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Possible applications of reflected UV photography in forensic odontology: food for thought.

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Abstract:

Usually, in forensic sciences, ultraviolet (UV) light is used to induce fluorescence on many samples to identify and evaluate proofs (ex. fibers, gunshot residue, biologic fluids, pigments, inks and fingerprints) and different wavelength are used to better enhance the material characteristics. On the contrary, the potential use of absorbed and reflected UV has not been deeply investigated, especially in forensic odontology. The aim of this study is to evaluate the forensic potential of dental materials UV absorption and reflection and to investigate if different dental tissues and materials interact in different ways with UV radiation. A digital camera modified so to be UV sensible only and a modified flashlight were used to produce images of absorbed/reflected UV radiation of different dental materials. First results show the promising potentials of the technique in detecting dental composite resin materials, in enhancing image contrast between dentin and enamel, in enhancing enamel infractions and in possible age estimation future applications.

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Introduction.

The electromagnetic radiation is a radiant energy with wave-like properties that goes through space. The electromagnetic spectrum is divided in intervals, depending on the wavelength: γ-ray, X-ray, Ultra Violet (UV) radiation, visible light, Infra Red (IR) radiation, microwaves and radio waves.

The visible light, or white light, is the radiation wavelength interval perceivable by human eye; visible wavelength from blue/violet to red, range from 400 to 700 nm; therefore, limits of the visible spectrum are blue/violet and red; colors from blue/violet to red are characterized by increase of the wavelength and decrease of energy.

Radiations with a wavelength lower than the violet wavelength are UV: UV have a wavelength range from 10 to 400 nm; the region near to the visible spectrum (400-300nm) is defined near-UV. The region between 200 and 300nm is defined far-UV. The region in the electromagnetic spectrum below 200nm is called "vacuum UV region": the evaluation of this interval must be done in vacuum otherwise atmosphere would absorb almost all of the radiations.

When UV radiation interact with matter it can be absorbed, reflected and, due to the release of energy by the material, it can cause fluorescence of the material: an emission of light in the visible spectrum during the material exposition to UV radiation.

Forensic use of UV light refers to the use of a UV light source and a camera set to capture visible fluorescence caused by UV rays or set to capture UV reflection (visualization of non-visible findings in the UV range by special photography). Filters are essential: in fluorescence they can shield the sensor from rays coming from the source to highlight the material radiation. In reflection, filters allow only UVs to reach the sensor and shield other wavelengths. Another option, to avoid the use of filters in fluorescence photography, is to take pictures in a dark room with a light source emitting only UVs.

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Literature review

Literature review underlined the presence of papers regarding fluorescence properties and the lack of research on UV reflection and absorption properties. One of the first observation of teeth fluorescence was reported in 1928 [1]. Foreman in 1980 extracted from dentine two fluorophores and he studied their emission spectra [2]. In 1985, Krauss & Warlen [3] wrote a paper stating the utility of UV photography in several areas, from bite marks analysis to child-abuse documentation. They highlight the ease and cost-effectiveness of the technique. In 1994, David and Sobel [4] published a paper documenting the use of UV photography to picture an aged bite mark. The technique was useful to associate a rape suspect to the victim. In 1997, Carson et al. [5] analyzed several dental materials using an alternative light source (ALS). Results highlight ALS validity in restorative materials identification even on burned teeth. In 2002, Pretty et al. [6] used induced fluorescence on dental composite. Two sets of pictures of composite restored teeth underwent examination by ten forensic dentist; the first set was under visible light range, the second set was under 370nm wavelength illumination and QLF technique (Quantitative light induced fluorescence). The study showed how restored teeth were more recognizable in photos shoots with QLF if compared to the ones taken in visible light range. In 2003, Tani et al. investigated the differences between composite resin and teeth using fluorescence emission [7]. Lee et al in 2005 [8] used a color-measuring spectrophotometer to study the fluorescence of layered resin composites. They also noticed [9] that sealant application decrease fluorescence of resin composites. In 2006, the same authors [10] noticed the absence of resin composites fluorescence after accelerated material aging. "Ultraviolet Illumination as an Adjunctive Aid in Dental Inspection" was published in 2008 [11]. As restorative materials mimic the natural color of teeth and may be difficult to be detected, authors performed this study to quantify fluorescence properties of restorative materials. Restorative materials were analyzed at several wavelengths, between 445 and 480 nm, in order to assess which wavelength ensure highest fluorescence degree. In 2010 Wright and Golden [12] expanded photography to the whole electromagnetic spectrum as a useful tool in forensics analysis. Considering the behavior of electromagnetic radiation on human skin, it was possible to adjust the light to highlight a specific kind of lesion. This has been found useful in highlighting bite marks that cannot be seen in the visible spectrum. Meller and Klein in 2012 [13] provided reference for optimal fluorescence induction in commercial resin composites. In 2013 "Dental Fluorescence: potential forensics use" [14] evaluated the relation between age and teeth fluorescence. Authors highlighted how enamel and dentin fluorescence do not change between 7 and 20 years of age, then it decreases. Guzy in 2013 [15] successfully tested an ultraviolet light emitting diode flashlights in two forensic dental identification cases. The book "Alternate Light Source Imaging: Forensic Photography Techniques" [16] is a complete and practical manual to photography under different light sources. UV photography is discussed in its multiple purposes, with a description of practical protocols. Meller in 2015 [17] compared fluorescence qualities of different resin composites. In 2017, Kiran et al [18] compared the fluorescence properties of a variety of restorative materials using a fluorescence based digital single lens reflex (DSLR) camera. The same authors in 2019 [l9] compared digital imaging fiber optic transillumination and fluorescence-aided identification of restorations, stating that the last one in more reliable in identifying colored restorations.

