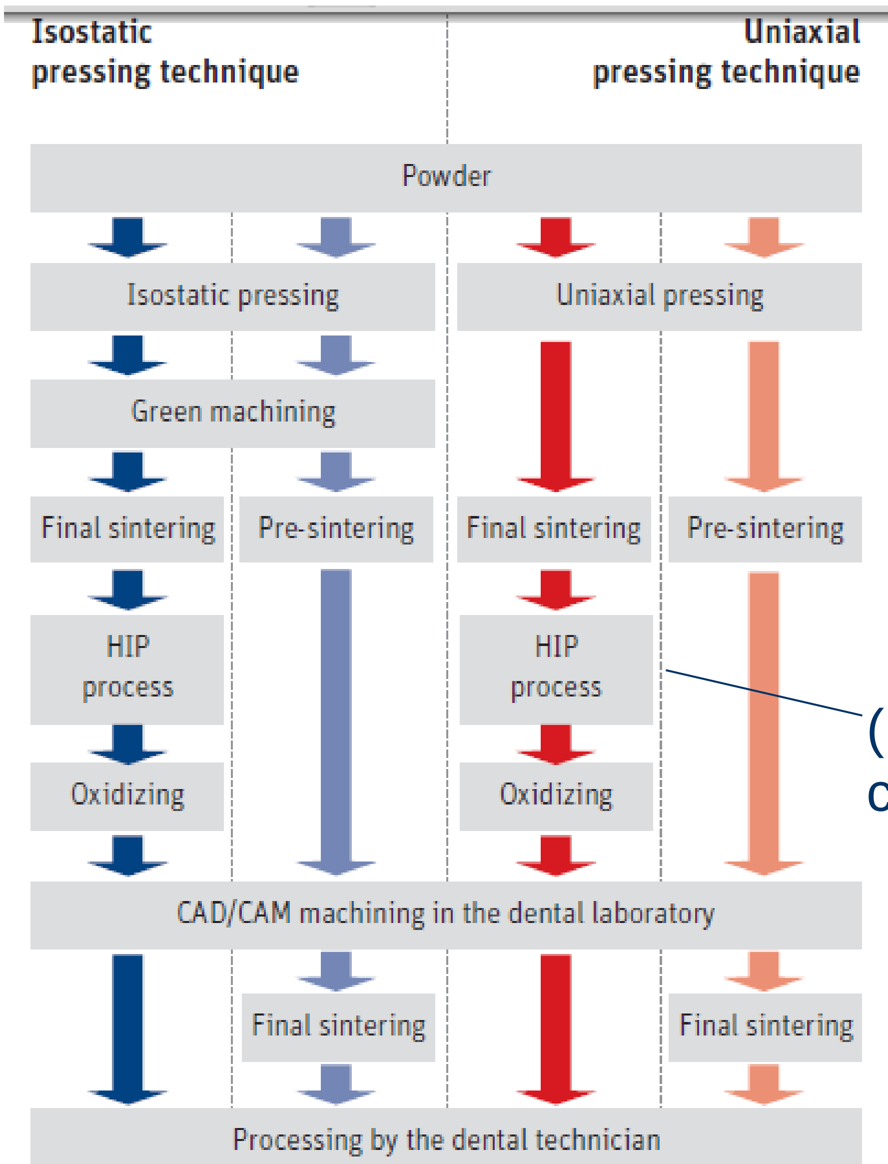
Hardness **Fracture resistance** **Grain size**
Tension strength **Elasticity module** **Opacity**
Sintering time

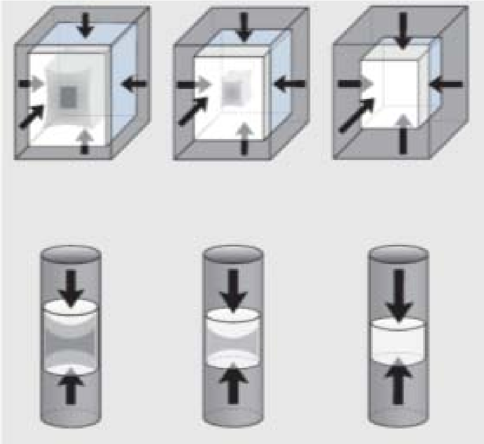
Who do you believe checks:
Veneering ceramic compatibility?
Optimal core-veneer layering thickness?

