



A study on improving the surface appearance of low-quality *Pinctada maxima* bead cultured pearls

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Figure 1. Five low-quality *Pinctada maxima* bead cultured pearls showing dull surface lusters, yellowish brown imperfections and residual organic-rich features on their surfaces. Photo by Nuttapol Kitdee.

Abstract

GIA's 7 Pearl value factors are used to help determine the value of pearls. These factors are: size, shape, color, luster, surface, nacre quality and matching (Gemological Institute of America, 2011). Ideally all of these criteria should be natural and not be impacted by any human interaction; however, many pearl manufacturers usually improve the appearance of the low-quality pearls to increase their perceived value. As part of its research activities, GIA's Bangkok laboratory received five low-quality bead cultured pearls directly from a local pearl factory. All clearly lacked an appealing, luster and most possessed prominent imperfections and residual organic-rich features on their surfaces. During the examination all their surface features were recorded prior to being returned to the supplier who subsequently processed them to improve their appearances. Post processing, they were returned and reexamined. All the samples were also examined at both stages by real-time microradiography (RTX) to check potential differences in their nacre thickness, and observe their fluorescence reactions under ultraviolet radiation. After processing, one of the samples was selected for further analysis in order to check the chemical composition and mineral composition using energy dispersive X-ray fluorescence (EDXRF) and Raman spectroscopy, respectively.

As a result of the processing, two of the samples lost their nacre coatings and only their shell bead nuclei remained. Interestingly, both samples revealed surfaces in keeping with those frequently observed on artificially-coated imitation "pearls." The surfaces of the other three samples appeared to have improved as their lusters were more pronounced and the remaining nacre was smoother after the original imperfections disappeared. Even so, their appearances would still be considered unattractive in the trade so it isn't really possible to say the process improved their quality. The RTX results of the three samples that survived the process revealed thinner nacre coatings to varying degrees. The fluorescence reactions under shortwave UV (SWUV) did not vary significantly, but the reaction under longwave UV (LWUV) exhibited a strong chalky bluish green post processing indicating the likely use of some chemicals during the process. The two samples that lost all their nacre revealed a greenish blue reaction under the ultra-shortwave UV exposure (DiamondView) which unsurprisingly differed from the reaction observed pre-process. Since an artificially coated shell bead is not typically used in the culturing industry, one of them was checked using EDXRF and Raman spectroscopy. The results showed that bismuth (Bi) was a component of the coating and a feature at 1602 cm^{-1} in the Raman spectrum proved that an artificial coating was applied to the surface of the shell bead nuclei.

The methods used during the process were not fully disclosed; however, some surface features provided clues. Even though the appearances of three samples improved, some pearl value factors were impacted; therefore, it is unlikely that the end result would benefit the owner monetarily. This study demonstrates that pearl surface processing is not always successful, and the level of success may not cover the expense involved. All aspects need to be taken into account in order to evaluate the pros and cons and see whether the potential results make the effort economically viable.

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Introduction

A pearl's value is determined by a number of factors which GIA refers to as the 7 Value Factors. This system is used internationally to describe and classify pearls and thus provides the pearl trade and end consumer with an acceptable and widely used way to judge and compare pearls and their features. These characteristics may affect their beauty and durability, and take into account size, shape, color, luster, surface, nacre quality and matching (Gemological Institute of America, 2011). Of these considerations, size is perhaps the most important factor with luster close behind, all other factors being equal since nobody appreciates a dull or lifeless pearl. Perfectly round pearls are very rare, especially when it comes to natural pearls, and hence are more desirable, while pearls with flawless surfaces are also the exception rather than the rule. On the other hand, a pearl's nacre quality may directly affect its durability, particularly in cultured pearls where the nacre may be very thin and could result in damaged surfaces, and in some respects relates to the resulting luster. When it comes to color, pearls with distinct and well-saturated, pink, yellow, orange, gray, or black appearances are rarer than the usual white to cream range, and therefore their desirability increases. Matching is the last value factor discussed and is important when two or more pearls are used in an item of jewelry or layout (Gemological Institute of America, 2011). Of course, ideally all of the factors are judged using pearls that are unaltered in any way apart from routine cleaning, tumbling and buffing. However, most pearls in the trade go through a series of other processes to improve their appearance and increase their marketability.

Nowadays, numerous methods are used to improve this marketability. Some are proprietary and hence are not disclosed. Some methods are considered acceptable, while others are clearly considered treatments (Shor, 2007) and must be declared according to the US Federal Trade Commission's (FTC) guidelines (Federal Trade Commission, 2018). Most of the pearls in the supply chain are routinely improved using processes after harvesting such as maeshori and bleaching which are widely used for primary cleaning and removing surface impurities (Akamatsu, pers. comm. 2007). Maeshori¹ is normally performed on most cultured pearls; the method typically uses a methyl alcohol solvent to clean the surface and improve the luster simultaneously (Akamatsu, pers. comm., 2007; McClure et al., 2010). Bleaching is considered an acceptable treatment as many cultured pearls are routinely bleached, i.e. akoya cultured pearls and freshwater cultured pearls, and it is even often applied to natural pearls in the Middle East and India (author NS experience). The method typically uses hydrogen peroxide with heat and/or light to remove surface impurities and lighten/whiten the color (McClure et al., 2010).

Pearl manufacturers usually process low-quality pearls in order to improve their appearances and potentially benefit them financially. If all goes smoothly with the processing technique(s) applied, the pearl quality and pearl value factors will improve. Some pearl producers concentrate on improving a pearl's luster as this factor is often considered the most important aesthetic aspect. Routine methods used to improve the luster and potentially transform a pearl's surface appearance include tumbling, buffing and polishing. Tumbling is used to remove surface imperfections but may also improve the shape of the pearl slightly. Natural substances such as walnut chips, bamboo chips, salts or sand are usually used (Paspaley, pers. comm., 2007; McClure et al., 2010). Buffing is used to remove imperfections that tumbling fails to remove and sometimes employs mildly abrasive substance like wax during the process (Matlins, 2008). Polishing is a commonly applied process widely

¹ "Maeshori" is a term that covers several techniques used to improve the luster of pearls in the market today.

used by pearl producers to improve the surface luster. Various techniques, including vibrating units, or tumblers, that employ abrasive materials such as walnut, wood, paraffin, bee wax or metal powder in the drum, or polishing via felt wheels with mild polishing agents, are employed (Strack, 2006). More rigorous buffing, or even fine grinding and polishing using substances such as toothpaste may be applied (author NS experiences).

Other methods such as “working” and “peeling” which have a greater impact on the external appearance of pearls also exist. Working is used to remove or modify the nacre layers by removing imperfections and unwanted surface areas that may detract from a more favorable shape. In extreme cases this re-shaping is sometimes referred to as “heavily worked” and can transform the pearl’s appearance quite markedly (Sturman et al., 2011, Dirlam and Weldon, 2013; CIBJO, 2017). Pearl peeling, often performed by a “pearl doctor” or “pearl cleaner” mainly on natural pearls is a well-known method employed since at least the 17th century to obtain higher-quality pearls from poor-quality starting material. Several techniques were used to peel off the outmost nacre layers of a suitable pearl in order to potentially reveal better-quality nacre underneath. However, this method is rarely used today as it is a dying art and there are few skilled practitioners remaining (Strack, 2006; McLaurin-Moreno, 2018). In 1993, one successful pearl peeling experiment was recorded. Mr. Yousling recovered a round black cultured pearl from a baroque black cultured pearl by carefully peeling the nacreous layers using a variety of techniques over several days. However, he only managed to obtain 10 round cultured pearls from the 80-100 baroque pearls he worked on over a five-year period (Koivula et al., 1993). Pearls suitable for the peeling process require thick nacre, hence the association with natural pearls more than cultured pearls (McLaurin-Moreno, 2018). Any type of process has the potential to damage a pearl though, and as a result impact a pearl’s durability. It may crack or break if carelessly applied, or the skills of the worker may not be up to the job. Pearl producers performing any type of process on pearls in bulk need to be even more aware of the risks since the financial losses may be magnified greatly over those incurred by an individual.

Pearl producers may also use more than one method to improve pearl quality and remove unwanted natural nacre features from the surface. The lack of any original surface structure makes it challenging for pearl dealers to know what the true appearance was in the past and the degree to which the pearl may have been modified. Such modification may also impact decisions made by pearl testers attempting to identify whether any treatments may have been applied. Even though GIA’s Bangkok laboratory had the opportunity to study the low-quality pearl samples prior to their processing, the methods applied during the process are very rarely disclosed by the pearl manufacturers as they are often proprietary and hence kept confidential (Strack, 2006). However, the results of this study give some idea about some of the characteristic features to look for on the surfaces of pre- and post-processed pearls. The results may also help pearl traders understand whether a pearl has been processed by methods simply meant to improve the surface appearance or whether deeper investigation into the use of any other potential form of modification has taken place. They will also alert anyone to the potential durability issues that any type of surface modification, especially on bead cultured pearls, may create in the future. Since it is important to be transparent and open with clients, it is the pearl dealer’s responsibility to declare and correctly inform clients about the pearls they are selling.