The aim of this study is to evaluate the forensic potential of dental materials UV absorption and reflection and to investigate if different dental tissues and materials interact in different ways with UV radiation. Fluorescence properties are not taken into consideration.

Materials and methods.

UV absorption/reflection was tested: on 50 teeth in various condition (sound teeth, teeth with cavities and filed teeth) from a skeletal collection to evaluate enamel and dentin properties; on three indirect and five direct restorative composite resin materials, on four dental ceramics (porcelain), on a glass ionomer cement, on four acrylics used for dentures. As the purpose of this pilot study is to evaluate the possible future use of UV photography in forensic odontology, we tested just a few dental material samples. Future research will take into consideration various commercial brands for each material group.

Each sample was photographed in the visible spectrum with a Nikon D5000 reflex camera and in the UV spectrum using a Canon EOS modified camera. Pictures were taken, processed and evaluated by two dentists and an experienced forensic odontologist.

The interaction between materials and UV radiation was evaluated using a modified DSLR camera. DSLR are the type of cameras working at the best in different light condition, they offer many possibilities of settings customization, adapting them to different tasks. The sensor is often separated from the optic by a "hot mirror", a filter used to have a better quality for professional pictures allowing only wavelengths between 350 and 750 nm to pass through. Hence, to take shots in Infra-Red or UV spectrum it is necessary to remove the hot mirror. A camera without hot mirror is called "full spectrum camera". The digital camera used in this study (Canon EOS T4i modified by LDP LLC, Carlstadt, USA, www.maxmax.com) allows ultraviolet light only to pass through it; the color filter array has been removed and substituted with a specific filter sensitive just to ultraviolet radiation so that the UV sensibility becomes 6 times greater. The UV source used is a Canon Speedlite 600ex-rt flashlight converted to ultraviolet by LDP LLC.

Pictures from the UV camera have a purple aspect; therefore, in order to better appreciate the details, every photo was desaturated (Adobe® Photoshop® software) to a grey scale.

Results.

In the visible spectrum photography, an object appears white when it reflects all the wavelength radiation of the electromagnetic spectrum: enamel is white meanwhile dentin and cement are darker, that is because enamel reflects most of the wavelengths and dentin and cement absorb part them. The same happens in ultraviolet photography (fig.1), but in a more enhanced way: enamel is visible as white / light grey whereas dentine and cement have a similar, very dark grey shade: they absorb almost all the UV radiation. Therefore, Uv photography may be used as an aid to enhance the contrast between enamel and dentin as shown in fig.2 where abrasion signs are very easily detectable.

Fig. 3 shows the comparison between some dental materials in visible photography vs. UV photography. Dental indirect composite resins are in the first upper row (a): in UV spectrum both veneers are black, meaning that this material absorbs almost completely UV radiation. Examples “b” and “e” are made of dental ceramic (porcelain); they reflect almost all the visible and UV radiation and they appear much more lighter than the indirect composite resin ones. Last couple “d” is again a composite resin material: as for samples “a”, visible spectrum is mainly reflected while UV spectrum is almost completely absorbed. These comparisons show the potential use of reflected UV to detect and discriminate indirect composite resins from porcelain. Same results are obtained with acrylics used for dentures: they absorb the majority of the radiation (fig.4). Five different direct composite materials and a glass ionomer cement have also been tested. As seen in fig.5 all direct resin composite samples absorb UV radiation. A different interaction is observed with ionomer cement that reflect almost completely the UV radiation (fig.6).

Figures 1 to 6 show the UV interaction with some dental material samples and the possible future use in the forensic field to detect them in a simple and fast way. Differences in UV absorption may be explained by the different ratio between organic part of the material that absorb UV radiation and inorganic component that reflect radiation. A clear example of possible use in the forensic field is appreciable in fig. 7 where composite resin fillings become highly visible in the UV spectrum. The same happen in fig.8 where indirect composite resin bridges become evident in UV spectrum.

One last feature that may have a forensic potential, came to our attention: enamel UV reflection seems to decrease in older subjects as visible in Fig.9 where UV pictures are taken to subjects in their 30’s, 40’s, 50’s and 80’s. In the same figure, the second picture (subject in his 40’s) shows another unexpected characteristic of UV pictures: the clearly visible vertical enamel infractions on the upper central incisors are not easily detectable naked eye or with classical photography (fig.10).

