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INDUSTRY-HOUSE FABRICATION

An article by Dipl.-Ing. (FH) Johannes Anders, Koblach/Austria

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Fabrication of titanium abutments in the Ceramill Motion 2 combines the economy of in-house with the quality of industrial manufacture

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Outsource or in-house manufacture, this is the ever recurring question. The question is certainly not easy to answer, as the decision for the one or the other version depends on many individual factors. The fact is that today a large number of materials and indications can be covered with flexible in-house systems. Dental engineer Johannes Anders presents the development of an indication in this article, with which in-house fabrication of customised titanium abutments is possible on the Ceramill Motion 2.

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Preface

The indication range covered by CAD/CAM systems has been continually increasing for many years. In addition to standard indications such as crowns, bridges and inlays this also includes, for example bite-raising appliances, diverse types of implant restorations and bars in the repertoire of many dental CAD/CAM providers, which can realise the fabrication process digitally from scanning and design to designing and fabrication. Further developments in the sector of computer-supported, dental fabrication processes are already apparent by the announcements of the industry.

To increase the value creation of the CAD/CAM production processes for the dental laboratories the trend is more towards so-called in-house fabrication. Thus, in addition to the diversity of indications, the amount of materials that can be processed with the aid of the CAD/CAM technology in dental laboratories increases using the processing machines installed in laboratories. Two different development approaches can be seen from the sides of industry: on the one hand new materials are being developed according to the requirements of CAD/CAM processing, on the other hand new types of processing procedures for existing materials such as titanium and titanium alloys are seen as a challenge and implemented. Processing systems for use in the dental laboratory, which already cover a large number of materials and indications and which can also guarantee to be future-proof, have proven ideal for use in the dental laboratory. This is because the view to upgradeability should never be lost because of possible new developments.

High demands are put on this type of unit with regard to flexibility, as its type of construction and machine concept must be designed to meet the different requirements.

Product idea

Implant restorations represent a growing proportion of the range of indications of a dental laboratory. At the present moment, only a few CAD/CAM solutions exist for the fabrication of customised abutments on in-house fabrication systems.

The existing machines are mainly limited to the fabrication of so-called hybrid abutments (prefabricated adhesive bars and customised, CAD/CAM fabricated abutments). As two units have to be fitted together hybrid abutments are, however, often regarded as problematic due to the limited space availability in the jaw.

This forces a compromise with vestibularly angled implants between the aesthetics and size of the adhesive surface required for the bond strength. The space necessary for the required tooth shape in such cases is often created by manual removal from the titanium base in the vestibular region and consequently a reduction of the essential adhesive surface. There are problems with space in particular with implant restorations, which consist of a total of three elements (crown, customised abutment and titanium adhesive base) and are also usually fitted with a veneer. This reduces the already low space availability to an even greater extent. In addition to aspects relevant to the design, it is also important to keep in mind the costs for an implant restoration. Milling of one-piece, customised titanium abutments with integrated connection geometry is one solution with which the prosthetic components required for implant prosthetic reconstruction and also the associated costs could be reduced. Diverse milling centres have these types of abutment in their product portfolio. A negative aspect for the laboratory is the additional costs, which are incurred for the external manufacture. This reduces the value creation of this type of restoration.

It is therefore the wish of many laboratories to be able to reproduce this process with their in-house machines. The precision requirements which are placed on the connection geometries to the implant have proven problematic with in-house fabrication. Reproducible fabrication of such geometries is not currently possible on desktop machines taking into consideration warranty claims and the necessary design parameters. The minimum requirement for correct fabrication of the respective implant connection is the use of special instruments such as shank cutters or end-cutting drills. It should be taken into consideration thereby that the absolutely necessary quality control and quality assurance of the in-house fabricated unit must be ensured by the dental laboratory. To minimise the risk of errors factors such as instrument wear, incorrectly calibrated machines or control gauges are subjected to continuous checks. The biggest possible warranty risk for a laboratory, which completely fabricates in-house customised abutments including the connection geometry, is in certain circumstances the explantation of a damaged implant due to an incorrectly fabricated connection geometry.