Materials and Methods

GIA's Bangkok laboratory received five low-quality *Pinctada maxima* bead cultured pearl samples that were reportedly unprocessed or treated in any way. All the samples showed surfaces with a dull/poor luster, and some possessed additional yellowish brown imperfections and residual organic matter on their surfaces (figure 1). The supplier stated they were low-quality pearls not worthy of marketing, and that their appearances may be improvable through their in-house processing techniques. The opportunity to carry out a before-and-after comparison of the samples seemed to be worth pursuing, so they were sent to the laboratory in order to document them in detail. Their surface features were particularly important in this respect so details of their unmodified surfaces prior to processing (pre-process) were first collected. This was subsequently followed with the same methods once the samples had been processed (post-process) and returned for comparison.

All the samples were predominantly white, but some of them showed uneven silver-gray color patches, noticeable yellowish brown imperfections and residual organic matter on their surfaces. Their shapes varied from near-round to semi-baroque drop, while their sizes were in the typical range expected for South Sea cultured pearls. The pearls weighed from 18.56 to 35.22 carats and ranged from 13.84 x 13.68 mm to 19.26 x 16.11 x 16.06 mm (see individual details in table 1 [left]). Post-processing, their appearances were transformed to white, cream, silver or gray, with only one sample still retaining a small residual yellowish brown imperfection on its surface. Their shapes were also transformed to a more symmetrical form, improving to round and near-round. Only one sample retained its drop form although a degree of improvement was noted. The weights, as expected, also changed and can be compared to the original records in table 1 (right).











All the samples were examined with advance instrumentation to collect their data before and after processing. Real-time microradiography (RTX) results were obtained using a Pacific X-ray Imaging (PXI) GenX-90P X-ray inspection system with a 4-micron microfocus, 90 kV voltage, and 0.16 mA current X-ray source with an exposure time of 300-400 milliseconds per frame and maximum 128 frames average, incorporating a PerkinElmer 1512 flat panel detector with 74.8 micropixel pitch and 1944 x 1536 pixel resolution.

A GIA binocular gemological microscope was used to observe the characteristic surface features of each pearl. The photomicrographs were obtained using a Nikon SMZ18 stereomicroscope with SHR Plan Apo 1x objective lens and NIS-Elements imaging software.

The fluorescence reactions were observed under ultraviolet (UV) radiation using a GIA MULTISPEC shortwave and longwave ultraviolet unit with a 4-watt UV lamp emitting shortwave 254 nm and longwave 365 nm radiation, and a DTC DiamondView unit with a xenon flash lamp source fitted with a special ultraviolet filter generating ultra-shortwave ultraviolet radiation below 225 nm.

Additionally, another sawn pearl sample was provided for interest. It was sawn in half by the owner to confirm it was a bead cultured pearl, and representative of the pearls in a lot of similarly-appearing pearls. The macro images and photomicrographs of this sample were also recorded.

Table 1. Details of the pearl samples before and after processing.

Sample number	Pre-process			Post-process		
	Macro Image	Carat weight	Measurements (mm)	Macro Image	Carat weight	Measurements (mm)
1		35.22	19.26 x 16.11 x 16.06		33.06	18.92 x 15.75 x 15.71
2		32.31	20.01 x 16.42 x 16.25		24.08	14.93 x 15.06
3		31.43	20.56 x 16.58 x 15.84		21.47	14.30 x 14.90
4		22.39	14.95 x 14.56		21.43	14.39 x 14.49
5		18.56	13.84 x 13.68		17.77	13.50 x 13.64

Post-process, sample 3 was selected in order to examine its chemistry. A Thermo Scientific ARL QUANT'X Energy Dispersive X-ray fluorescence (EDXRF) spectrometer incorporating a 50 W, 4-50 kV voltage, and 0.02-1.98 mA current X-ray source with a silicon-lithium drifted detector was used. In order to determine the mineral components of the surface, Raman analysis was performed using a Renishaw inVia Reflex micro-Raman spectrometer system with a Leica objective lens and a 514 nm argon-ion laser. Rayleigh radiation was blocked using edge filters. A laser power of 50 mW was set at 100% power with three accumulations and an exposure time of 10 seconds with a grating of 1800 grooves/mm was also applied.

Results

General observations. The external appearances of all the samples were modified to varying degrees post-process. As may be seen in table 1, the surface of sample 1 was dull before processing and lacked any obvious overtone. White frosty imperfections covered most of the surface. After processing, its color slightly changed from matt white to white with a hint of silver, while its luster became brighter and shinier, and a weak orient resulted. Although its final shape and size seemed similar to those observed pre-process, and the measurements varied insignificantly (maximum difference 0.40 mm), its final weight showed a loss of 2.16 carats.

The external appearances of samples 2 and 3 changed the most post-process. Not only did their physical features change, but their identities also changed from nacreous pearls to artificially color-coated shell beads, owing to the complete removal of their overlying nacreous layers during the process. The large differences in their weights pre- and post-process, 8.23 and 9.96 carats respectively, also proved that they had undergone significant modification.

Sample 4's appearance was also modified by the process. Some nacre layers peeled off, revealing the hidden colors and imperfections underneath the original surface. Its color altered from white and silver to cream and light gray, but a large yellowish brown organic-rich area was removed. Even though the external appearance obviously improved, its weight and measurements only resulted in slight changes, less than 1.00 carat and 0.50 mm respectively, while the lack of an overtone remained the same. Sample 5 showed the least impact, its external appearance post-process looking similar to that pre-process. The surface improved only slightly (better luster) and it became a touch creamier in color, while its weight and measurements only differed slightly, by 0.79 carat and 0.34 mm respectively.

Surface characteristics. Sample 1 exhibited overlapping nacre platelets on the surface in the form of parallel curved swirly lines before and after processing (table 2, E and J). Nacre is a characteristic feature normally observed on nacreous pearls (CIBJO, 2017), and when examined under magnification is called platy structure by gemologists (Sturman et al., 2019). Pre-process the pearl showed white frosty ragged layers covering most areas of the surface (table 2, B-E), resulting in a dull and lifeless luster. Some white shallow dimples and many tiny spotted white features were visible on the pearl's base (table 2A). After processing, the appearance improved. The nacre platelets on the surface looked more even and possessed smoother edges (table 2, I and J), which resulted in a smoother and shinier surface (table 2, G and H). Moreover, the tiny spotted features seen prior to the processing disappeared (table 2F). Nevertheless, many curved uneven color bands were visible on the pearl's base (table 2F). These resulted from the very thin nacre coverage in this area as confirmed by the RTX results (figure 2). In bead cultured pearls where the nacre thickness becomes too thin, the underlying banded structure of the shell bead nucleus is often apparent, a fact that can be very helpful as a quick and simple test, sometimes referred to "candling" (Gemological Institute of America, 2011), when identifying bead cultured pearls without using advanced equipment.

Sample 2 showed platy structure with obvious sharp edges (table 3C) together with many broken yellowish brown organic patches distributed over many areas of its surface (table 3, A and B), and other thin yellow organic-rich layers in some areas too (table 3D). When the cross-section of the thickest yellowish brown organic piece was examined in more detail, it showed stacked unevenly colored layers relating to the non-crystalline deposition of organic matter (table 3E). After processing, the sample's appearance changed completely. Only a yellow artificially-coated shell bead nucleus

(table 3I) remained. All the nacreous layers were removed during the process. When strong transmitted light directed into the resulting clear banding was observed, and when overhead lighting or oblique lighting was applied, numerous minute glistening particles (table 3J), typically observed on imitation pearls to simulate pearl nacre were observed (Krzemnicki, 2005; Gemological Institute of America, 2011; Hyatt, 2011; Zhou and Zhou, 2014). Additionally, a relatively large brown area was clearly evident on the surface (table 3I, red arrow). This color concentration penetrated into the surface, and did not appear to be natural. A broken piece of nacre that had peeled off during the processing was also returned with the item (table 3, F-H). It was very thin and fragile (table 3, F) and matched, per the black organic-rich and white frosty features, the nacre layer that existed at one end of the pearl prior to processing (table 3, B and G). In addition, some areas of the broken piece showed white frosty clusters with dark brown organic-rich surface features (table 3H), that were not evident before processing since they were masked by the fragmented yellowish brown organic layer (table 3A).

