
Nanomaterials in Dental Materials

Position Paper of the Dental Industry

1. Summary

Rule 19 of the new Medical Device Regulation¹ defines the classification of medical devices that contain nanomaterials or consist of such materials. The key parameter for defining the (risk) class, from which the extent of the conformity assessment process depends, is according to this rule the “potential for internal exposure” of nanomaterials.

The present Position Paper deals with the question how to classify a "potential for internal exposure" emanating from dental materials. Based on scientific studies and other relevant sources four scenarios were examined and evaluated:

- *Dental materials, which are placed into patient's mouth in paste form* such as filling materials, dentin adhesives, luting cements, impression materials, temporary crowns and bridge materials. No significant exposure to nanoparticles can be expected from pastes, and due to the very short contact time (the pastes harden within a few minutes or even faster) the potential for internal exposure is to be rated as negligible.
- *Dental materials in a set (hardened) state*: SCENIHR² has stated that for these products no or only a negligible amount of nanoparticles is released
- *Exposure of nanoparticles as dusts, which may emerge from the intra-oral processing of dental materials*: Based on worst case calculations the potential for internal exposure to nanodust can be regarded as negligible both for patients and professionals.
- *Exposure to nanoparticles by intra-oral wear of dental materials in the patient's mouth*: Based on worst case calculations the potential for internal exposure to nanoparticles produced by the wear of dental materials can be regarded as negligible for patients.

Consequently, in all cases studied the potential for internal exposure is negligible. Therefore, dental medical devices evaluated in this paper should be classified in Class IIa in accordance with Rule 19.

2. Medical Device Regulation - MDR¹ – Specific stipulations

Medical Devices are categorized into risk classes as e.g. stated by MDR recital no. 58 “The classification rules, which are based on the vulnerability of the human body, should take into account the potential risks associated with the technical design and manufacture of the devices.” The Medical Device Regulation¹ establishes four risk classes: class I (low risk), class IIa (medium risk), class IIb (medium to high risk) and class III (high risk).

The classification rule 19 states:

“All devices incorporating or consisting of nanomaterial are classified as:
 - class III if they present a high or medium potential for internal exposure;
 - class IIb if they present a low potential for internal exposure; and
 - class IIa if they present a negligible potential for internal exposure”

In other words, according to the MDR legislation, medical devices containing nanomaterials possess at least a medium risk (at least class IIa), a low risk is in principle excluded. According to rule 19 the classification depends on the potential for internal exposure, described as negligible, low, medium and high.

This present Position Paper outlines FIDE’s (Federation of the European Dental Industry) rationale regarding the application of this rule to dental materials.

3. Internal Exposure

Although the “potential for internal exposure” is one of the key parameters for the determination of the risk class, there is no further definition or description of this term within the MDR¹. Furthermore, there is no explanation of the characteristics “high, medium, low and negligible” describing this potential exposure.

The same terms can be found in the SCENIHR Opinion regarding the potential health effects of nanomaterials². Unfortunately, the SCENIHR Opinion also does not contain definitions for the terms used. However, these terms are used in Table 3 (of the Opinion), where an estimation of the potential external and internal exposure as a starting point for a risk evaluation for medical devices containing nanomaterials is proposed. The authors of the Opinion recommend using this table for risk management. The final classification of the internal exposure has to be discussed case by case.

The inhalation exposure is defined by ECHA³ to reflect the airborne concentration that is available in the breathing zone. Generally, the exposure could be regarded based on this definition as the available substance for uptake via the relevant route (inhalation, dermal, oral). The internal exposure would be based on the dose of a substance that is actually taken up by the body and which does not only have an (external) contact to the body.

As defined by rule 19 only the potential for internal exposure shall be regarded for classification, without considering the risk related to this exposure.

4. Exposure of users, patients and third parties to nanomaterials from dental materials

The potential for exposure is depending on a) the amount/quantity of the nanomaterial in question and b) the duration of potential contact.

Both the SCENIHR Opinion² and a recent publication⁴ mentions internal exposure from dental products in connection with pastes and cured products during intraoral processing as well as by abrasion.