Recently, so-called Preform blanks made from titanium have been supplied to allow fabrication of customised abutments with integrated connection geometry taking into consideration possible warranty claims. These are already available for diverse dental milling machines (for example: Datron M5 and M7, Röders RXD, Sauer Ultrasonic 20). The special characteristic of these cylindrical blanks is that they are a type of hybrid workpiece or blank, which already has a preformed implant connection geometry on the one side and a customisable section on the other side. The milling machine can mill out the customised part of the abutment, which has been designed in the CAD software, from the millable section of the blank. The result is a customised abutment with an integrated, highly precise prefabricated connection geometry at the implant interface that corresponds to the manufacturer's specifications (Fig. 1).

Problem

Processing titanium preformed blank places increased demands on the milling machine and its components. This applies in particular for purely desktop milling machines, for

01 Ceramill Ti-Form blank with prefabricated implant geometry – a so-called Preform blank – for the fabrication of customised titanium abutments

02 Incorrect placement of blanks with prefabricated connection geometries in the processing machine can result, among other things, in errors in angles between the implant connection and the customised abutment

example the Ceramill Motion 2, which is why a milling process had to be developed with milling results that correspond at least to those of large milling machines and that should not be inferior in this technique in any way.
The economic aspect was also decisive, thus the milling and down times had to be taken into consideration.
Another challenge is the considerably higher loading during metal and titanium processing than is the case when processing relatively soft materials such as presintered zircon oxide, waxes or PMMA.
The custom abutment design to be milled must also be in the correct position in relation to the prefabricated connection geometry. The blank must be able to be placed reproducibly and in the correct position to guarantee this.

The following properties of the machine parameters and components must be more closely considered for metal processing:

- Stability of the axis system (torsional rigidity)
- Performance of the axis system (feed rate, torque)
- Spindle performance (torque and rotational speed)
- Cooling system
- Instruments

In addition, it should also be taken into consideration that with inaccurate placement of the Preform blank in the milling machine the customised abutment to be milled from the blank would not be in the correct alignment to the implant connection. Excessive deviation of the position of an abutment Preform blank in a milling machine can result in several problems:

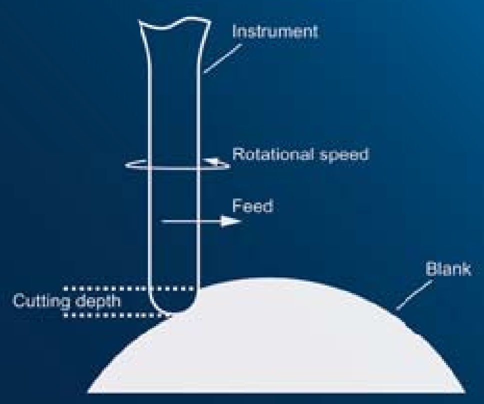
- Incorrect abutment height
- Incorrect abutment diameter
- Incorrect position of the angle between the implant connection geometry and the milled custom abutment along its symmetry axis' (Fig. 2)
- Damage of the preformed connection geometry

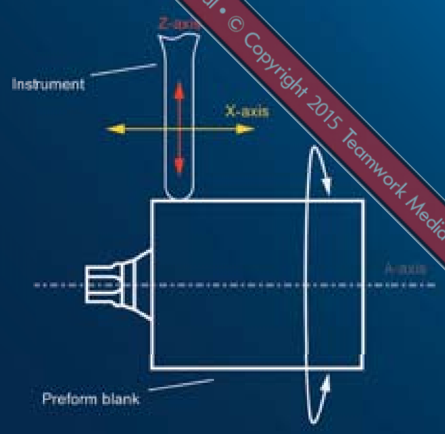
Technological details

On the one hand the basic metal processing and on the other hand the exact positioning of the blank in the in-house milling machine were therefore set as the main requirements in the development of a manufacturing process for titanium Preform blanks.

