The evolution of 3D printing materials for dental splint manufacture

LuxaPrint Ortho Comfort

LuxaPrint Ortho Comfort and the evolution of 3D printing materials

3D printing has become firmly established within the dental industry as a digital manufacturing technology. As well as the economic benefits, the ability to quickly and efficiently manufacture cast models and appliances is another good reason for using this method in day-to-day practice. One unique selling point of additive manufacturing over classic manufacturing technologies or subtractive manufacturing with CAD/CAM milling is that it creates only the specific component geometry (as well as any necessary support structures) that will actually be used, all without the use of any other shaping tools. This is significantly more resource-efficient and generally more sustainable than other methods[i]. Since 3D printing becomes more cost-effective the higher the component complexity and the lower the quantities produced, the dental industry is a prime candidate for the use of this technology and, with annual sales of roughly 4 billion dollars, it accounts for almost a third of the entire market for additive manufacturing[ii]. Almost every part manufactured is a unique specimen, and almost every surface has a high degree of complexity. After the manufacture of dental models for a range of indications, the production of splints is one of the key indications for dental 3D printing with polymer-based materials[iii].

Boosting efficiency with 3D printing systems

For the 3D printing of dental splints, patient dentition models are generally used in addition to check or further adapt the fit of the splints. This method is a relic of non-digital manufacturing and offers the dentist a high degree of certainty with regard to the finished appliance. This approach is becoming increasingly obsolete owing to the development of specialist 3D printing systems for the dental industry and validated workflows that ensure precision and reproducibility when it comes to the manufacture of the printed objects. The use of digital scanners and specialist design software like DentaMile connect, coupled with relevant experience on the part of the user, is already making it possible to manufacture dental splints with precision without the aid of a 3D-printed or conventionally produced cast model. This means the full patient treatment, from the dentition scan, splint design and manufacture using 3D printing right through to polishing and intra-oral insertion, can be completed in just over an hour. This time-saving use of the technology allows for treatment in just one sitting. While bringing significant added convenience for patients, this approach offers organisational and economic advantages for dental clinics too.

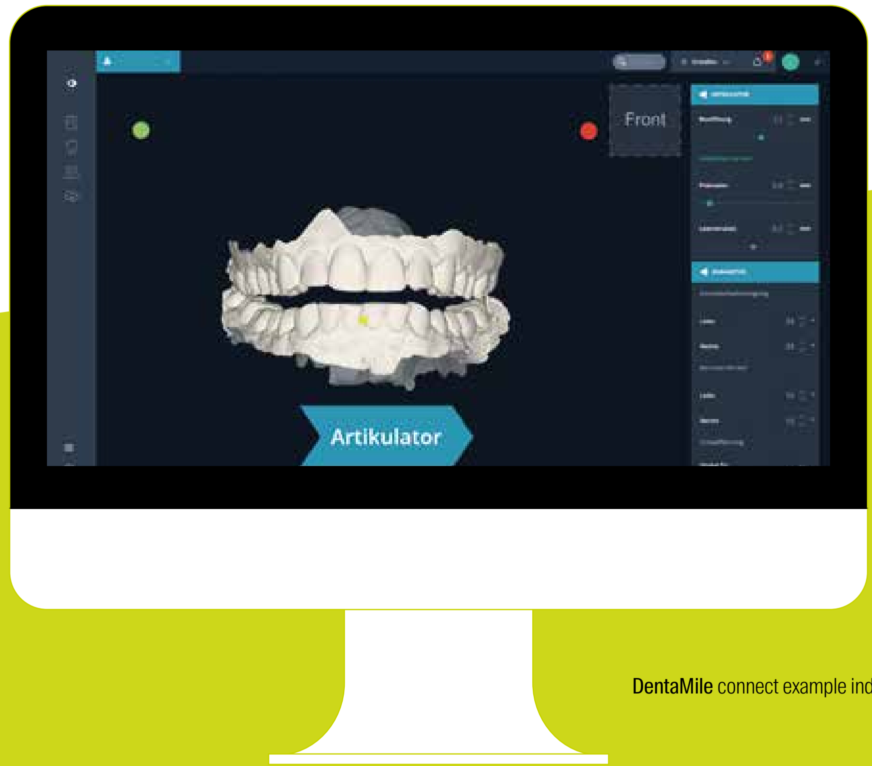
Advantages of modern 3D printing resins

3D printing resins for the manufacture of dental splints have been available for a number of years. The first generation of these materials produced hard and rigid bite splints used for bruxism (teeth grinding) or as retainers for use after orthodontic treatments. While they are well suited for a range of indications and meet all the regulatory and clinical requirements, they are brittle and therefore limited in their resistance to breakage. This means they may break on heavy impact, for example if they are dropped and hit a hard floor or the sink. The reason for this is the dramatically different chemical microstructure, which differs in particular from traditionally manufactured splints, or splints milled or vacuum-formed from thermoplastic materials. The latter may also be hard, but they enable greater expansion and are therefore tougher and more resistant to breakage than 3D-printed equivalents of the first-generation material.