Sample 3's appearance was unattractive; it exhibited a rough surface skin with uneven yellowish brown organic-rich layers covering most of the surface (table 4, A and B). Some areas on the irregular end lacked organic-rich layers and showed obvious nacre platelets with sharp edges (table 4C). Many of the yellowish brown organic-rich layers, and areas of the nacreous surface, revealed numerous unevenly distributed white sub-surface veins (table 4, D and E), which resemble the parasite or worm tubes often encountered in shell blisters and blister pearls examined previously by the authors. Following processing the sample looked similar to the post-process appearance of sample 2, with the majority of the surface displaying a yellow artificial coating over a shell bead nucleus. Only a residual nacreous component with yellowish brown organic-rich layers remained on approximately 10% of the surface (table 4, F and G). The parasite or worm tube features that showed pre-process all disappeared from the remaining nacreous and yellowish brown organic layers (table 4, I and J). The artificially-coated shell bead exhibited obvious banding by transmitted light, and as with sample 2, numerous minute glistening particles were evident within the coating (table 3J). In addition, some areas revealed irregular zones in the coating where the white surface of the underlying shell bead nucleus was visible (table 4H), thus confirming that the shell bead nucleus was coated by a yellow artificially-colored substance.

The appearance and color of sample 4 changed radically after processing; however, it wasn't clear whether the pearl's surface showed any improvement. Originally the pearl appeared milky white and lacked luster. Numerous white spots were also visible on the surface, and a large yellowish brown organic-rich area with additional thinner yellowish brown organic patches (table 5, A-C) and indistinct silver bumps and veins (table 5, D and E) were apparent on the surface. Although the surface of sample 4 was shinier and smoother post-process, its appearance was still unattractive (table 5, F and G). Its color altered to cream and silver (table 5G), and noticeable gray bumps, veins and patches that were not clearly present prior to processing were now obvious (table 5H). Upon comparing the key characteristic features pre- and post-process (table 5, red and green arrows), the cluster of bumps and veins became more visible following the work, and appeared darker and more prominent than prior to processing. Other uneven bumpy surface areas also developed (table 5J); however, they were not present before processing. Thus, it appears that the processing removed the outermost surface layers from the sample and allowed existing concealed or partially-concealed imperfections to show more readily. Such a result would not be expected after most pearl processing techniques and it proves how important it is to start with material that is suitable for the processing and likely to benefit from it in a positive way.

Sample 5 possessed a dull surface that lacked luster. Numerous tiny white spots and white frosty layers covered most areas of the surface (table 6, A-C). The tiny white spots were not only found on the surface but were also visible within underlying layers just beneath the surface (table 6E). A group of small bumps combined to form one large silver bumpy area on the surface (table 6, A and C) with additional smaller bumps and veins (table 6B). Several tiny white spots matching those found in other areas were also observed on, and within, the bumpy silver features when magnified (table 6D). Although the processing improved the luster, smoothed much of the surface, and eliminated the tiny white spots (table 6J), noticeable surface imperfections were still present (table 6, F-H). A long, fairly indistinct vein feature prior to processing (table 6B, red arrow) became shinier and more noticeable after processing (table 6G, red arrow). Moreover, the large bumpy silver area became smoother, shinier and darker (table 6I), thus appearing even more prominent (table 6D). As with sample 4, the processing actually made some of the imperfections more obvious while improving other aspects; hence it is questionable whether the surface was improved. In value terms the answer is likely to be negative, since the appearance did not change to a degree that would warrant a rise in value, but from a purely visual stance the appearance did improve to some extent, albeit marginally.

Table 2. Comparison photomicrographs of sample 1 showing the surface characteristics before and after processing. Photos by Kwanreun Lawanwong.











Pre-process	Post-process
<p>A</p>  <p>FOV 19.20 mm</p>	<p>F</p>  <p>FOV 19.20 mm</p>
<p>B</p>  <p>FOV 19.20 mm</p>	<p>G</p>  <p>FOV 19.20 mm</p>
<p>C</p>  <p>FOV 14.40 mm</p>	<p>H</p>  <p>FOV 14.40 mm</p>
<p>D</p>  <p>FOV 4.80 mm</p>	<p>I</p>  <p>FOV 4.80 mm</p>
<p>E</p>  <p>FOV 4.80 mm</p>	<p>J</p>  <p>FOV 4.80 mm</p>

Table 3. Comparison photomicrographs of sample 2 showing the surface characteristics before and after the processing. Photos by Kwanreun Lawanwong.




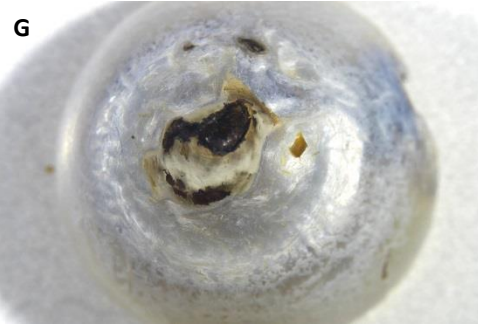






Pre-process	Post-process
A  FOV 19.20 mm	F  FOV 19.20 mm
B  FOV 19.20 mm	G  FOV 19.20 mm
C  FOV 4.80 mm	H  FOV 14.40 mm
D  FOV 3.60 mm	I  FOV 19.20 mm
E  FOV 4.80 mm	J  FOV 3.60 mm

Table 4. Comparison photomicrographs of sample 3 showing the surface characteristics before and after processing. Photos by Kwanreun Lawanwong.



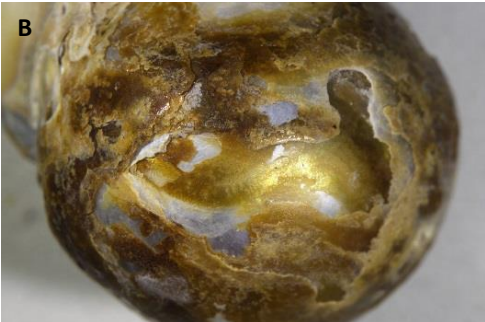



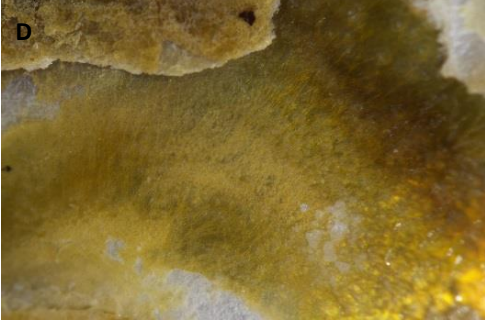



Pre-process	Post-process
A  FOV 19.20 mm	F  FOV 19.20 mm
B  FOV 19.20 mm	G  FOV 19.20 mm
C  FOV 7.20 mm	H  FOV 14.40 mm
D  FOV 4.80 mm	I  FOV 4.80 mm
E  FOV 3.60 mm	J  FOV 3.60 mm

Table 5. Comparison photomicrographs of sample 4 showing the surface characteristics before and after processing. Photos by Kwanreun Lawanwong.