Conclusions

First results from this pilot study show the promising future use of reflected UV photography in forensic odontology and the possible use of it by now in conjunction with classical and already tested techniques.

The post mortem examination of an unknown cadaver may be facilitated, as composite resin fillings are very easily detectable via UV photography. Furthermore, the technique does not need any specific skill, it is simple, fast and can be applied under any kind of illumination as the used camera is only UV sensible and it doesn’t need to be used in a dark room as visible light do not interact with it.

Pictures can be safely shoot at living persons too, expanding the possible applications, beyond composite resin and porcelain detection, to clinical or malpractice aspects of dentistry (e.g. enamel infractions are more easily detected).

Future studies are needed and should be focused on the specific different absorption (and its quantification) of UV radiation of various material of different brands so to try to detect the specific material via UV reflected photography. Further studies should be conducted as well to look for a possible correlation between the absorbed quantity of UV radiation by a tooth and the age of a subject.

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Figure captions **fig. 1** Dentin and cementum appear much more darker than enamel in UV photography (on the right). **fig.2** Dentin exposure pattern and roots are easily distinguished from enamel in UV pictures.

fig.3 Indirect composite resin and dental porcelain under visible spectrum (on the left) and under the UV spectrum (on the right). **fig.4** Acrylic used for dentures.

fig.5 Different composite resin materials interact in a similar way with UV radiation: UV spectrum absorption (in the lower row) is clearly detectable. a, b and c samples are different shades of 3M ESPE Filtek Z250 ; d and e are different shades of Enamel Plus HFO.

fig.6 Ionomer cement (Ketac) in UV picture (on the right) reflect the radiation.

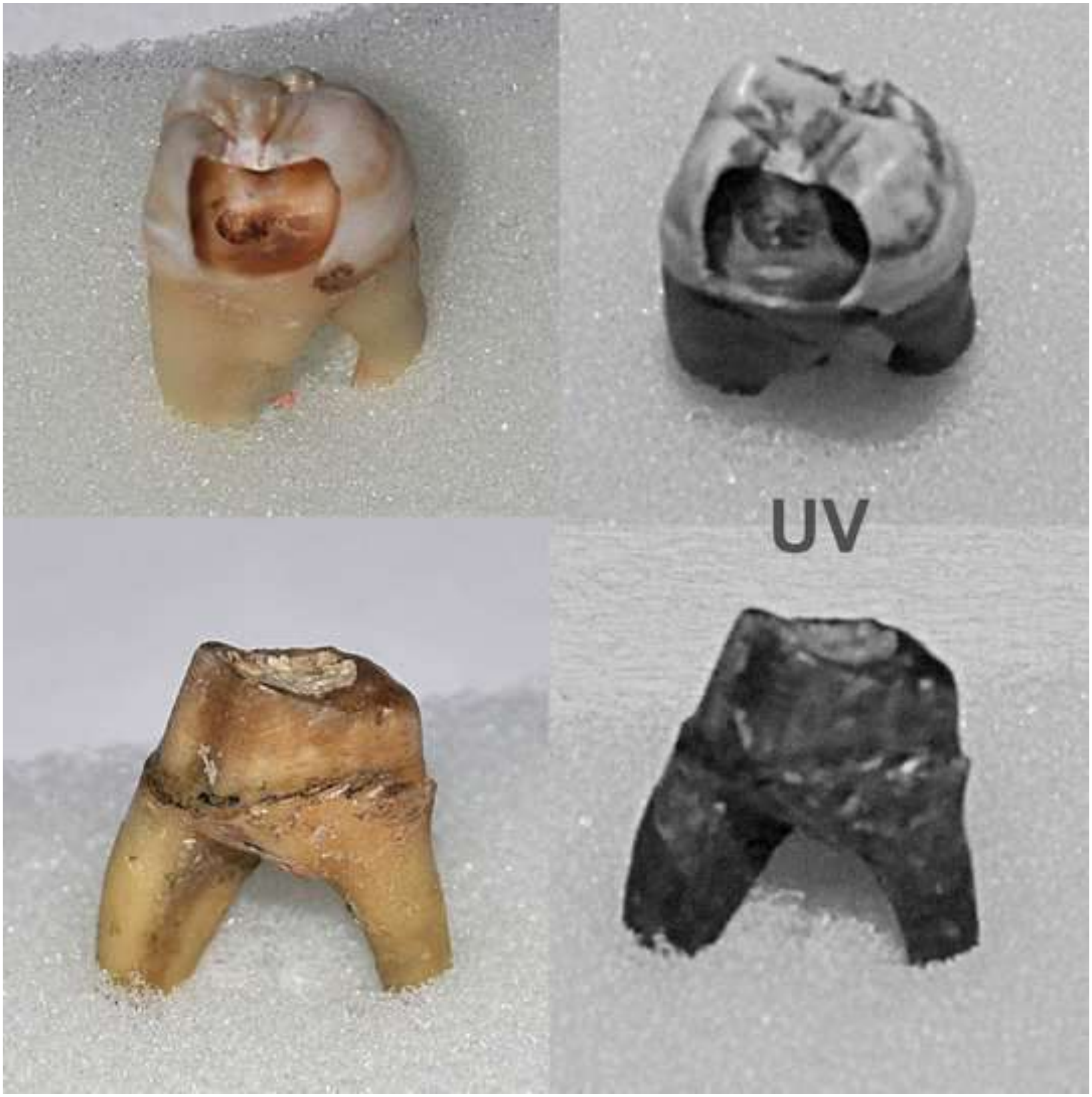
fig.7 UV photography (on the right) shows the presence of composite fillings not easy to be seen in the visible electromagnetic spectrum.