*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)

Zirconia milling substrates are not alike! 3/3

3 point 4 point biaxial flexural test

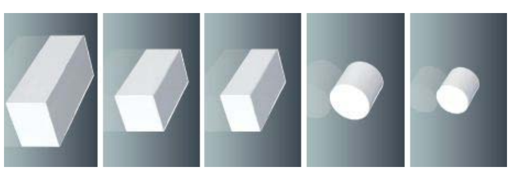
Prefabricated blanks for supra-construction

examples

Sirona

ø99 mm x 10 - 25mm

DCS (Hip)



KaVo Everest

E4D

CAM fabricated bodies – a concern today for problems tomorrow?

Proc Inst Mech Eng H. 2005 Jul;219(4):233-43.

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

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Abstract

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

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

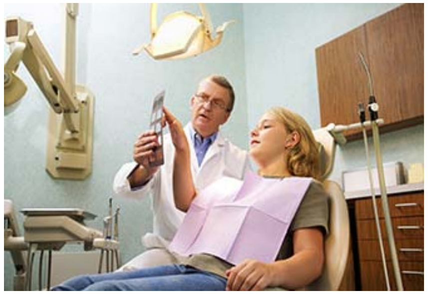
OCCUPATIONAL OUTLOOK HANDBOOK

Dentists

Summary

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

Occupational Outlook of members of the Dental Team (in USA)



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Quick Facts: Dental Hygienists	
2010 Median Pay	$68,250 per year $32.81 per hour
Entry-Level Education	Associate's degree
Work Experience in a Related Occupation	None
On-the-job Training	None
Number of Jobs, 2010	181,800
Job Outlook, 2010-20	38% (Much faster than average)
Employment Change, 2010-20	68,500

Quick Facts: Dental Assistants	
2010 Median Pay	$33,470 per year $16.09 per hour
Entry-Level Education	Postsecondary non-degree award
Work Experience in a Related Occupation	None
On-the-job Training	None
Number of Jobs, 2010	297,200
Job Outlook, 2010-20	31% (Much faster than average)
Employment Change, 2010-20	91,600

Quick Facts: Dental Laboratory Technicians	
2010 Median Pay	$35,140 per year $16.90 per hour
Entry-Level Education	High school diploma or equivalent
Work Experience in a Related Occupation	None
On-the-job Training	Moderate-term on-the-job training
Number of Jobs, 2010	40,900
Job Outlook, 2010-20	1% (Little or no change)
Employment Change, 2010-20	300

Source: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Outlook Handbook, 2012-13 Edition

Dental Laboratory Technicians

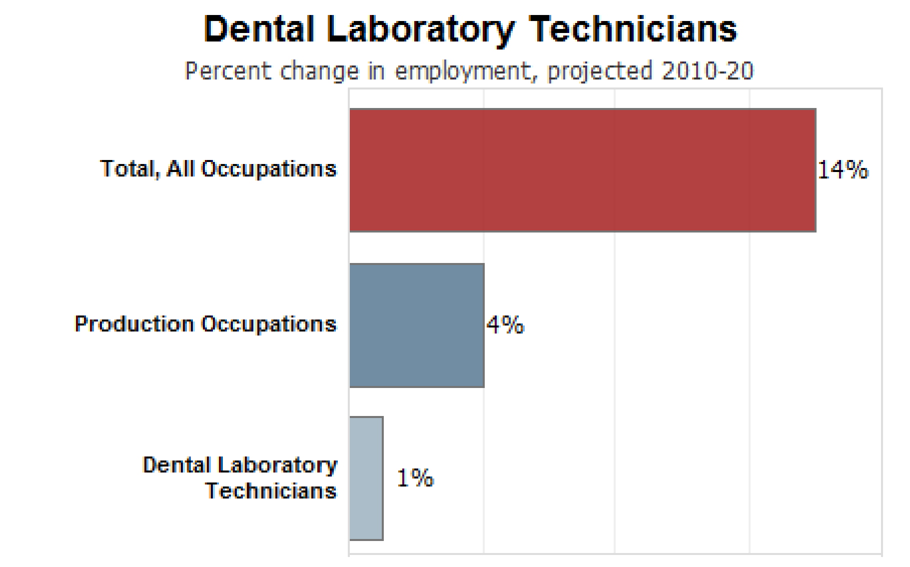
Job Outlook

About this section

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

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

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



Note: All Occupations includes all occupations in the U.S. Economy.
Source: U.S. Bureau of Labor Statistics, Employment Projections program

Employment projections data for dental laboratory technicians, 2010-20

Occupational Title	SOC Code	Employment, 2010	Projected Employment, 2020	Change, 2010-20		Employment by Industry
				Percent	Numeric	
Dental Laboratory Technicians	51-9081	40,900	41,200	1	300	[XLS]