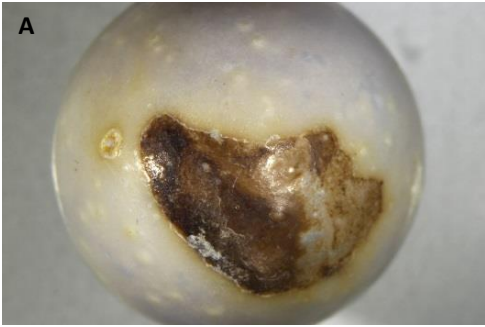
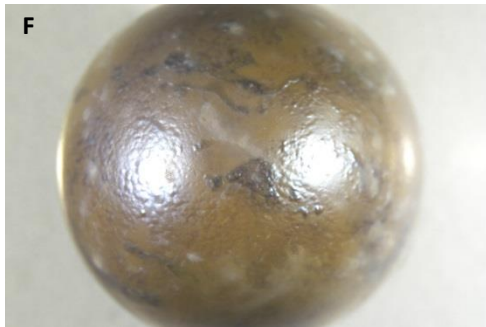
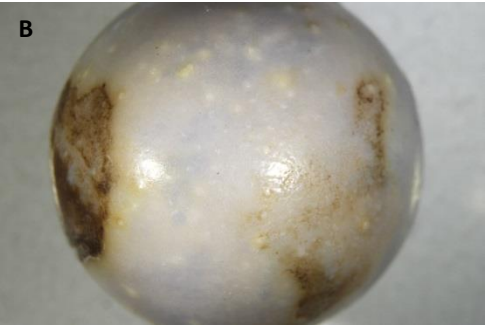
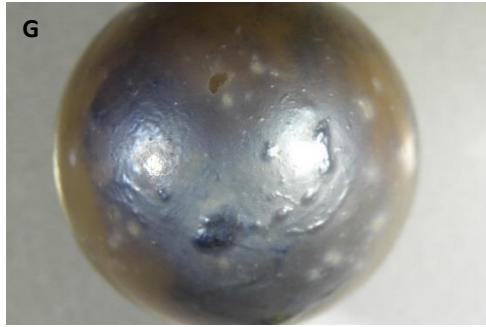
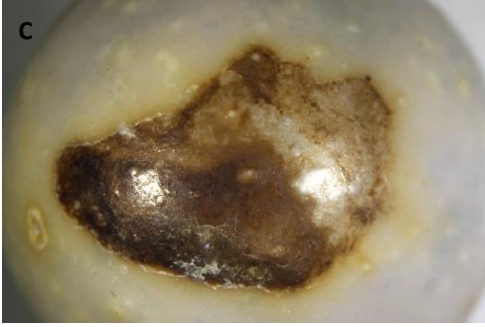
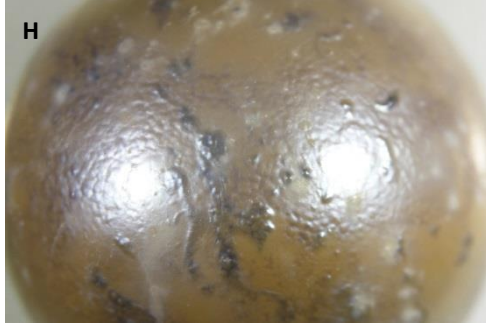
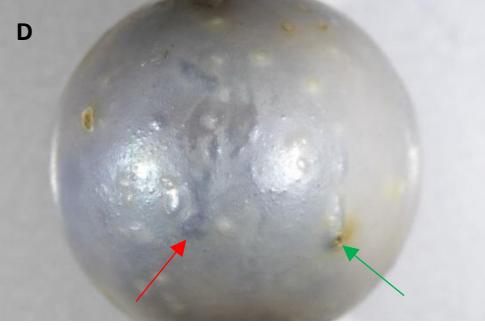
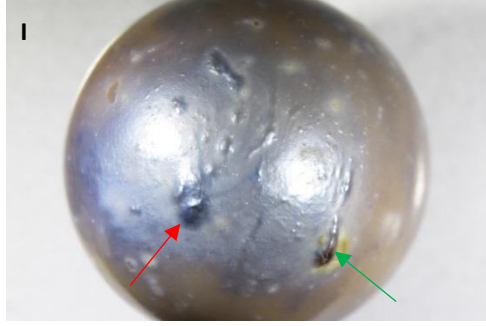





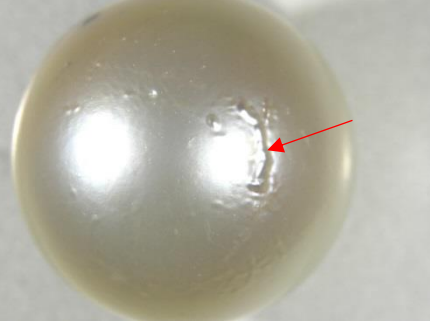


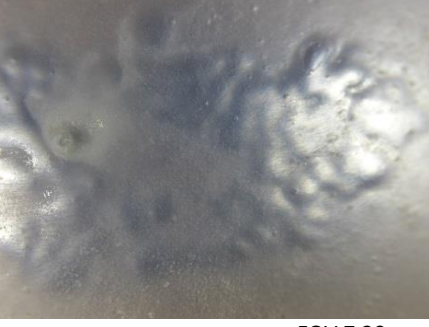

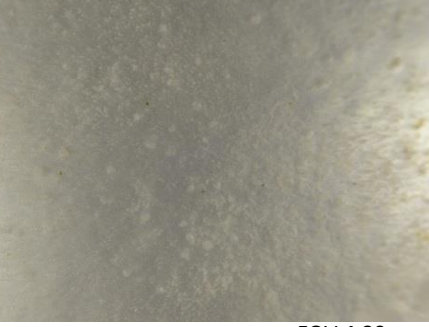

Pre-process	Post-process
A  FOV 19.20 mm	F  FOV 19.20 mm
B  FOV 19.20 mm	G  FOV 19.20 mm
C  FOV 14.40 mm	H  FOV 14.40 mm
D  FOV 19.20 mm	I  FOV 19.20 mm
E  FOV 7.20 mm	J  FOV 7.20 mm

Table 6. Comparison photomicrographs of sample 5 showing the surface characteristics before and after processing. Photos by Kwanreun Lawanwong.

Pre-process	Post-process
A  FOV 19.20 mm	F  FOV 19.20 mm
B  FOV 19.20 mm	G  FOV 19.20 mm
C  FOV 14.40 mm	H  FOV 14.40 mm
D  FOV 7.20 mm	I  FOV 7.20 mm
E  FOV 4.80 mm	J  FOV 4.80 mm

Internal structures. All the samples were examined by microradiography using a real-time X-ray machine with a high resolution flat panel detector (FPD) to reveal fine internal structural details with optimum clarity (Karampelas et al., 2017). The identification of all samples proved to be straightforward. They were found to be bead cultured pearls with each showing an obvious shell bead nucleus lacking any obvious structures inside the bead (figure 2-6), similar to other traditional bead cultured pearls with a FW shell bead nucleus recorded previously (Sturman et al., 2016; Kessrapong et al., 2017). The nacre thickness overlaying the bead nucleus was also measured for each sample. The measurements were taken from the bead nucleus outline (boundary) to the outer layer of the pearl in order to compare the nacre thickness measurements before and after processing.

While the surface luster of sample 1 improved post-process (figure 2, A and D), the shape and size showed little difference. The RTX results of the sample pre-process (figure 2, B and C) and post-process (figure 2, E and F) showed the bead demarcation indicated by the red circles (figure 2, C and F) and the nacre thickness between the bead nucleus outline and pearl's surface. The nacre thickness towards the more tapered end was much thicker than the circumference and base. At its thickest the nacre measured 4.50 mm pre-process, while the thinnest part measured only 0.24 mm (figure 2, B and C). The average nacre thickness of the sample pre-process (figure 2, B and C) was thicker than that post-process (figure 2, E and F), measuring approximately 2.15 mm and 1.95 mm, respectively. These results showed that the processing removed the outermost layers of nacre and only reduced the nacre by approximately 0.20 mm.

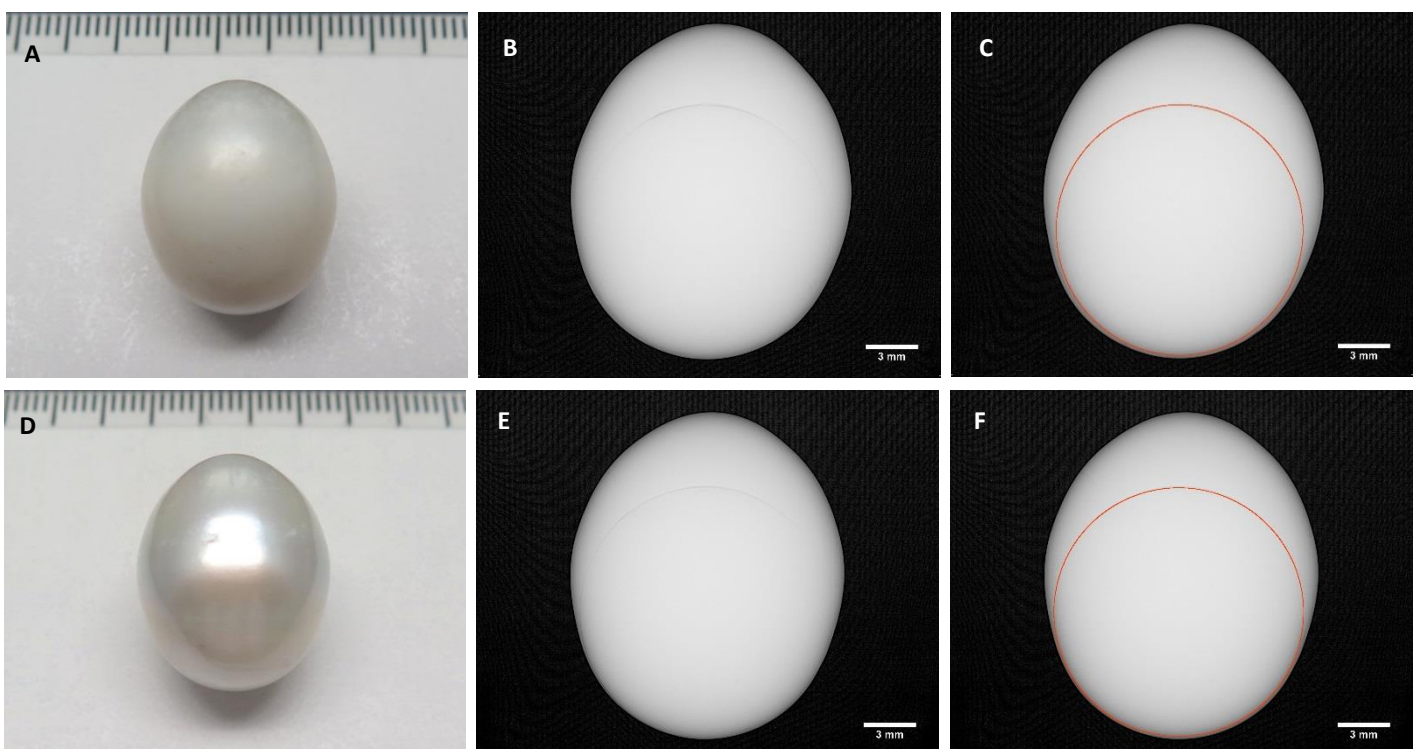


Figure 2. The macro images with a millimeter scale, and RTX images of sample 1, before (A-C) and after (D-F) processing. Photos by Nanthaporn Nilpetploy. The RTX results revealed the bead nuclei, indicated by the red circles (C, F) and the nacre thickness overlaying the bead nuclei, scale bar 3 mm.