Fig.8 UV photography (on the right) shows the presence resin bridges.

Fig.9 Frontal teeth UV spectrum absorption in subjects at different ages.

Fig.10 Enamel vertical infractions in central upper incisors become easily detectable in the UV spectrum (on the right)

Figure



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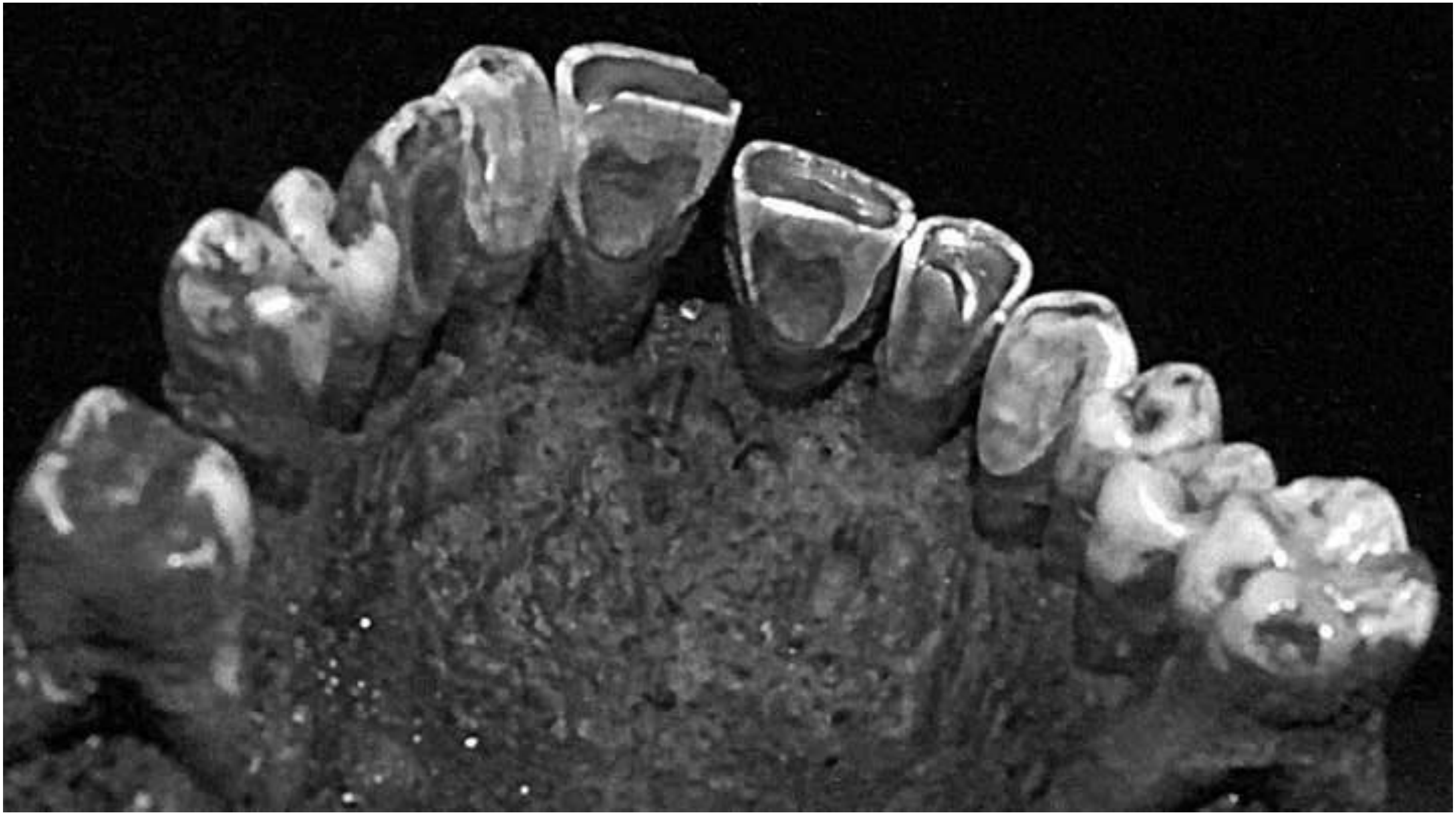