The second generation of splint materials is characterised by flexible and, in some cases, elastic materials with different degrees of hardness. Depending on their characteristic profile, they are used as bleaching trays, splints for the indirect adhesion of brackets or else as sports mouthguards. The materials are resistant to breakage, but far too soft and in some cases not resistant enough for use as bite splints.

A third generation of 3D printing resins for the manufacture of dental splints is now available. These resins deliver splints that are hard but also slightly flexible and therefore fracture-resistant. The materials are resilient and their unique flexibility makes them especially comfortable for patients and thus ideally suited for use as a bite splint. This category of materials also includes DMG's recently developed LuxaPrint Ortho Comfort.

This article sheds light on the challenges faced in the development of splint materials and the advantages of LuxaPrint Ortho Comfort in comparison with other slightly flexible third-generation splint materials.



DentaMile connect example indication

LuxaPrint Ortho Comfort

After years of research into dental 3D printing resins, DMG has now developed a material for bite splints that combines all of the advantages of previously available splint materials. LuxaPrint Ortho Comfort can be used to manufacture colourless and transparent, slightly flexible, comfortable and above all fracture-resistant splints. The material's unique formulation is completely free from any colour pigments and offers excellent workability without any shaking or waiting, making the manufacture process even faster. Furthermore, DMG DentaMile ensures a smooth and validated workflow from splint design right through to post-processing, enabling patients to receive an accurate, biocompatible and comfortable appliance after every 3D printing process. The low dilution monomer content[1] in liquid resin guarantees the utmost safety and biocompatability in the printed objects and offers countless other benefits like excellent restoring forces and minimal temperature susceptibility, ensuring the splint retains its optimal elasticity and fit on every insertion into the mouth.

1 Dilution monomers are small reactive molecules that are added to 3D printing resins, normally in very small doses, to give them low viscosity so that they can be used for printing.

Transparency and colour

From the patient's perspective, it is very important for dental splints to be highly transparent and completely colourless. Ideally, these properties will make it difficult or impossible for people to tell that they are wearing an appliance, even up close. The more discreet, the better. However, this poses major challenges for material developers.

Absorption and colour

In the printing process, UV light is irradiated into the printing resin at wavelengths of 385 nm or 405 nm and absorbed by the resin, resulting in the curing of the material. As 405 nm is visible light, and 385 nm is very close to the visible range, the light appears blue in the 3D printer. This also means that the resin has to absorb some visible light in order to start the chemical curing reaction, which gives it a slightly yellowish colour. This is particularly unpopular with users because it distorts the natural colour of the teeth. In addition, many of the raw materials used in 3D printing already contain a slight yellow tinge. This can increase further during the wearing time of a splint due to weathering or other ageing processes.

One method adopted frequently by many manufacturers is the addition of blue dyes or pigments, which drown out the slightly yellow tint. The result is a blue tint that is better accepted by patients than the otherwise visible yellow, although a colourless splint is actually preferable.

LuxaPrint Ortho Comfort – pigment-free and discreet

However, colour pigments do have disadvantages. Pigments are actually small particles. When they are thoroughly mixed within the resin, they produce a colour tint and the individual particles cannot be seen. During storage, however, the particles sink to the bottom of the resin bottles – especially during longer storage periods. With that in mind, materials containing pigments must be mixed thoroughly before use. In most cases, shaking is enough, but for certain resins, additional equipment or mixers must be purchased to ensure a homogeneous distribution of the colour pigments. In any case, this approach is inefficient and time-consuming. Shaking and mixing will also introduce air bubbles into the resin, and the splints need to be free from bubbles during the printing process. This means that the materials usually have to rest for some time after shaking before they can be processed in the 3D printer. This prevents use without preparation time. In practice, splints cannot be printed spontaneously and the time required for a complete workflow increases significantly.

The pigment-free composition of LuxaPrint Ortho Comfort, on the other hand, does not require any shaking or any other preparation. The resin can be used immediately at any time, allowing for spontaneous printing in the dental clinic and splint production in just one sitting. Thanks to the use of high-quality resins and additives, the bite splints produced are completely colourless and transparent, as shown in Figure 1, and thus pleasantly discreet when worn.