Only an artificial yellow coating remained over the shell bead nucleus of sample 2 (figure 3D). The end result looked completely different from the pre-processed pearl that possessed nacre and exhibited an imperfect surface (figure 3A). The RTX results showed the bead nuclei demarcation pre-process (figure 3, B and C) and post-process (figure 3, E and F) indicated by the red circles (figure 3,

C and F). The nacre thickness between the bead nucleus outline and the pearl's surface prior to processing is also visible. Post-process only an artificially coated bead nucleus lacking any nacre remained. The nacre thickness at the tapered end of the pearl pre-process revealed the thickest nacre up to 3.60 mm, while the pearl's average nacre thickness measured approximately 1.31 mm (figure 3, B and C). Post-process nacre thickness measurements were not applicable as all the nacre was removed.

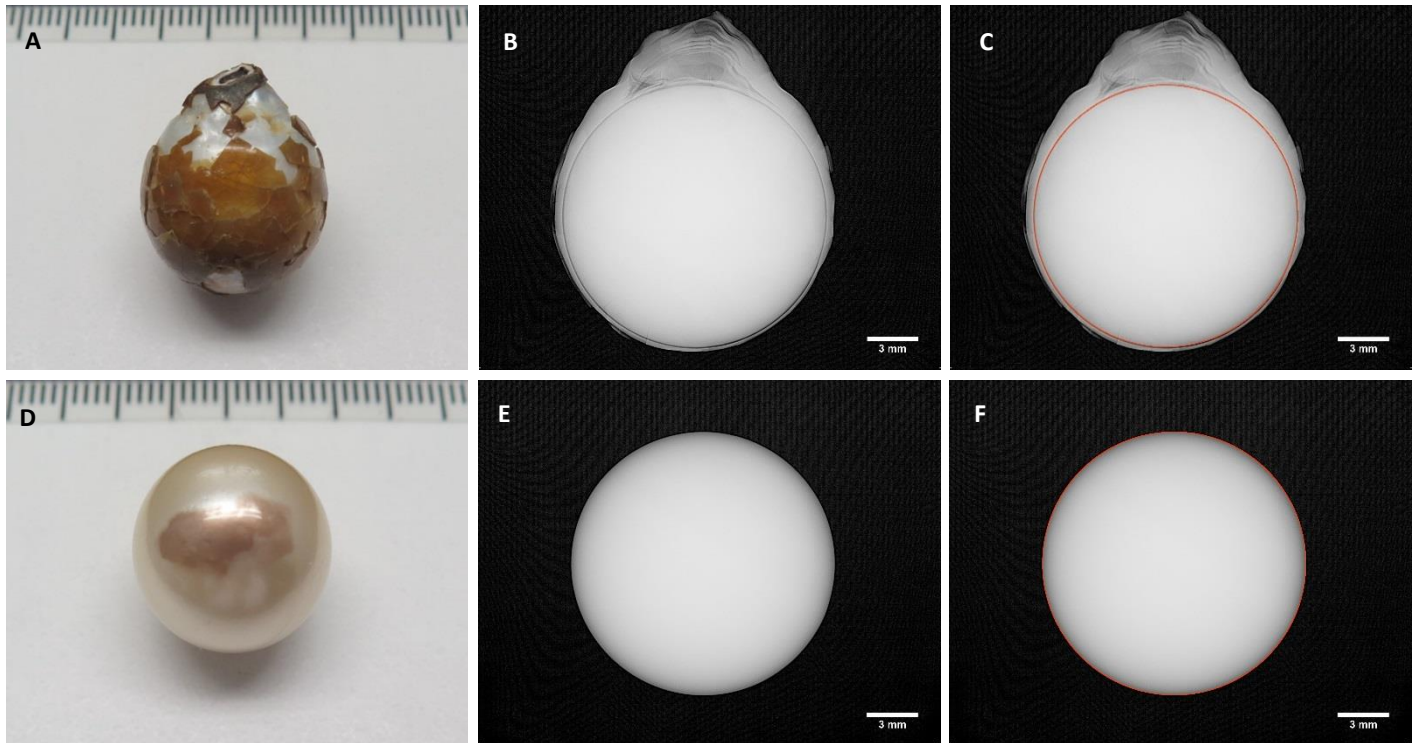


Figure 3. The macro images with a millimeter scale, and RTX images of sample 2, before (A-C) and after (D-F) processing. Photos by Nanthaporn Nilpetploy. The RTX results revealed the bead nuclei, indicated by the red circles (C, F), the nacre thickness overlying the bead nucleus pre-process (B, C), and lacking any overlying nacre post-process (E, F), scale bar 3 mm.

An artificial yellow coating covering the majority of the shell bead nucleus remained on sample 3 post-process. Only a few small areas of residual nacre were visible on the surface (figure 4D), in contrast to the pre-process where the entire pearl was covered with nacre and surface imperfections (figure 4A). The RTX results showed the bead nuclei demarcation pre-process (figure 4, B and C) and post-process (figure 4, E and F) indicated by the red circles (figure 4, C and F). The nacre thickness between the bead nucleus outline and the pearl surface edge in the pre-process is very evident (figure 4, B and C), while the post-process results mainly showed the bead nucleus and only some small remnants of very thin nacre coverage (figure 4, E and F). Prior to processing the nacre thickness on the top part of the pearl was thickest, and measured up to 5.40 mm with an average over the whole pearl of approximately 1.83 mm. The nacre remnants on the bead nucleus after processing (figure 4F, green arrow) measured 0.17 mm at the thickest part. Additionally, some areas of the artificial coating were damaged and revealed the underlying white shell bead beneath (figure 4D). As expected, the missing coating showed on the RTX image as an “empty area” (figure 4F, red arrow) where the bead nucleus outline used to exist (figure 4F, red circle) and it met the overlying nacre.