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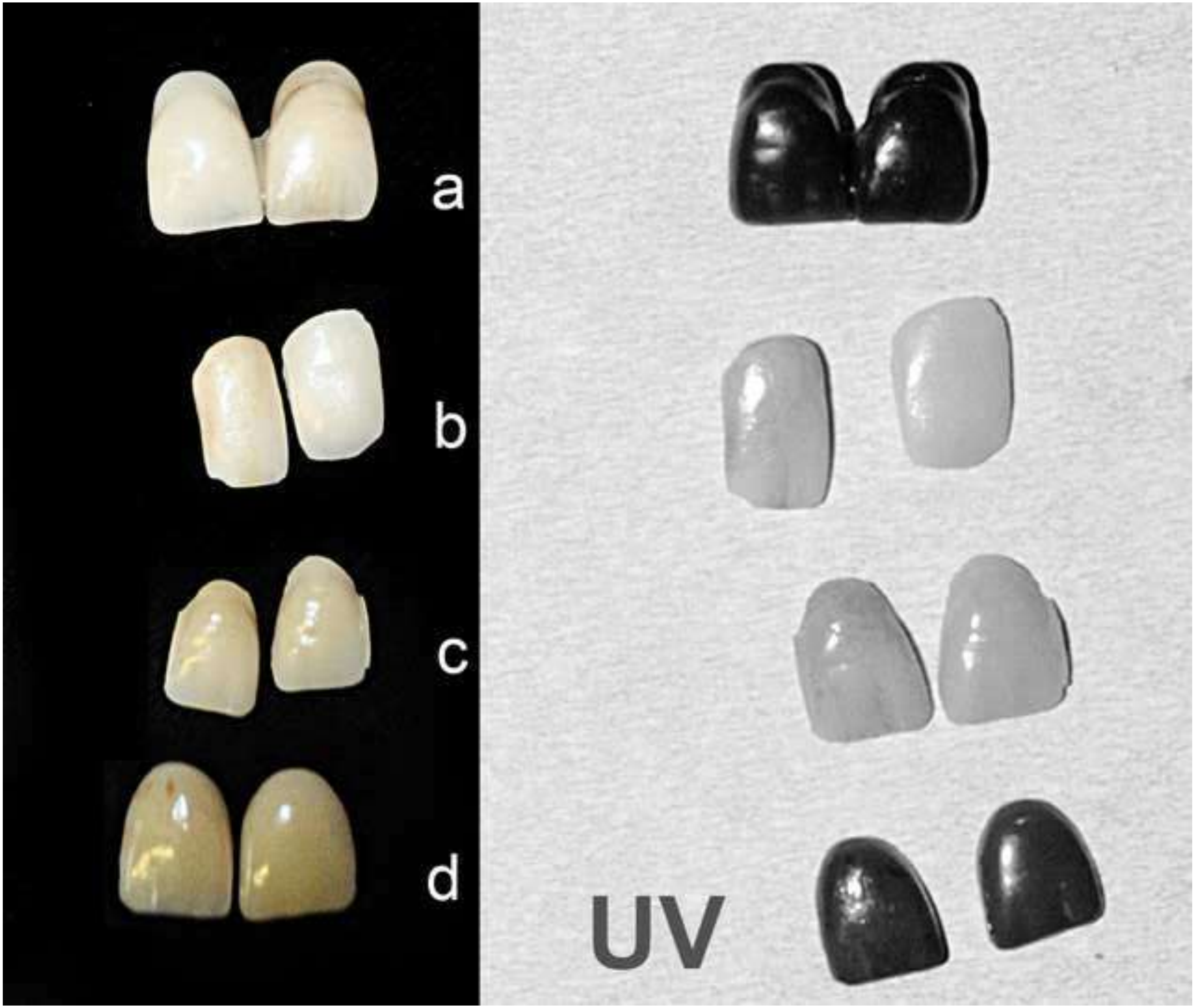