4.1 Exposure from pastes

Many dental materials (filling materials, dentin adhesives, luting cements, impression materials temporary crown and bridge materials, ...) are placed in the patient’s mouth in a paste form where hardening of these materials occurs (either by self-curing after mixing of the two components by the dentist before placement in the patient’s mouth or by light curing). The SCENIHR Opinion² mentions that nanomaterials in paste-like formulations must be regarded as “free nanomaterials”.

This statement is misleading. It gives the impression that nanoparticles in dental pastes can easily escape from the surface. In reality, movement of particles in dental pastes is limited on the one hand

by the viscosity of the liquid phase and on the other hand by a phenomenon called “capillary transverse pressure”^{4,5,6}. This pressure exists between liquids and opposing solid surfaces that are wetted by the liquid and also where the solid surfaces are at a distance of some micrometers. The pressure is directed to keep opposing walls or particles in a liquid at an equilibrium distance. This distance depends on interfacial properties of the materials involved and on their size and shape. This means that above the equilibrium distance, attractive forces exist and below the equilibrium distance repulsive forces exist. A typical example of particles in a liquid kept at equilibrium distances is a suspension, in which particles are kept at a constant distance and floating against gravity.

Calculations⁷ show that equilibrium distances and pressures between particles are higher when the particles are smaller. It has also been shown⁵ that the capillary transverse pressure keeps wetted particles away from the surface of a paste-like material. This means that nanoparticles in dental pastes are not available on the surface. They can only reach the surface at a relatively high pressure acting on the paste.

Based on these considerations no significant exposure to nanoparticles can be expected from pastes, and due to the very short contact time as paste-material with the patient (the pastes harden within a few minutes or even faster) the potential for internal exposure is to be rated as negligible.

4.2 Exposure from cured products

After implanting pastes such as filling or luting materials into the dental cavity, they cure from paste to a solid form. From this time onwards, the dental materials can be regarded as solid materials containing bound⁴/ embedded nanoparticles (see SCENIHR² Opinion, 3.5.1). In principle the cured products remain virtually unchanged during their lifetime. This represents the longest exposure period for the patient for dental materials. The SCENIHR Opinion states that for these products no or only a negligible amount of nanoparticles are released (see SCENIHR Opinion², Table 3). However, the cured material is subject to two further aspects that are regarded in the following sections.

4.3 Exposure during intra-oral processing

The literature^{2,4} mentions dental materials as products that can release nanoparticles by intra-oral processing during treatment (grinding, polishing). Therefore the potential inhalative exposure of dental professionals and patients by possibly released nanoparticles should be considered^{2,4,8}.

4.3.1 Qualitative considerations

Many publications regarded the release of nanoparticles during mechanical treatment of different technical materials. It could be demonstrated that by mechanical treatment (like cutting, drilling, sanding, abrasion testing) of different technical products no or no significant difference in nanoparticle-release can be found for products containing nanoparticles and similar products without such ingredients^{9,10,11,12}. Additionally, it could be demonstrated that for products incorporating nanomaterials practically no pristine nanoparticles are released, but the released nanoparticles are coated by matrix material^{9,11,13,14}.

Similar results could be shown for dental materials. During processing, no difference in nanoparticle release between nanoparticle-containing materials and materials free of nanoparticles could be found¹⁵. It could also be demonstrated that the original nanoparticles are embedded in the filling composite matrix^{15,16,17}. Beside these embedded nanoparticles, carbon-rich particles were found that probably originated from a thermal decomposition of the matrix^{15,17}.

The effect of water spray during processing is not fully clear, but the use of water spray and effective suction during grinding is recommended by specialists⁴. It can be expected that water spray will bind nanoparticles generated by these mechanical processes. However, it is not possible with the current measurement procedures to distinguish clearly between nanoparticles and nanodroplets of water^{9,15}.

4.3.2 Quantitative considerations for dental materials

In most publications (for example¹⁶), only the particles up to 100 nm or a few 100 nm are considered. However, there are two publications in which both fractions (both the nano- and microscale) are presented^{17,18}. The available data allow only a rough estimation of the order of magnitude of the exposure to nanoparticles. In one publication¹⁸ the size distribution by the number of particles is indicated for seven composite-materials for five fractions (1-100 nm up to > 5000 nm). Assuming that

- all nanoparticles of one fraction are spheres having the medium diameter of the fraction (arithmetic medium), and
- for the largest fraction as worst case the diameter is 5 μm

it can be calculated that the nanoparticle-fraction corresponds to a concentration of 0,0004 – 0,0013 wt% of the total dust.