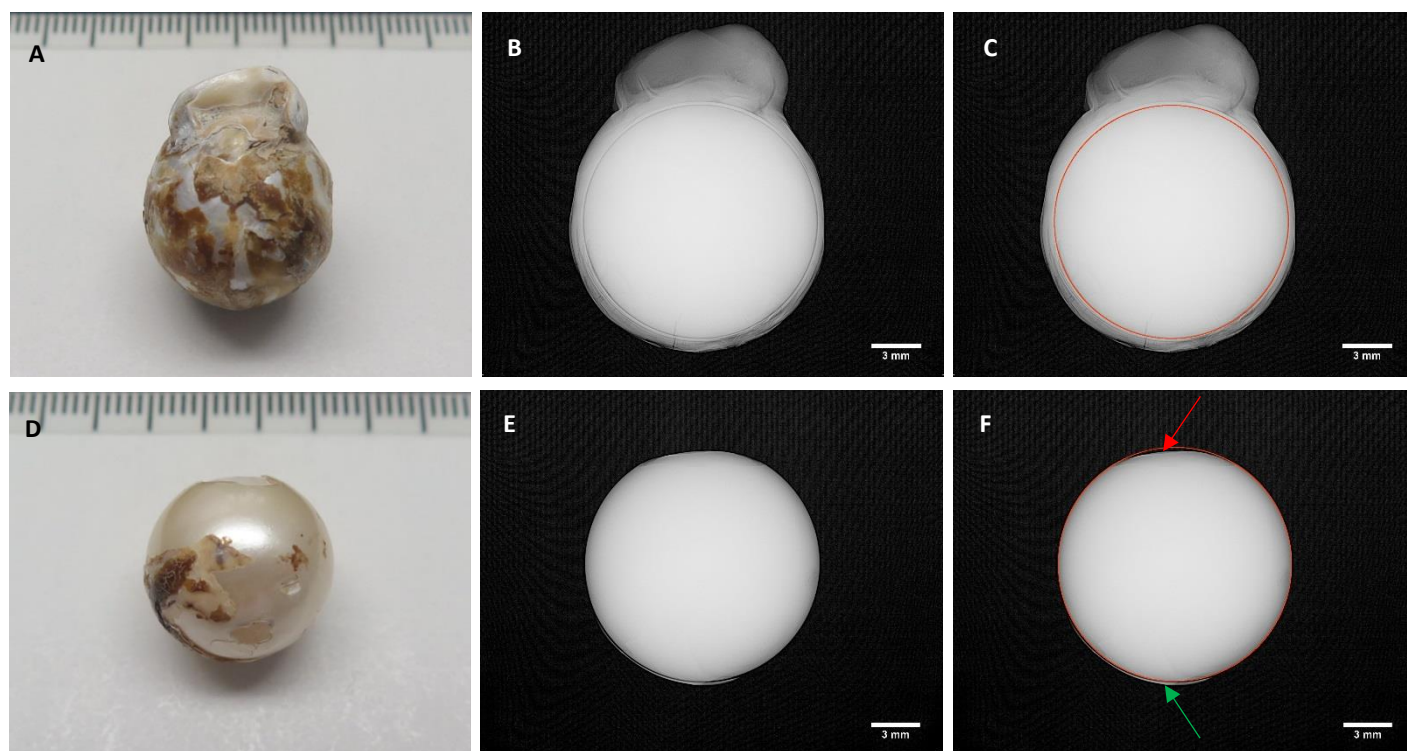


Figure 4. The macro images with a millimeter scale, and RTX images of sample 3 before (A-C) and after (D-F) processing. Photos by Nanthaporn Nilpetploy. The RTX results revealed the bead nuclei, indicated by the red circles (C, F), the nacre thickness overlying the bead nucleus pre-process (B, C), a small area of thin nacre overlying the bead nucleus post-process (F, green arrow), and a damaged area of the coating on the bead nucleus (F, red arrow), scale bar 3 mm.

The appearance of sample 4 changed after the processing, especially in relation to its color and luster (figure 5, A and D). The RTX results in the pre-process (figure 5, B and C) and post-process (figure 5, E and F) showed the bead nuclei's demarcation indicated by the red circles, and the nacre thickness between the bead nucleus and the pearl's surface. The average nacre thickness of the pearl pre-process and post-process measured approximately 0.26 mm and 0.17 mm, respectively. This difference showed that only 0.09 mm of the outermost nacre layers were removed. Even though this seems to be a minor change, the sample's color increased in saturation and the imperfections became more visible. This is the opposite result of what would normally be expected.

The difference in appearance of sample 5 pre- and post-process was the least apparent of all the pearls (figure 6, A and D). The RTX results pre-process (figure 6, B and C) and post-process (figure 6, E and F) showed the demarcation of bead nuclei indicated by red circles, and the nacre thicknesses between the bead nucleus and pearl's surface. The average nacre thickness of the pearl measured approximately 0.39 mm pre-process and approximately 0.30 mm after processing, hence only 0.09 mm nacre was removed. Although the amount of nacre removed was similar to that removed from sample 4, its appearance did not transform as much as it did with sample 4.

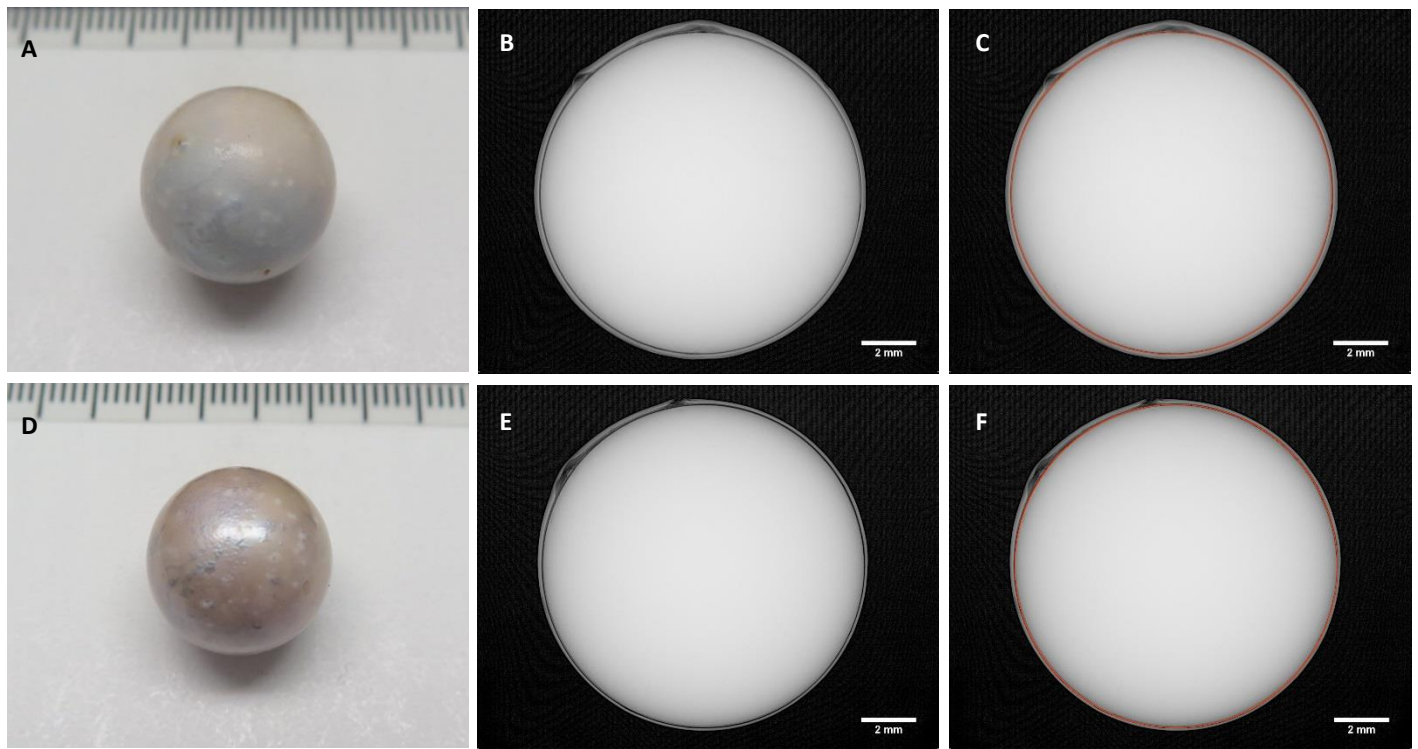


Figure 5. The macro images with a millimeter scale, and RTX images of sample 4, before (A-C) and after (D-F) processing. Photos by Nanthaporn Nilpetploy. The RTX results revealed the bead nuclei, indicated by the red circles (C, F) and the nacre thickness overlying the bead nuclei, scale bar 2 mm.