Metal processing

Apart from other instrument geometric parameters, the cutting force is a relevant factor for the machining milling process, which is produced between the instrument cutting edge and material. Thereby, penetration and removal is only possible by forming an adequately large pressure for each instrument cutting edge on the material. If this pressure is too low for the respective material, there is no material removal in certain circumstances. If it is too high, it can result in increased instrument wear. A considerably higher pressure between the instrument and blank surface is required for milling dense metals than, for example for milling presintered zircon oxide.
To achieve the required cutting force for the processing of metals the rotational speed of the instrument, feed rate and cutting depth etc. must be coordinated with each other (Fig. 3). The ideal rotational speed and cutting speed of the special titanium instrument are already prescribed to a large extent by the recommended guideline values.
Only the feed rate and cutting depth can therefore be varied. In the broadest sense the speed of the rotating instrument in the material to be processed represents the feed





03 Milling of a material generally depends on the rotational speed, cutting depth and the feed movement of the milling instrument on the blank. The feed rate can also be achieved by the movement of the blank

04 During rotational processing the stresses are distributed on two separately mounted axes. The instrument performs a uniform movement along its X-axis, the blank rotates around A-axis, which is mounted independently from it

rate. The cutting depth defines how deeply the instrument penetrates the blank and consequently also how large the volume to be removed is. The deeper the penetration of the instrument the more material can be removed with a constant feed. However, this increases the forces that occur and therefore also the loading between the instrument and the blank. The same applies for the increase of the feed. Although both result in an increased removal rate, they also cause a higher wear of the instruments. The latter is decisive for the cost-effectiveness of the milling process in dental laboratories. It is always important to achieve an ideal relationship between cost-effectiveness and efficiency.

The two parameters are closely related with the axis system of the manufacturing equipment. Both the torque of the axis and spindle motors and also the rigidity of the system are important in compensating for the forces and loading that arise. Machine, blank and instrument form a complete system, which could start to vibrate. Depending on the rigidity of the machine these vibrations can have an effect on the surface quality and service life of the blank. A milling machine basically operates more stable the fewer acceleration movements and load change and consequently the resulting vibrations per axis that occur. This stability is particularly important for the metal processing, as the cutting force is comparatively high and must be kept constant with each positional change of the instrument. And, the more individual the shape to be fabricate, the more movements must be completed by the axis and the more decisive the dynamic stability of the system components.

How the movements of the axis are in relation to the positioning of the instrument depends on the design of the machine. With the majority of manufacturing equipment both the spindle and blank holder have independent axis drive elements.

The movement of the instrument in its required position on the component can therefore be performed by the instrument or blank. With a view to the rigidity of the machine, in particular to that of purely desktop machines, the ideal processing version is rotational milling, which enables such an axis system.

In rotational milling the blank executes a constant rotational movement around its central axis while the instrument mills the blank laterally. This rotary processing counteracts the unfavourable vibration behaviour and the respective, negative results and also leads to above-average surface quality. Thereby only two axes are essentially required for material removal – one for the rotation of the blank and one for the lateral movement of the instrument parallel to the rotation axis.

The excursion paths that result in vibrations and therefore the kinetic energy produced are thus distributed to both drive elements. As the implant connection geometry is exactly on the central axis of the cylindrical blank due to the shape of the Preform blank, this processing technique can be considered for the fabrication of customised abutments.

One advantage of this technique with regard to the machine loading is among other aspects in the distribution of the required cutting force to two independently mounted axes: the cutting movement is completed by moving the cutting instrument along the X-axis. The rotation of the blank around the A-axis is the feed movement.

The other axes are only subjected to slight changes in acceleration (Fig. 4).

The processability of titanium Preform blanks is also considerably favoured in as much as, similar to glass ceramic blocks, they are designed for only one abutment and not for multi-use.