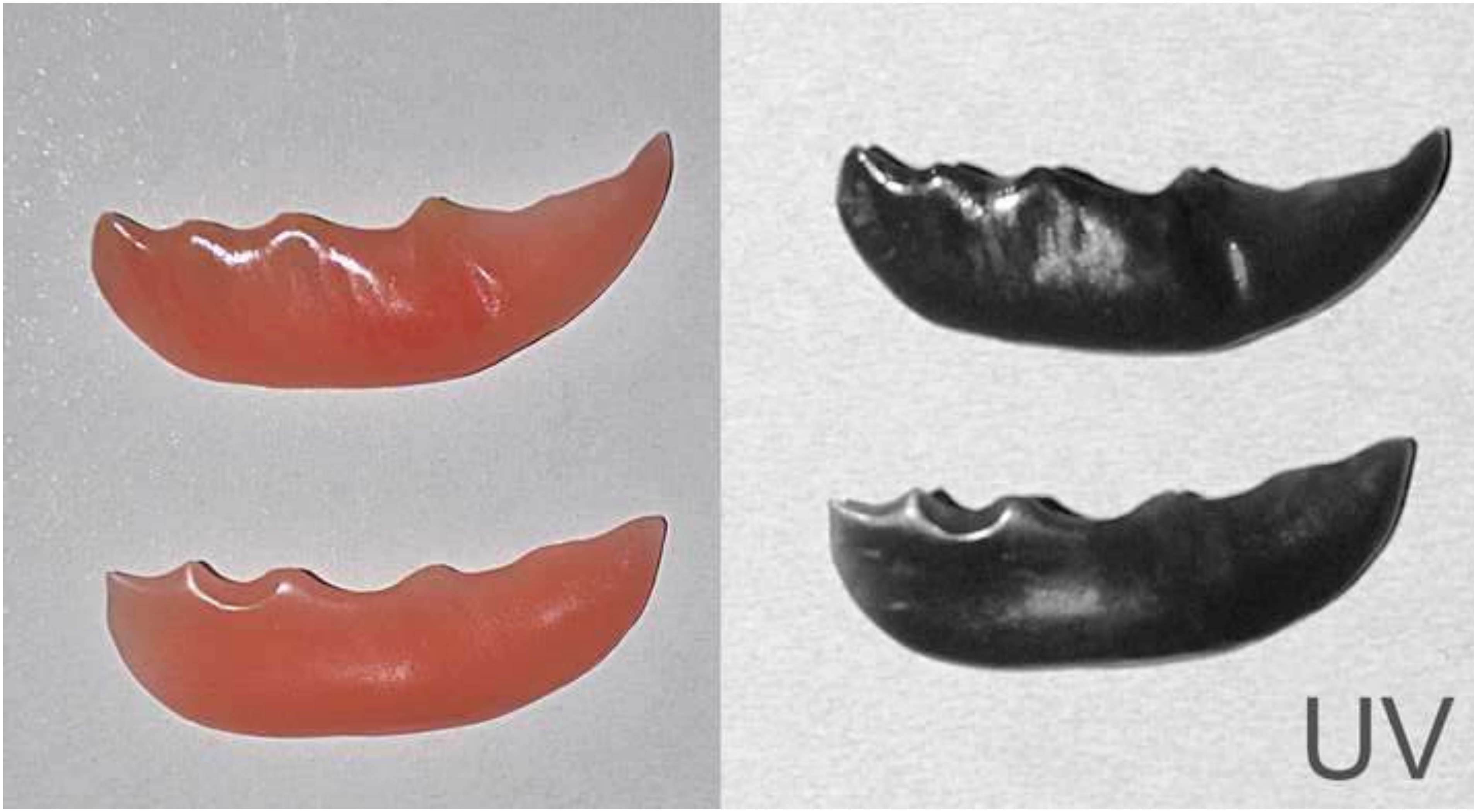
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Figure