Figure 1: Colour comparison between two splints. **Left:** LuxaPrint Ortho Comfort, **right:** flexible splint produced by another manufacturer

Fracture-resistance and monomer content

The evolution of splint materials, from the first brittle resins to the break-resistant, slightly flexible products available today, is attributable to intensive research on the part of material manufacturers, as well as the support of raw materials suppliers, who, with the increasing popularity of 3D printing technology, are offering more and more new raw materials with interesting property profiles. The properties crucial to obtaining fracture-resistant splints are high expansion and a balanced rigidity of materials.

High monomer content for high expansion – the easy way

One way of achieving high expansion is to use specific dilution monomers that bear a certain similarity to thermoplastic materials such as vacuum-formed splints after curing. One disadvantage of this class of substances is that even small amounts of unreacted molecules can cause an unpleasant smell and taste in the manufactured appliances. In the worst case, they can cause allergies or irritation but this is very unlikely if the processing specifications are adhered to strictly. This point shows why validation and adherence to specified manufacturing processes is so essential for safe and reliable medical devices.

In order to achieve the desired high degree of expansion and fracture strength, some splint materials contain large quantities of these dilution monomers. This makes the splints very unsuitable for permanent use. Another characteristic of high monomer content is high susceptibility to temperature fluctuations, and as a result materials that exhibit good properties at mouth temperatures of 37 °C are often very stiff at room temperature. It is therefore often recommended that the splints be heated before use to enable comfortable insertion. Other materials can also be used comfortably at room temperature, but are then too soft in the mouth to perform the desired functions. A high content of certain dilution monomers also means that while the splints are flexible and elastic, they lack the restoring forces to regain their original shape. If they are inserted several times or subjected to other forces, this can lead to an imprecise fit or the splint may fall out.

LuxaPrint Ortho Comfort from DMG uses very low amounts of monomer in the liquid resin and performs well when it comes to the issues described above. Extensive biological and chemical testing ensures that all printing processes validated by DMG deliver biocompatible and safe splints that are odourless and tasteless and exhibit excellent restoring forces, meaning that the splints retain their original shape and therefore an optimal fit even after frequent insertion or high impact such as bending or being dropped.

Figure 2 shows the elasticity (modulus of elasticity) of LuxaPrint Ortho Comfort and other slightly flexible splint materials available on the market at room temperature (left) and mouth temperature (right). This is where the advantage of LuxaPrint Ortho Comfort's low susceptibility to temperature comes into clear focus.

While material 2 exhibits a high degree of stiffness at room temperature and should therefore be heated before use, LuxaPrint Ortho Comfort is already sufficiently flexible to enable comfortable insertion. Once in the mouth, it then achieves optimal elasticity, similar to material 2. Material 3 is already flexible at room temperature, but becomes so soft in the mouth that it falls short of the required bite splint properties.

Due to its low monomer content, LuxaPrint Ortho Comfort not only ensures a particularly high level of safety – it is also odourless and tasteless, and provides optimal restoring forces and balanced stiffness for frequent and comfortable insertion and removal of the splint without impairing the fit.

Elastic modulus (elasticity) comparison

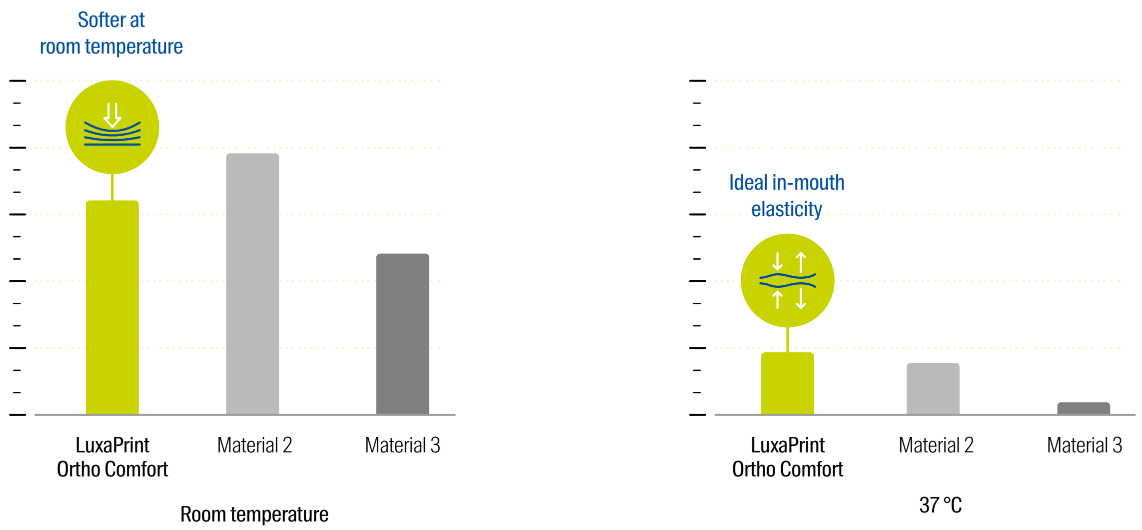


Figure 2: E-modulus (elasticity) of Luxaprint Ortho Comfort in comparison with other flexible splint materials at room temperature (left) and 37C (right)