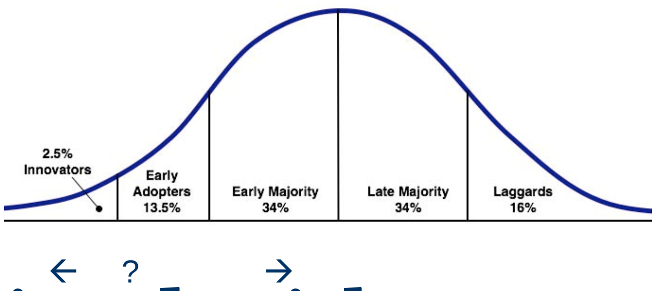
SOURCE: U.S. Bureau of Labor Statistics, Employment Projections program

NADL Fights Unskilled Labor Label for Technicians

A federal shuffle has reclassified dental technicians as unskilled labor, a false label that could have far-reaching effects on the profession. NADL is lobbying the U.S. Department of Labor to restore technicians to the skilled labor category.

"The proposed classification change for dental technicians to another occupational rating could adversely affect the ability of economic

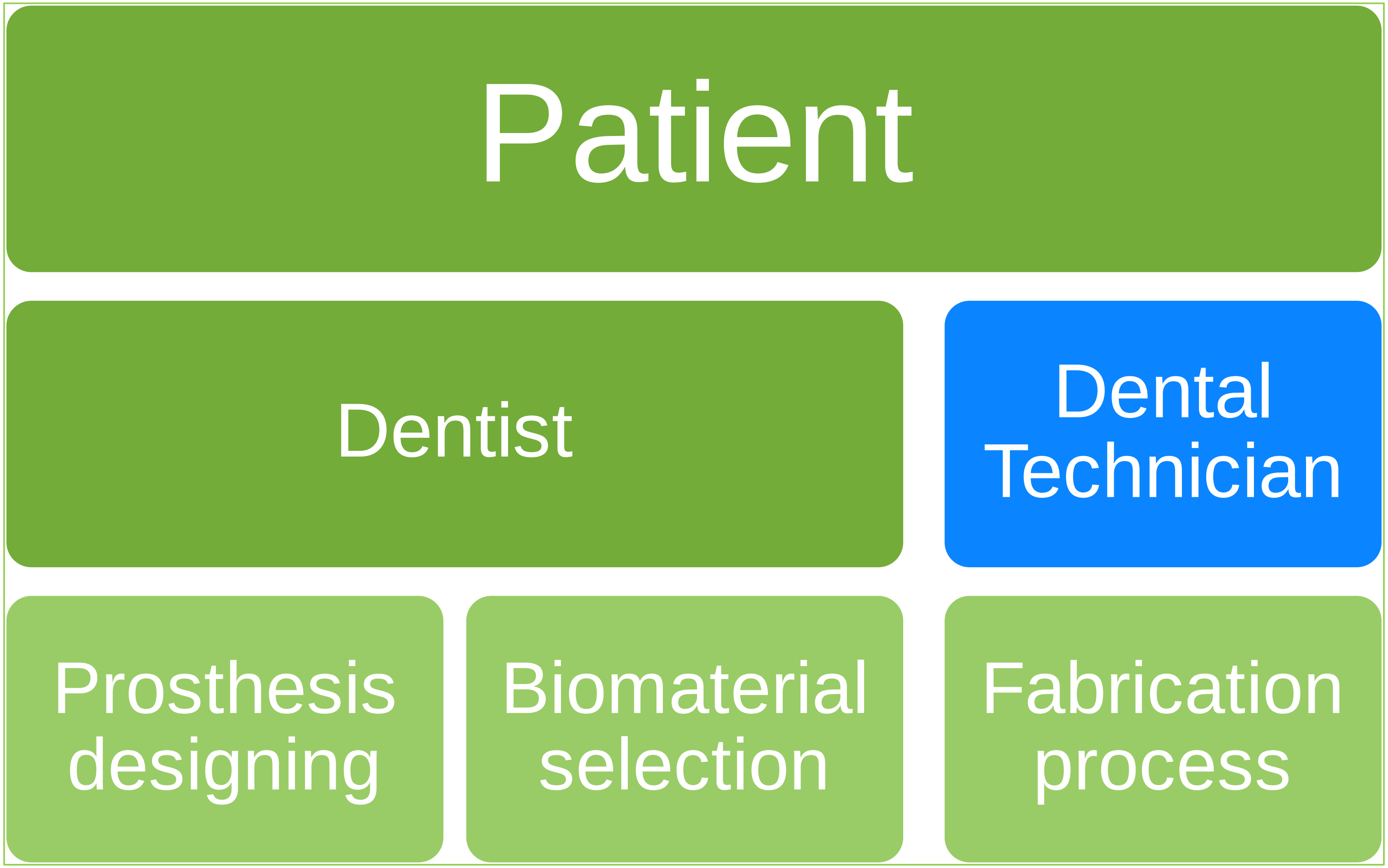
- Typical Entry-Level Education: High school diploma or equivalent
- Previous Work Experience in a Related Occupation: None
- State Licensing: Yes (Editor's Note: A few states require laboratories or technicians to be registered or certified.)