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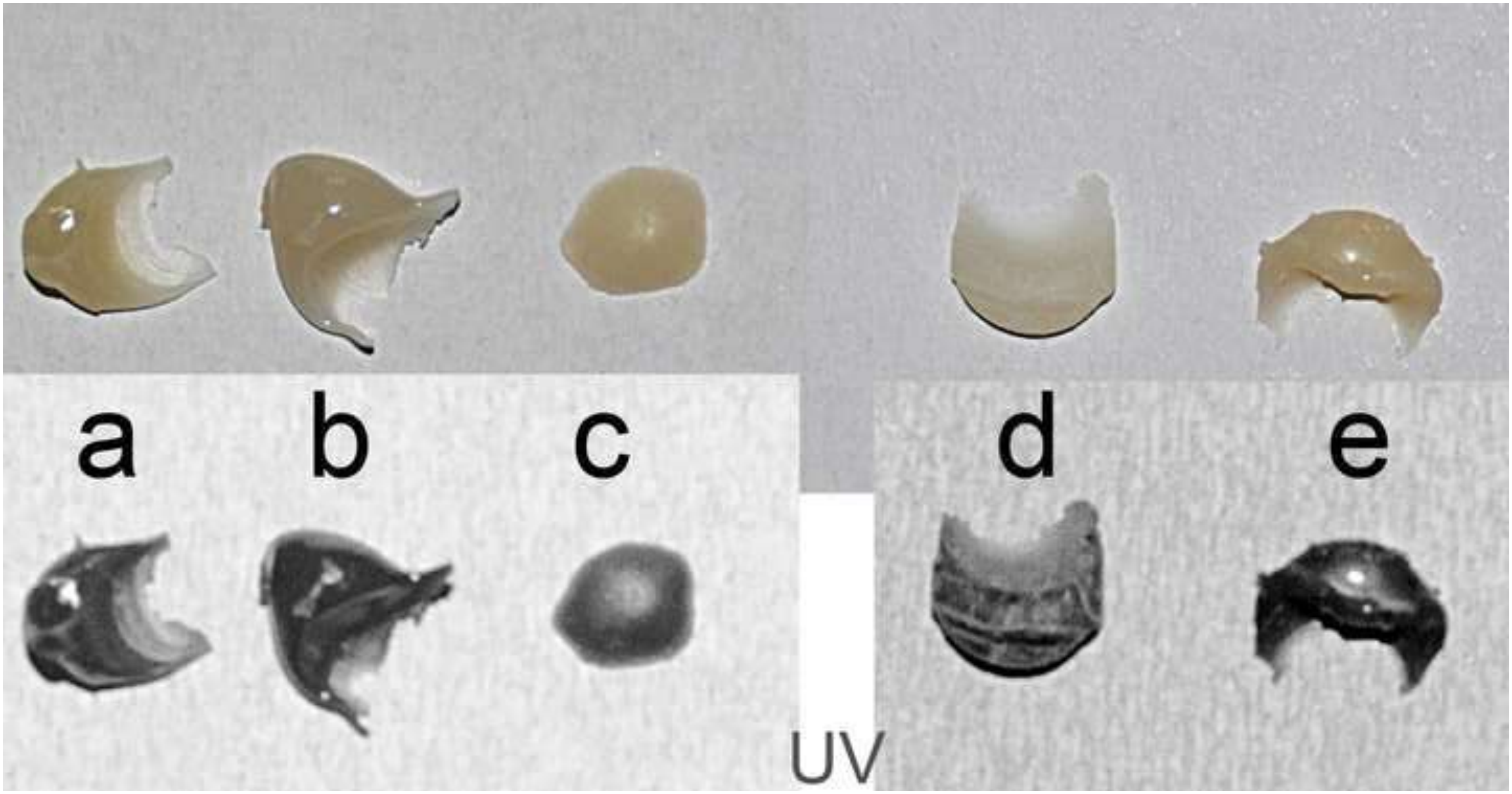

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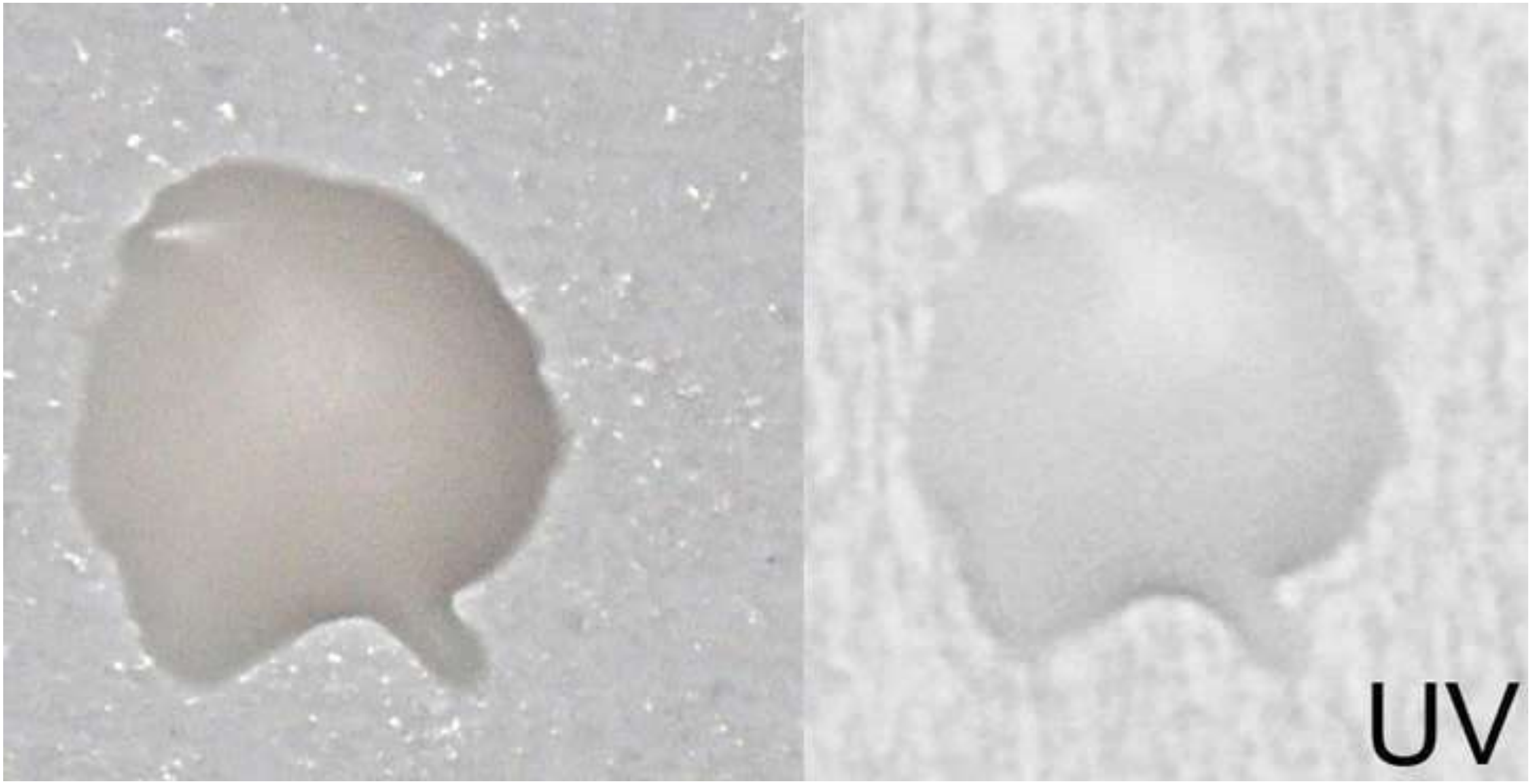