According to Bradna¹⁷ the particle size distribution of the processing dust of three composites (two defined as nano-composites) and one unfilled resin (Sealer) are described as bimodal with one peak in the nano- and one peak in the micro-range. The particle size of the maximum is indicated in a table, the particle-concentration at maximum can be estimated from the graphs. Assuming that the ratio of peak heights is proportional to the ratio of peak surfaces, the concentration of the nanoparticle-fraction can be calculated (considering that all particles are spheres with the diameter of the peak maximum). Depending on the burr used for preparation and the material in question, a concentration of nanoparticles in the range of 0.00016 to 0.0040 wt% in the total dust can be estimated. These values are in the same order of magnitude as calculated from Van Landuyt's work¹⁸. The highest nanoparticle concentration in the (processing) dust is measured for a hybrid composite using a tungsten carbide burr, whereas the lowest concentration is measured for a nano-composite and the unfilled resin using a diamond burr.

For estimation of a worst-case exposure, it is considered that the processed filling material has a density of 2 g/cm³. The amount removed during processing corresponds to a surface area of 1 cm², and a height of 1 mm. In this case, the total amount of dust formed would be 200 000 μg . The nanoparticle-fraction of this dust is 8 μg (using the highest calculated w/w concentration). In their proposal, the German Agency on Workers Safety (BAuA)¹⁹ indicates a maximum acceptable nanodust concentration of 110 - 190 $\mu\text{g}/\text{m}^3$ over a working day of 8 hrs in the working environment. ISO 10993-17²⁰ indicates the air uptake during an 8hrs working day as 10 m³. Based on these considerations the daily acceptable intake would be in a range of 1100 - 1900 μg .

Those calculations are based on rough estimation and few data. Nevertheless, no significant exposure for patients would be expected, because a very conservative calculation of exposure was performed and the calculated margins of safety are in a range of 130 to 230.

Based on Bogdan et al.¹⁵ (grinding of a filling in a standardized environment: closed box, extracted tooth) it can be calculated that a maximum concentration of nanodust of 0.55 $\mu\text{g}/\text{m}^3$ is present in the surrounding atmosphere that could be inhaled by dental professionals. This is much lower (> 200 times less) than the proposed acceptable level of 110 to 190 $\mu\text{g}/\text{m}^3$ ¹⁹.

Similar calculation results are shown in recent publications⁴.

Based on this evaluation the potential for internal exposure to nanodust by processing of dental materials can be regarded as negligible both for patients and professionals.

4.4 Exposure by abrasion during use period

The abrasion of dental composite materials has been a topic of discussion. A survey of many clinical studies²¹ indicates a 245 μm height loss of restorations as the highest wear rate *in vivo* during 3 years. Similar or lower loss is indicated in a recent publication⁴. As a worst case, it is assumed that all 32 teeth of an adult person are filled with composite restorations. Based on a literature overview the number of occlusal contacts per jaw is indicated by most researchers to be below 20 (only a few publications indicate higher numbers of occlusal contacts)²². As a result, 40 contacts for all teeth are considered as a worst case, wherein the contacts represent an area. The length of occlusal glide was measured by *Hayasaki*²³ to be 2.8 mm. Based on this and considering as a worst case that the complete gliding surface is abraded to the maximum, it can be calculated that the total abraded volume in 3 years is about 123 mm^3 corresponding to an abrasion rate of about 250 $\mu\text{g}/\text{day}$.

A different approach for a worst-case evaluation is given by *Heintze*²⁴. Based on different *in-vivo* abrasion measurement procedures it is concluded that under worst-case conditions (all molars and premolars are restored with large fillings and a linear loss occurs over time) the maximum material loss is between 28.8 mm^3/year and 35.6 mm^3/year . For the calculation of a worst-case daily intake the higher value is used resulting in a total material loss of about 195 $\mu\text{g}/\text{day}$. This is in the same range as calculated based on the data above.