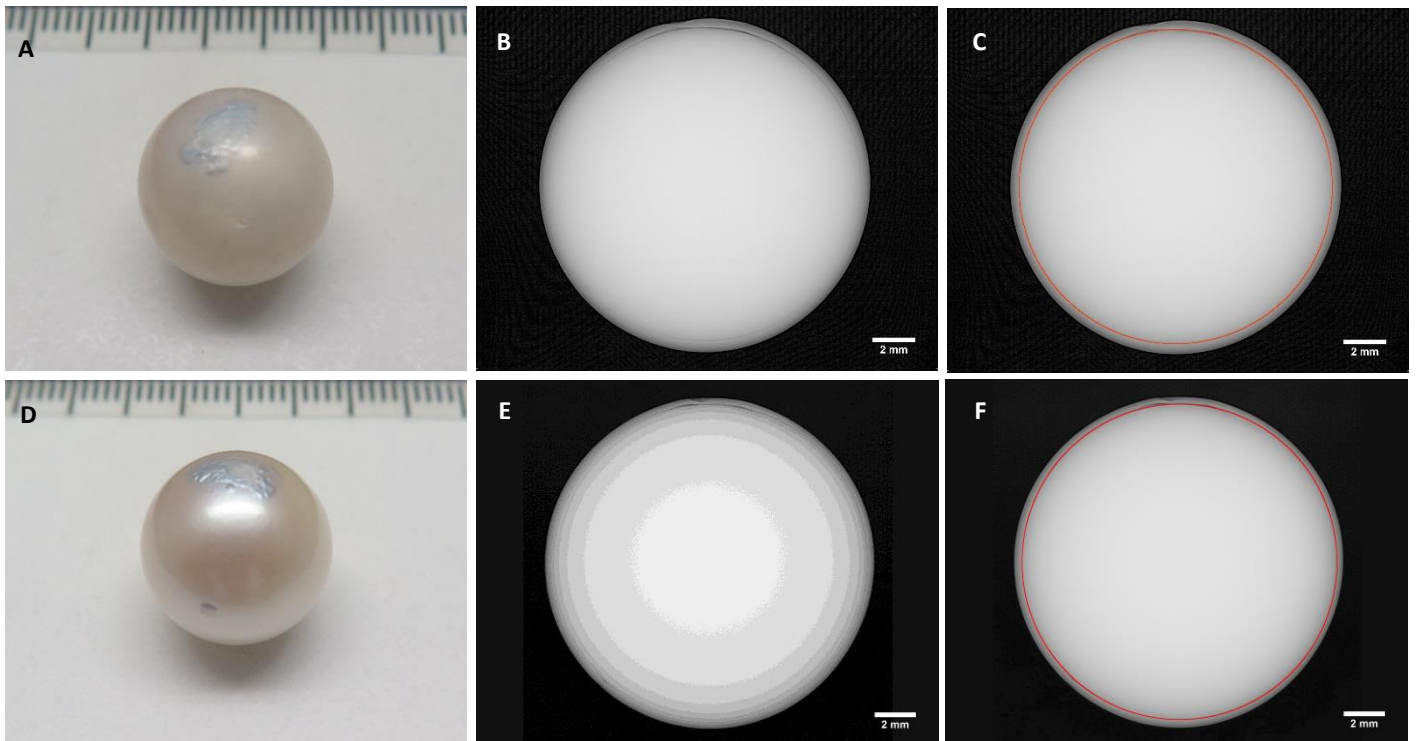


Figure 6. The macro images with a millimeter scale, and RTX images of sample 5, before (A-C) and after (D-F) processing. Photos by Nanthaporn Nilpetploy. The RTX results revealed the bead nuclei, indicated by the red circles (C, F) and the nacre thickness overlying the bead nuclei, scale bar 2 mm.

Fluorescence reactions. The reactions under longwave ultraviolet (LWUV) and shortwave ultraviolet (SWUV) radiation of the samples before and after the processing varied in relation to their color saturation. The darker areas showed weaker reactions while the lighter areas exhibited stronger reactions. The LWUV reactions post-process revealed stronger chalky greenish blue reactions (figure 7D), while those pre-process were a weaker bluish white (figure 7C). Samples 2 and 3, which only possessed an artificial coating over most of their surfaces post-process, exhibited the weakest reactions (figure 7D). However, the damaged area in the artificial coating of sample 3 revealed a strong greenish blue reaction that corresponded to the white shell bead underneath (figure 7D, red arrow), similar to the reactions observed for the white nacreous samples 1 and 5. Although sample 4 was also a nacreous pearl, its color turned cream and light gray after processing, which resulted in a weaker LWUV reaction. The SWUV reactions of all samples, pre- and post-process, were not noticeably different (figure 7, E and F).