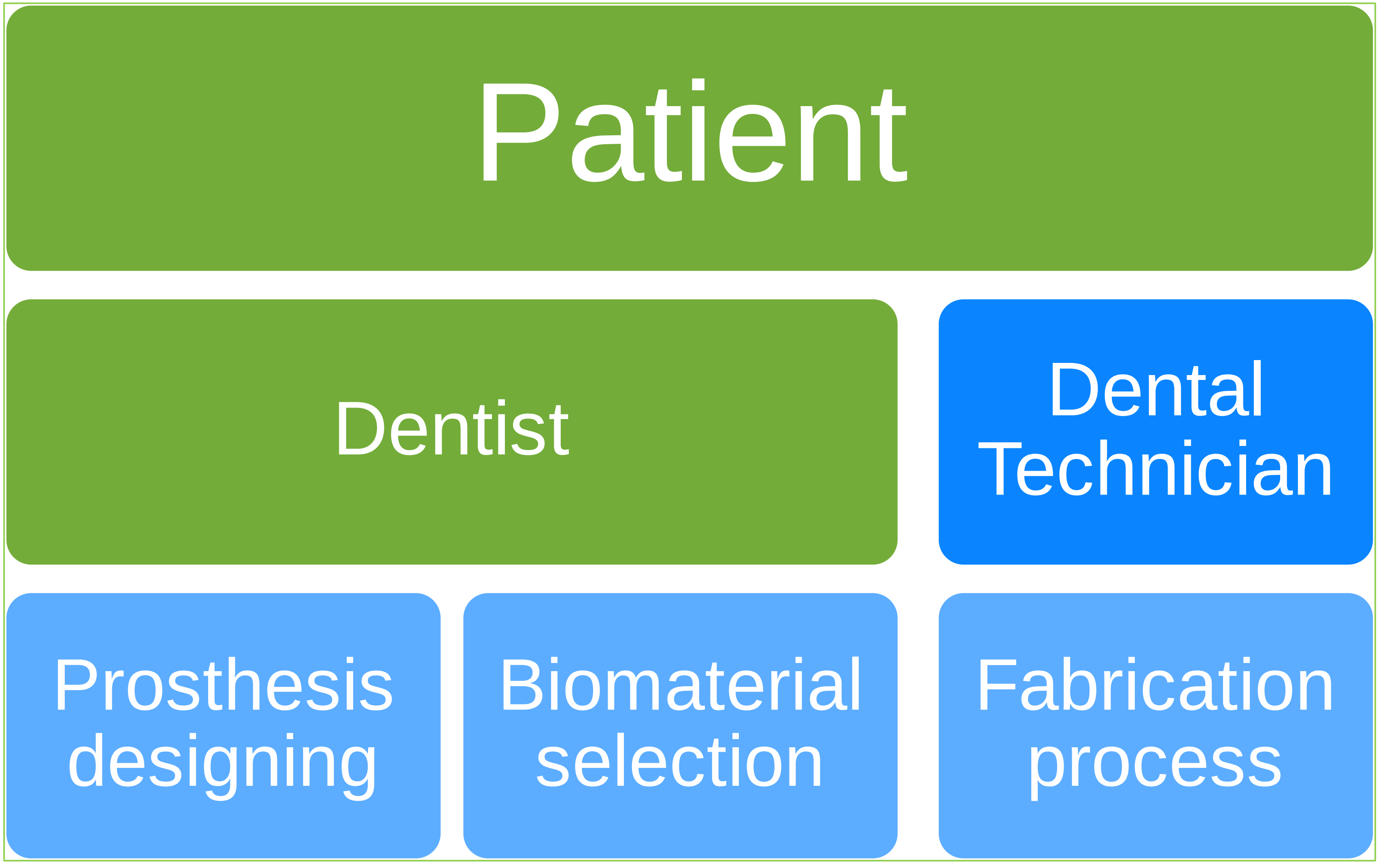


Rapid Developments combined with compressed learning curves of using

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

give rise to a new “bundle package industry”


Patient
Dentist
Dental Technician
Prosthesis designing
Biomaterial selection
Fabrication process


Patient
Dentist
Dental Technician
Prosthesis designing
Biomaterial selection
Fabrication process

Prefabricated blanks for customised implant abutments

ESSENTIAL:

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