Workflow

Like the instructions for conventional dental materials, the workflow for 3D printing resins is significantly influenced by the material properties. Only by taking this into account during development can a successful material with a seamless, indication-oriented workflow be created. For 3D printing resins, the workflow consists of the entire manufacturing process, i.e. print preparation, 3D printing, cleaning and post-curing, as well as all the necessary process steps that ultimately lead to a safe, stable, precision-fit and validated object. If materials are optimised exclusively with regard to their property profile, adding further process steps or waiting times to the workflow may be unavoidable when it comes to ensuring optimal component quality. This may include, for example, shaking, mixing or heating the materials, resting periods prior to the start of printing, waiting times after washing or drying the printed objects or further process steps after post-curing. Initially, this does not seem to be a major obstacle to the production of a high-quality dental appliance, but when it comes to cost-effectiveness or efficient production, these points can be a decisive factor.

LuxaPrint Ortho Comfort has been designed not just to achieve the best material properties but also to ensure a fast and user-friendly workflow, eliminating any waiting times or additional process steps. The production of a splint, from the intraoral scan to the insertion in the mouth, takes a little over an hour.

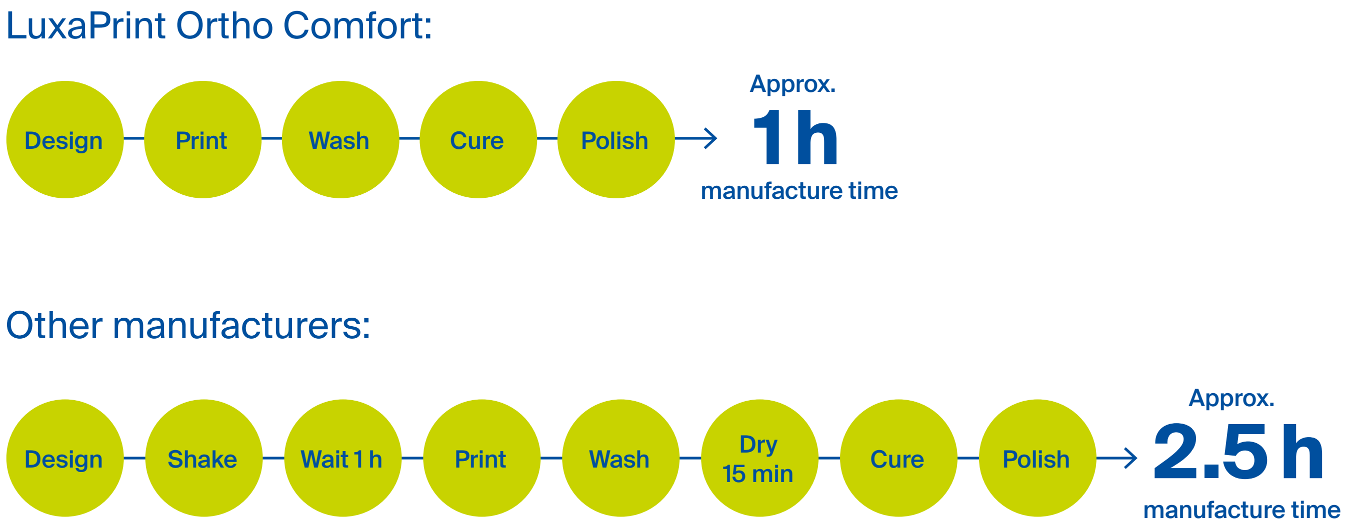


Figure 3: Workflow comparison of LuxaPrint Ortho Comfort and other comparable materials

Conclusion

The 3D printing of bite splints has now established itself as a reliable manufacturing process in the dental clinic. The latest generation of splint materials provides slightly flexible and fracture-resistant splints, offering advantages in terms of comfort and handling compared to the previous hard materials. With its innovative formulation, LuxaPrint Ortho Comfort from DMG is raising the bar within this material class. In addition to high transparency, excellent fracture stability and balanced flexibility, this material has been designed with a seamless, fast and validated manufacturing process in mind. This is the only way to exploit the full potential of dental splint 3D printing efficiently and economically.

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Kai Billerbeck studied chemistry at the University of Hamburg and has spent more than eight years in the Research and Development division at DMG. He has several years of experience in the development of 3D printing resins. A researcher in the Digital Application Centre (DAC), he specialises in process research and development for 3D printing workflows.

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