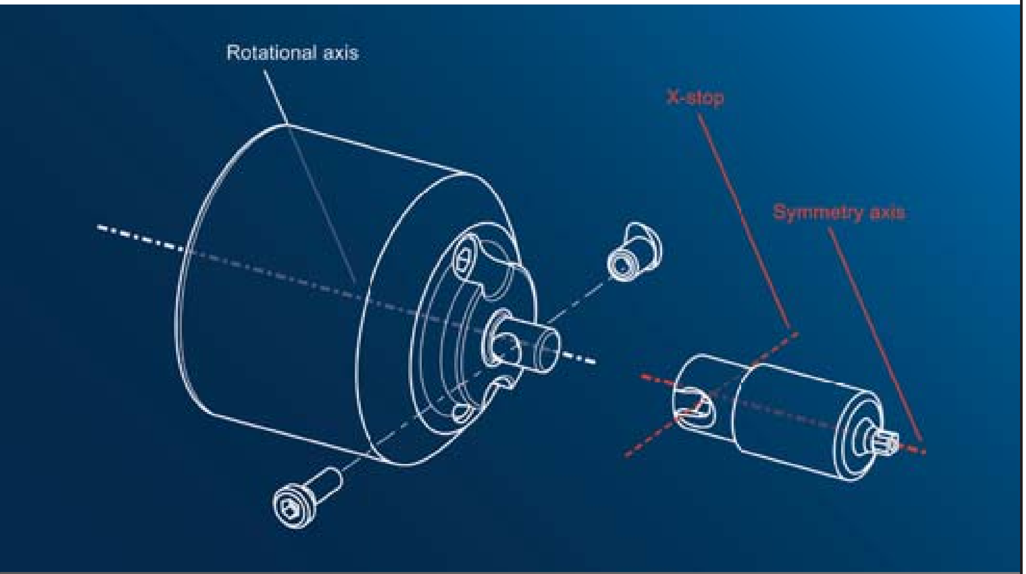
05 Ceramill Ti-Form instrument holder with calibration sleeve in the Ceramill Motion 2. The shape of this is custom milled to define the blank zero point in the machine

06 After the calibration procedure, the blank holder can be placed on the calibration sleeve and both screwed together. The blank zero point now corresponds exactly to the blank axis (the screw channel of the cylindrical blank)

It is therefore possible to process the blank from the outside to the inside without having to leave residual material. This guarantees all-round good accessibility to the milling object and instrument with coolant lubricant. In addition, it also has a positive effect on the loading and consequently the wear behaviour of the instruments in that the direction of the force application (lateral or axial) on the instrument can be varied to a greater extent.

Positioning the blank

A Preform blank is correctly positioned, if it is aligned exactly to the cutting instrument and relative to the machine coordinate system. This is a big challenge, however, particularly for machines that do not have a blank zero point detection. Machines that have this technology are able to determine the exact position of a workpiece or blank and automatically perform the milling process at an exactly defined point in the blank. The majority of dental manufacturing equipment, also including the Ceramill Motion 2, are designed so that the milling out of crowns and bridges is not in direct relation to the blank, which is why the blank zero point detection is not implemented. For example, a crown is milled from a full blank without an exact, uniform transition to prefabricated sections having to be taken into account and produced. Deviations of the position of the blank in the blank holder therefore do not have an effect on the shape or precision of the crown. As a more exact transition of a preformed and freeform sections must be created during fabrication of customised abutments from Preform blanks it important to take into account the exact position of the blank. This is because the correct positioning of the customised abutment in relation to the prefabricated implant connection geometry is a decisive factor in the quality of the implant abutment.
An equally pragmatic and simple solution, with which the blank zero point can be defined, is the newly developed, so-called calibration milling of the blank holder. With calibration milling the machine mills the machine-side holder once for the chuck of the Preform blank using an appropriate milling programme (Fig. 5). This ensures that all Preform blanks secured in the machine are aligned exactly in relation to the machine zero point, so that the customised abutments can be processed in an exact relationship to the preformed connection geometries. With regard to the durability of a blank holder and in certain circumstances the deterioration of the blank position that occurs due to the effects of wear and tear, the blank holder was manufactured from appropriately resistant stainless steel with a high-chrome content. More precisely, a sectioned blank holder has been developed for this purpose.
This consists of an exchangeable calibration element made from aluminium and the actual blank holder made from stainless steel. Both components are initially not connected with one another and can only be assembled after calibration has been completed. The reason for this is the deliberate excess material on the calibration element. The two components can only be connected interlockingly once the excess has been milled off by machine using the calibration milling programme. This ensures that no “uncalibrated” blank holder is used that would



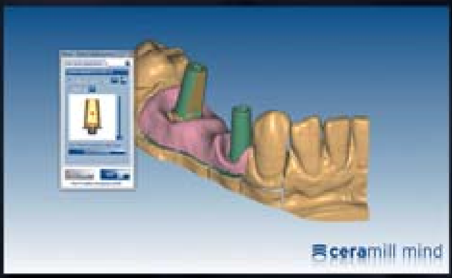
07 Schematic representation of the relevant coordinates and parameters for positioning the Preform blank on the blank holder. The symmetry axis of the blank must be aligned exactly to the rotational axis of the holder. Two precise countersunk screws ensure the central alignment on the rotational axis; the implant connection geometry remains untouched

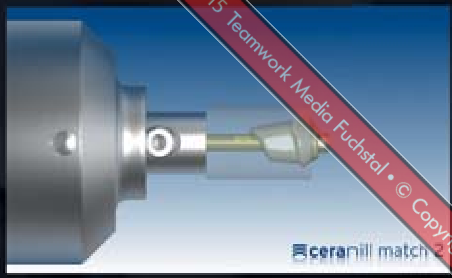
result in an incorrect milling result of the titanium abutment.

