Thank you for taking the time to listen to the interim presentation of my master’s thesis: " Investigation of the Coloring Behavior of Zirconiumdioxide (ZrO2) Dental Ceramics by Ink-jet Printing of Metal-ionic Inks "

**1 Application**Only in Germany more than 1 M teeth are replaced annually.

And the most popular crown material is Zirconia which is a high strength ceramic with a translucency similar to the natural tooth, but zirconia in its pure form is plain white so coloring is necessary, dentist are using such a shade guide for a side by side comparison to determine the color and the shade of the teeth.

- you will see that there are 4 color groups A B C and D and each of these colors have 4 shades coded with the numbers from 1 to 4. Where 1 is the least and 4 is the most saturated shade for each color. Therefor a dental technician uses at least 16 ink shades to cover the whole spectrum.

**2SoA**

On the left side you can see a cutout of a lab card. Dentists mark different areas of the crown with different colors from the guide for the technologist.

And on the right side are the tasks of the dental technologist, which are mainly:

-Milling the crowns from a bulk cylinder with a CNC

-Manually coloring using a brush and dental inks

-furnacing to provide the structural strength and burn the color to the Zirconia

-and lastly polishing for a natural look.

The coloring part is the process, on which this thesis is focused

**3Drawbacks**

Currently there are some drawbacks to the state of the art.  
1 Coloring a single tooth takes about 5 min, so for multiple teeth a considerable amount of time is required

2 If the experience of the dental technologist is not satisfactory, color differences may appear between sequential teeth

3 The whole crown coloring process relies on some receipts and mostly on experience, so there is not clear how much ink is required per mm^3 to make the crown look A3.

4 Also the number of inks needed to acquire those shades is unnecessarily high.

This is what the crowns look like after the technician is done with the manual coloring process. One can observe how much effort is required.

**4 Assignment**

In frame of this thesis a process is to be developed for generation the dental color shades using an inkjet printer. Firstly the specs of the printing system, like drop volume or the max printing distance, are to be determined. Afterwards an adequate droplet generator is to be selected. With piezoelectric droplet generators, smaller and faster drops are possible but electromagnetic ones are cheaper. At last the generated shades are to be verified with the existing color standards

**5 Expected advantages**

The first expected advantage of this work, which has to be mentioned, is quantification of the coloring process followed by the printing process. Thus, the automated printing can be enabled.

Finding out the adequate drop volume provides us the needed information for selecting the droplet generator type early in the product development cycle.

Also, the whole spectrum of shades can be obtained with only 5 inks by halftone printing.

**6 Concept structural**

The structural concept is utilization of a 5-axis printing system. 4 base colors with the highest saturation (A,B,C and D4) are to be used with the brightener instead of 16 predefined shades. The amount of the brightener determines the shade of the color.

A 3-axis table and the 2-axis nozzle holder are responsible for the coordination during the printing process..

**7 Concept Process**

The procedural concept is realized in three stages. Each stage depends on the previous one and That’s the progress so far.

First stage is finding the ink and ceramic properties, such as ink viscosity and surface tension, ceramic void fraction and ink absorption time.

Second stage is determination of drop properties and deployment metrics, which consist of drop volume, nozzle escape velocity of the drops, the optimal distance between the nozzle and zirconia surface and the angle between the drop projectile and the surface.

The aspects to be considered under the third stage shade acquisition are trace distance (the distance between two sequential lines on the printed surface), proximity effect, which refers to how the proximity of two colored areas affect the shade of the uncolored area in between and finally the dependency of the shade on the brightener ratio

**8 Claim**

The project is the first automated printing approach in dental coloring and also the first time the shades are generated with the base colors and a diluter

**9 Experimental equipment**

Before we move on to the experiments I want to show you the 5 axis printing system provided by Bredent for cuntuction of the experiments. It utilizes a single nozzle printhead and a piezoelectric valve to generate the droplets. Ink selection, positioning and drop generation commands are given in with G-Code.

**10 Exp1**

In the first experiment, the properties of the coloring agents A1, A2 and A3.5 are determined and compared to those of water. This comparison is conducted because the manufacturer claims that all of the inks have identical properties with water. The inks have a similar density to water, but with increasing coloring agent the surface tension gets lower and the viscosity gets 3 times higher in comparison to water.

Also, a porosity measurement for the zirconia is conducted, which revealed a 43 percent void fraction.

**10 Exp 2**

The absorption time for a single drop was measured at different temperatures ranging from 20 to 80 degrees Celsius on milled and sawn zirconia surfaces. Curves are fitted to data points for the milled and sawn surfaces, which are represented with the blue and red respectively. The result shows that the absorption time decreases with increasing temperature for both surfaces.

**10 Exp 3**

The purpose of the third experiment is deciding the optimum drop size. In this figure you can see a printed zirconia specimen. Each spot on the top half has a total ink volume of 800 nL and the ones on the bottom half 400 nL These spots are printed using drops with volumes of 100, 50, 25 and 12.5 nL.

The first image shows the spots right after printing. The one in the middle shows the surface after furnacing. The third image is the overlap of the first two images, where we can observe the spreading of the ink due to the furnacing.  
 A larger drop size results in shorter print duration. However larger drops tend to expand the spot area more compared to the smaller drops.

The graphs show the ink intensity along the red lines and the spreading of the ink in lateral direction for each drop volume. 12.5 and 25 nL drops result in a similar spot diameter but the spots tend to get significantly larger with 50 nL and 1000 nL Drops.

**11 Summary**

In summary the general inkjet printing concept is proven to be possible. Here you can see 4 shades generated on the zirconia specimen. 25nL is the largest volume which doesn’t have a negative impact on the resolution.

It is also revealed that the ink properties differ significantly from the properties of pure water in contrast to the manufacturers claim.

**12 Outlook**

There is still a lot to be done in frame of the thesis. The optimum nozzle velocity, maximum allowed distance and impingement angle are to be found out in order to generate proper drops. But most importantly a model for the shade composition over the entire zirconia surface has to be accomplished , regarding the trace distance, proximity effect and brightener ratio.

**13 Printing process**As an extra I want to show you the printing process.

Thank you for listening.