Using a different calculation approach in a recent publication⁴ a maximum potential intake of abraded particles in the range of 221 $\mu\text{g}/\text{day}$ is considered.

There is no qualitative or quantitative information available from the literature about the particles released by *in-vivo* abrasion of dental materials. However, there are some data available for non-dental composites.

*Vorbau et al.*¹³ could show that particles formed by abrasion of non-dental composite-materials are not pristine nanoparticles but nanoparticles embedded in the matrix. For non-dental composites such as technical coatings, based on the data presented by *Koponen et al.*¹² it can be calculated that the concentration of nanoparticles in the dust is in a range of 0.0004 % to 0.96 % (V/V or w/w) of the total dust.

Assuming that

- sanding is a process that is similar to abrasion in the mouth and
- the behavior of dental materials is comparable to the behavior of technical materials

it can be concluded that in the *in-vivo* abrasion of dental materials the nanoparticles will be embedded in the matrix and will be less than 1% of the total wear formed. Based on these assumptions it can be estimated that the amount of nanoparticles that can be ingested by patient due to wear is below 2,5 $\mu\text{g}/\text{day}$.

Compared to the nanoparticle intake from food – estimated for nano-SiO₂ to be in the range of 124 $\mu\text{g}/\text{day}$ ²⁵ or 400 $\mu\text{g}/\text{day}$ ⁴ – this intake can be regarded as negligible.

Abrasion of other dental products that are in the mouth in solid form (crowns, bridges, artificial teeth ...) is less well studied as for composite fillings. However, the order of magnitude is expected to be in the same range, so that the conclusion should be the same. In this context it is interesting to mention that the natural wear of enamel (e.g. by chewing) is about 40 $\mu\text{m}/\text{year}$ ²⁴.

Based on this evaluation the potential for internal exposure to nanoparticles produced by the wear of dental materials can be regarded as negligible for patients.

5. Classification proposal of dental materials according to Table 3 of SCENIHR Opinion

For typical dental materials the considerations above are applicable as shown in the table below:

Material	Potential for internal exposure to nanoparticles due to				Remarks
	application in paste form	presence as solid material in the mouth	grinding/ polishing during dental treatment	Abrasion during in-use period	
filling materials (e.g. composites)	X	X	X	X	
dental adhesives	X	X	-	-	No exposure, protected by the filling materials
liners/ bases	X	X	-	-	No exposure, protected by the filling materials
final crowns, bridges, inlays, onlays	-	X	X	X	insertion as solid
temporary crowns, bridges, inlays, onlays	X	X	X	X	
luting cements	X	X	-	-	No exposure, protected by crowns, bridges, onlay, inlay
artificial teeth	-	X	X	X	insertion as solid
Denture base materials	-	X	-	-	insertion as solid, not in contact with antagonists
impression materials	X	(X)	-	-	short contact (< 5 min) to the oral environment
Sealing materials including varnishes and lacquers	X	X	X	X	
Orthodontic brackets	-	X	-	-	insertion as solid, not in contact with antagonists

Note: for products sold as powder/liquid systems exposure of users by mixing should be regarded separately.

Based on the considerations above, the potential for internal exposure for these materials can be regarded as shown in the table below:

Product/Process	Expected potential for internal exposure	Explanation
Pastes during placement	negligible	absence of free nanoparticles on the surface
Solid/ cured materials	negligible	absence of free nanoparticles
Grinding/ polishing/ removing of fillings	negligible	procedure (use of water spray and high vacuum suction), the very low amount of released dust, low nanoparticle content in this dust, and limited process duration
<i>In-vivo</i> abrasion due to wear	negligible	low amount of nanoparticles that could be swallowed

However, a case by case evaluation of each individual product and its application is needed in the risk management.

6. Conclusions

The dental materials evaluated in this position paper show no or only negligible potential for internal exposure of patients or users to nanoparticles.

For a detailed risk evaluation the products must be regarded individually taking into account not only the exposure of patients and users to nanoparticles but also the potential hazards of the used and/or released nanoparticles based on their different chemical and physical characteristics.

7. References

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