Ti-After connection of the holder elements (Fig. 6), the blank holder of the stainless steel element and therefore the Preform blank fixed to it are in exact relation to the zero point of the machine. In addition to the machine-side blank holder, the connector element on the blank itself must fulfil the requirements to allow exact positioning. For this reason it is necessary to minimise significant alignment errors, which could occur in relation to the rotation axis. These include:

- the coaxial offset, i.e. parallel displacement between the cylinder axis of the Preform blank and the rotating machine axis,
- the angle error, i.e. an angle between the cylinder axis of the Preform blank and rotation axis of the machine, and
- the so-called X stop for the exact height of the abutment to the connection geometry (Fig. 7).

Due to the precision and rotationally symmetrical design of the implant connection geometry on the Preform blank it would seem obvious to use this as a fixation and alignment element. Among other things this would prove advantageous, as after completion of the milling process this would stay connected with the milled abutment and there would therefore not be any connectors to the residual material. There would also be good accessibility to the occlusal abutment areas. However, there are also disadvantages with this, as the areas of the blank used for fixation would have to be able to compensate, without damage, for the lateral loading required for producing the cutting force that occurs during processing of the titanium preform. The delicate connection geometry is only suitable to a limited extent, as it is designed for compensation of the mainly axially occurring intraoral forces. It would also be a disadvantage that for every implant system the Preform blanks have different connection geometries, which must be taken into consideration with this type of fixation device. Different, customised blank holders are thus necessary on the machine side. As the connection geometry for the fixation of the Preform blank





08 To detect the position of the implants in the model the stored scanbody of the CAD software (orange) is oriented over the scanned scanbody (green)

09 The corresponding Preform blank is visualised in the CAD software as orientation aid for designing the abutment, as the position of the Preform blank in relation to the implant is already known at this point in time

10 The CAM software already automatically places the abutment at the correct position in the blank. The CAM software refers thereby to the implant position determined during alignment of the scanbody and compares this with the designed data of the abutment

has to be enclosed there would not be any accessibility of the blank by the cutting instrument in this case, so that the contour of the emergence profile would be impeded. This would finally lead to the situation that the emergence profile of the milled titanium abutments deviates from the profile designed in the CAD software for the optimum gingival contour.

Manual reworking, in which under certain circumstances the connection geometry could be damaged, would be absolutely essential. The decisive disadvantage, which fixation of the Preform blanks via the implant connection geometry would involve is, however, that the connection geometries could be damaged. In order to be able to fabricate a precise and durable connection to the implant, the connection geometry should remain untouched as far as possible before fitting in the patient's mouth.

Taking it into consideration that fixation of Preform blanks via their connection geometries can result in a variety of impairments, Amann Girrbach has developed a solution in which the Preform blank can be fixed on the top side of the cylinder, i.e. opposite the connection geometry. The emergence profile region is thus easily accessible, customised retention elements per type of abutment are not necessary and this also effectively prevents the effects of wear of the connection geometry. All these aspects speak in favour of this newly developed solution. Nevertheless, both possible positioning errors of the blank and also processing forces must be compensated for and an adequate torsional rigidity fulfilled with the fixation approach. For this reason the connection was designed especially solidly.

Exact centring to the rotation axis of the machine is achieved by bilateral screw retention of the blank, which prevents parallel displacement between the central axis of the blank (corresponds to the screw channel) and the rotation axis of the blank holder (see Fig. 11). The screw retention also sets an exact distance between the connection geometry of the Preform blank and the blank holder of the machine.

Possible errors in the height, diameter and angle of the custom fabricated abutment to the connection geometry can thus be excluded.

Manufacturing process

The development and provision of solutions, placed on Preform titanium processing to meet the technical requirements described, form the basic prerequisites for the in-house fabrication process of customised titanium abutments in CAD/CAM systems.