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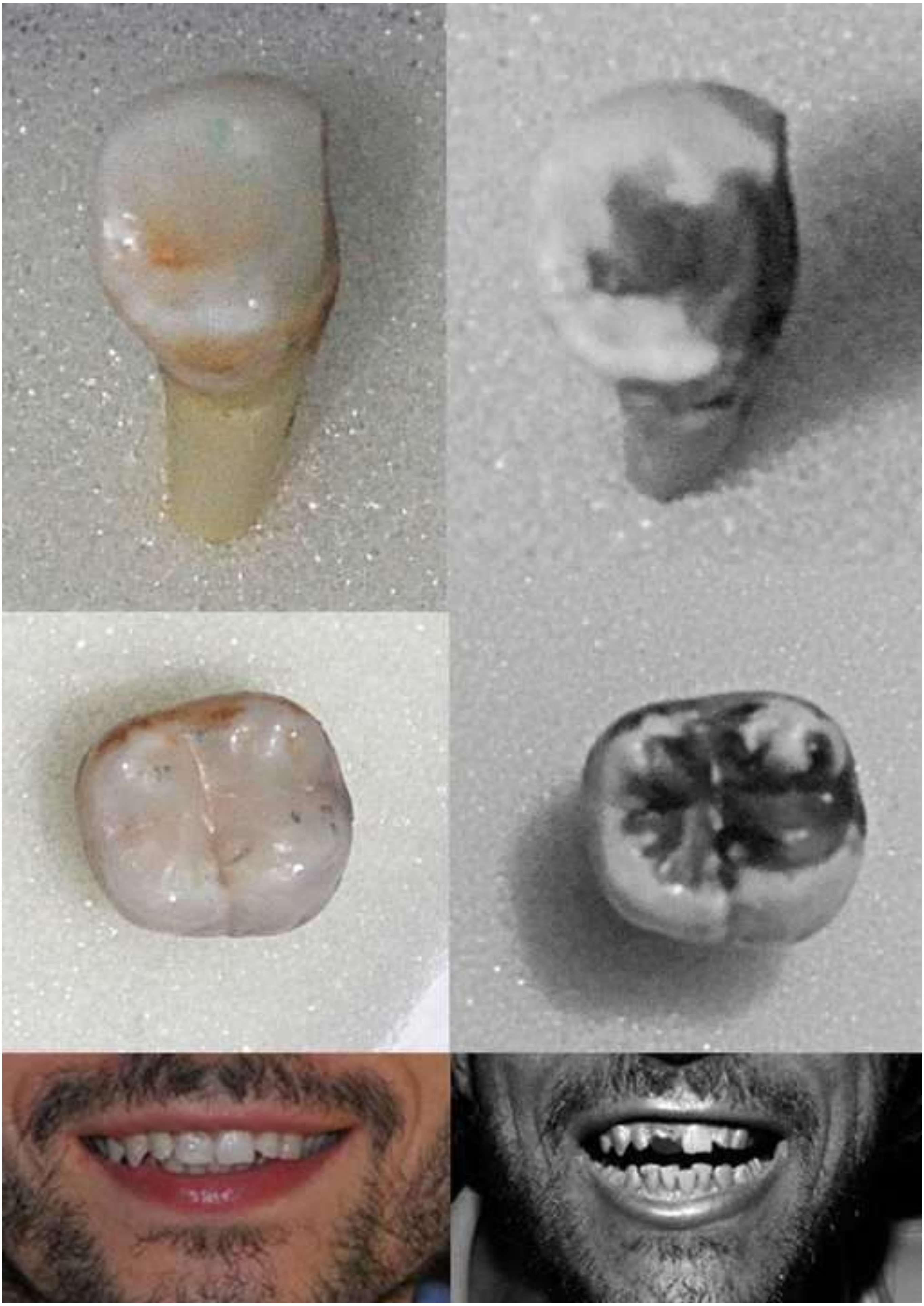

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