Technically, the CAD process that must be used initially to design the customised abutment should not be disregarded. Already at this stage the design of the implant abutment must be completed in the correct position to the implant. To exclude the possibility that the height and angle of the virtual abutment are positioned in the incorrect relationship to the implant, there are scanbodies with an appropriate connection geometry for every type of implant available. These are screwed together with

11 The Preform blank is screwed together with the blank holder of the machine and is thus both concentrically and axially aligned

12 Rotational milling of a titanium Preform blank in the Ceramill Motion 2 using coolant lubricant. The procedure is already completed after 20 to 30 minutes, depending on the size of the designed unit

the laboratory analogue of the respective patient model and scanned using a 3D scan process to obtain a digital image of the body. The digitised scan abutments in the Ceramill Mind design software are used for accurate determination of the implant and abutment positions.

To do this, their position is aligned by means of the virtual body saved in the CAD software (Fig. 8). Each scan abutment that is saved in the software is thereby assigned to a respective implant system. The position of the respective implant in the virtual jaw is determined and set by automatic alignment of this already saved scan geometry in relation to the scanned form of the patient case. The customised abutment is then designed on the basis of the calculated implant position. At the same time, this positional recognition is used to arrange the implant abutment already in the appropriate position in the Preform blank. This ensures that the abutment will be milled out of the Preform blank in the correct position by the milling machine later. Another advantage is that the blank can be visualised during designing, as the position of the Preform blank in relation to the implant is already known at this stage. This enables the dimensions and shapes of the customised implant abutment to be created to be designed also taking into consideration the available blank size (Fig. 9).

After completion of the design, the geometry acquired in this way is transferred to the production machine in the form of a milling file. The design is nested using the Ceramill Match 2 CAM software and positioned in the Preform blank for this purpose. As every implant system has its own connection geometries, there is a correspondingly large number of Preform blanks. The milling path calculation is completed automatically in the CAM software and is based on the Preform blank used for the design and the implant system selected. For this the customised abutment must also be positioned in the nesting in the correct relationship to the connection geometry of the Preform blank, as previously in the CAD software. To eliminate the risk of error in this positioning for the milling path calculation, automatic linking is necessary between the position of the custom-designed abutment to the respective Preform blank. The CAM software refers back to the implant position determined during alignment of the scanbody and matches this with the designed data of the abutment. This avoids manual alignment. The customised implant abutment to be milled is thus automatically in the correct position in the Preform blank (Fig. 10).

This reduces the amount of effort required for the operator in the CAD software for starting the milling path calculation. Individual, manual setting of milling parameters such as feed, cutting depth and speed is not necessary. The production machine is then equipped with the blank holder, Preforms blank and instruments, the milling programme is transferred and the milling process started (Fig. 11 and 12).

The milling process is carried out using coolant lubricant and is already complete after

13 An overview of the customised titanium abutments milled in the Ceramill Motion 2 in the rotational technique. As the blanks are not fixed in position via the precisely prefabricated implant connection geometry there is no impairment of the fit or even damage to be expected in this case

20 to 30 minutes depending on the size of the unit to be constructed.

Conclusion

Rotational processing of the abutment blank produces a high surface quality, which – particularly in the case of titanium – reduces unpopular reworking to a minimum. In addition, irritation of the soft tissue can be avoided due to the simplified polishability of the uniformly milled emergence profile. This also virtually excludes the risk of adjusting or even destroying the shape of the abutment, which was adapted to the oral situation previously in the CAD software. As a result a high-quality, customised titanium abutment is obtained with the highest degree of precision of the connection geometry, maximum surface quality and exact reproduction of the emergence profile and an abutment geometry that is true to the design. ▪

CAREER

Following completion of his training as a dental technician (Dentallabor Scheid, Zell an der Mosel, Germany), *Johannes Anders* decided to study dental technology at the University of Applied Sciences in Osnabrück, Germany, which he successfully completed in 2009. Still during his period of study he gained practice experience in implant research as a research assistant at the University of Otago in Dunedin, New Zealand, before he was employed at Amann Girrbach as product developer in the area of CAD/CAM. Today *Johannes Anders* is team leader for the development area scanning and CAM due to his comprehensive knowledge of practice and technology.