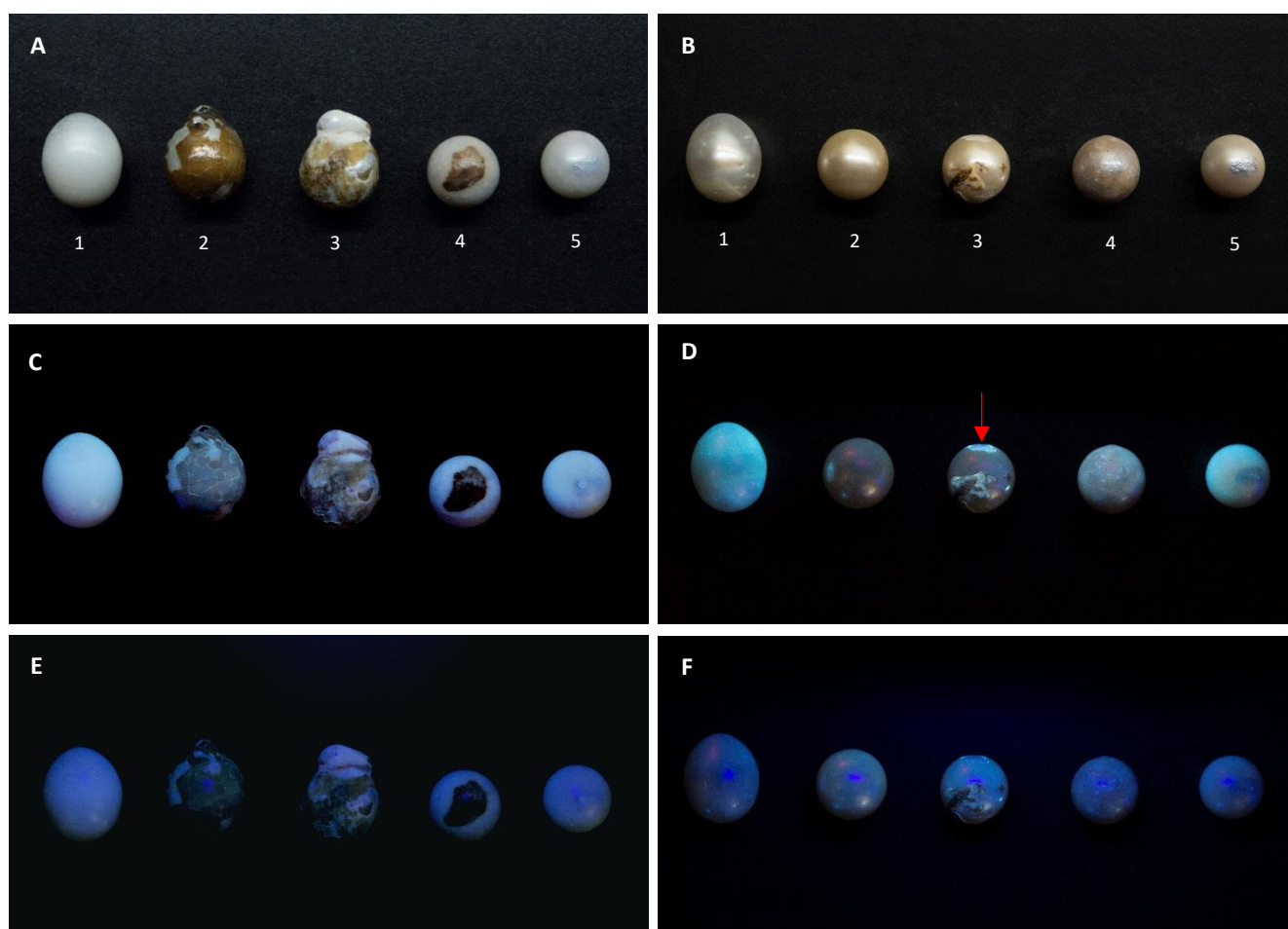


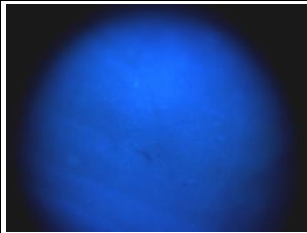
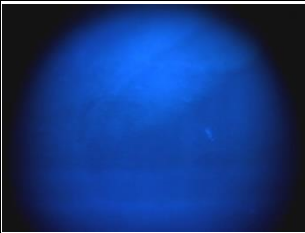
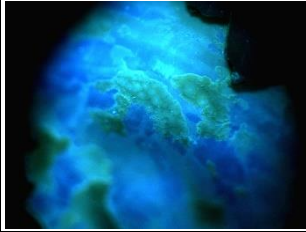
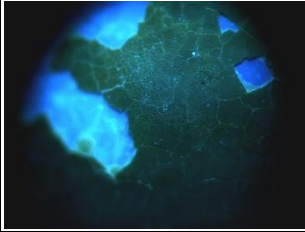
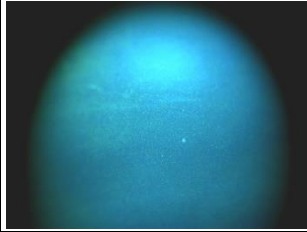
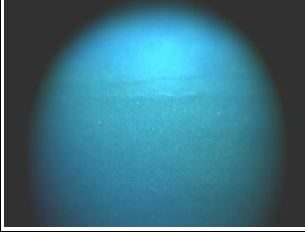
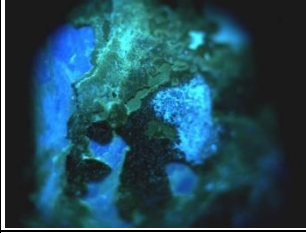
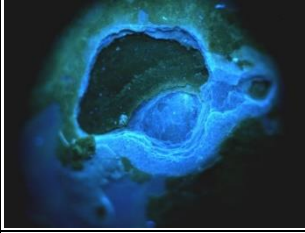
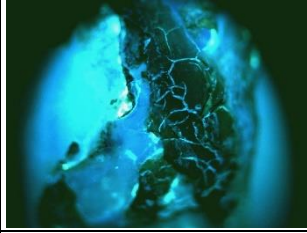
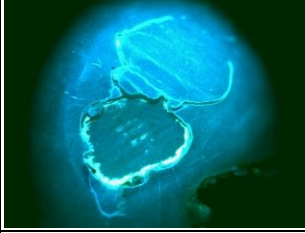
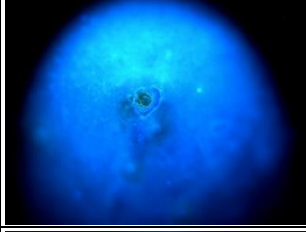
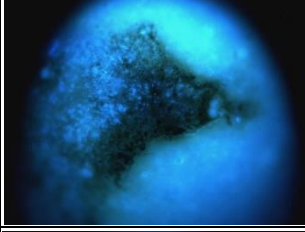
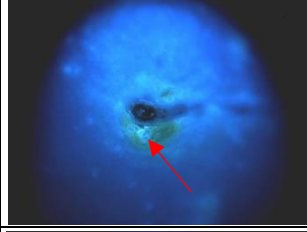
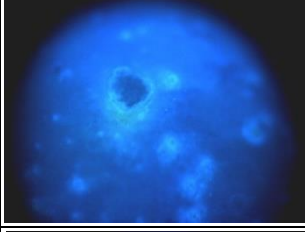
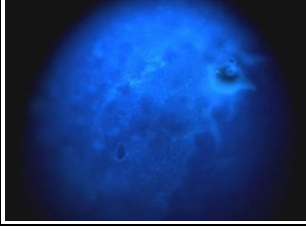
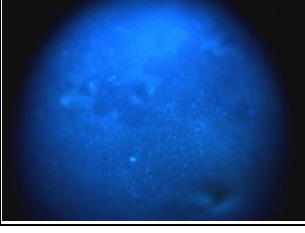
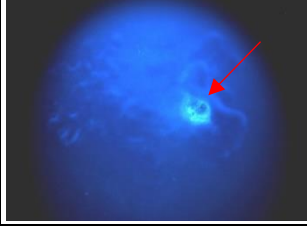
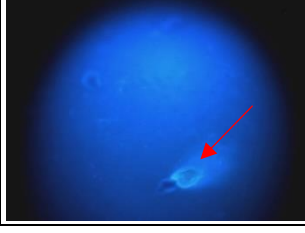


Figure 7. Comparison of the reactions of the pearl samples before (A, C, E) and after (B, D, F) processing under white fluorescence light (A, B), longwave ultraviolet (C, D) and shortwave ultraviolet (E, F).

Furthermore, the fluorescence reactions of all the samples were observed under ultra-shortwave ultraviolet radiation using the DiamondView pre- and post-process. Pre-process, they all showed a strong blue reaction over most areas of the surface (table 7, left) typical of other white South Sea pearls examined (Scarratt et al., 2012). Samples 2 and 3 showed additional weak to moderate yellowish green reactions on the non-nacreous imperfections and organic surface. After processing, most samples showed similar reactions to those observed prior to processing (table 7, right), but samples 2 and 3, the artificially coated shell beads, exhibited a bluish green reaction that

differed and supported their imitation pearl identity. Samples 4 and 5 also exhibited a stronger bluish white reaction around surface dimples and along imperfections (table 7, red arrows), indicating the possible application of chemicals during processing.

Table 7. Comparison of the fluorescence reactions of the samples observed in the DiamondView pre- and post-process.

Sample number	Fluorescence reactions under DiamondView			
	Pre-process		Post-process	
1				
2				
3				
4				
5				

Additional testing. Another pearl was also provided by the owner of the other samples. However, unlike the others this one was cut in half by the owner to confirm the inner bead cultured pearl structure (figure 8, A and B). Each half showed an obvious demarcation between the white shell bead nucleus and nacreous overgrowth (figure 8C). Some darker parallel bandings relating to the shells' banded growth structure and typically seen in other freshwater shell bead nuclei (Cartier and Krzemnicki, 2013) were visible in the nucleus. In addition, the sawn nature of the sample meant that the bead nucleus was dislodged in one half and was easily separated from the overlying nacre revealing the bead nucleus' surface that was hidden under the nacre. A cream-colored artificial coating exhibiting distinct glittering particles (figure 8D), similar to the surface appearances of samples 2 and 3 post-process (table 3 and 4), was revealed. This observation indicates that all the samples in this study likely contain a similarly coated shell bead nucleus.

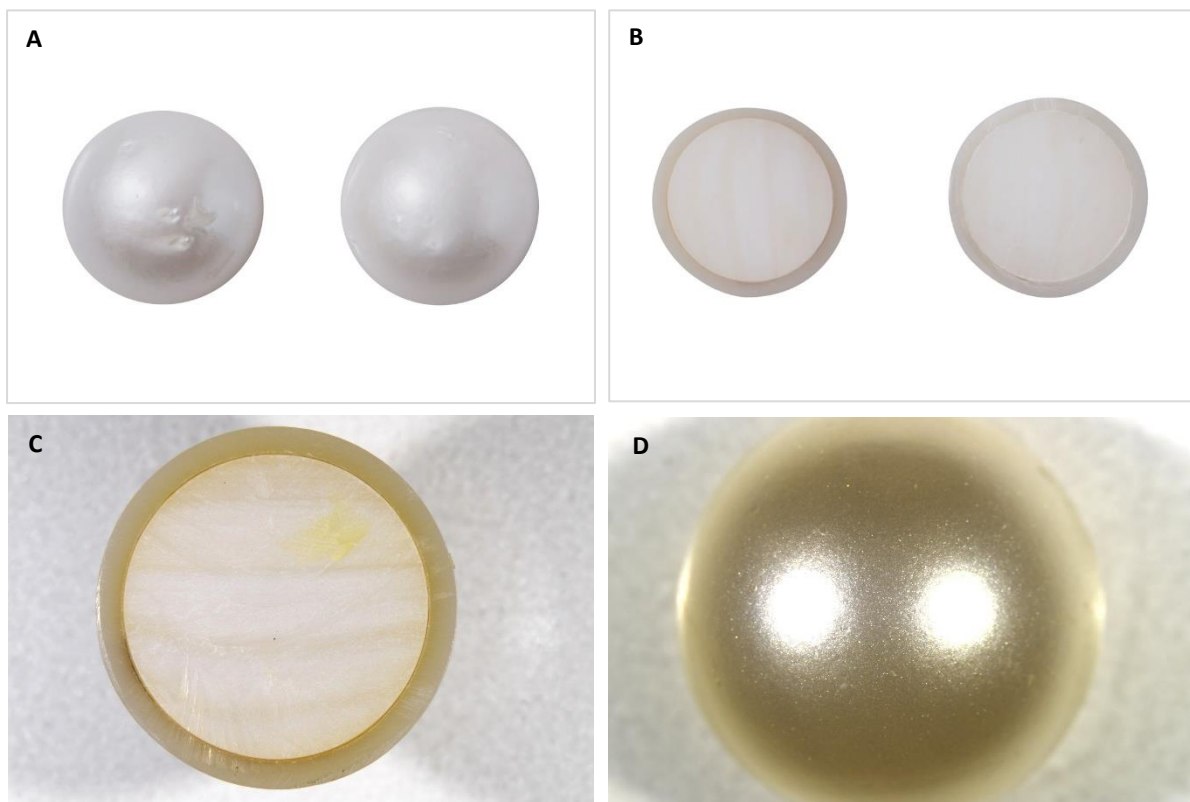


Figure 8. The macro images of a sawn pearl showing outer (A) and inner surface of each half (B). Photos by Nuttapol Kitdee. The photomicrographs of the inner half showed the demarcation between the shell bead nucleus and nacre overgrowth (C), and the appearance of the bead nucleus' surface under the nacreous overgrowth (D). Note the numerous glittering particles on the surface typically observed on imitation "pearls." Field of view 19.20 mm and 14.40 mm respectively. Photos by Kwanreun Lawanwong.

Since artificial coatings on shell bead nuclei are not typically used for nuclei in bead cultured pearl production (Cartier and Krzemnicki, 2013), sample 3 was selected for further study. Its chemistry was analyzed using EDXRF, and Raman analysis to determine the identity of the coating. Two other surface areas were also examined by each method; a small residual nacre and the original white shell bead nucleus. Manganese (Mn) and strontium (Sr) levels obtained from EDXRF analysis are the main elements commonly used to determine the environment in which pearls form. Low Mn (not over 100 ppm) levels usually indicate a saltwater environment while higher Mn (over 200 ppm) levels usually indicate a freshwater environment (Wehrmeister et al., 2007; Karampelas et al., 2019; Sturman et al., 2019). The EDXRF result from a small residual nacreous area detected high amounts

of Sr and no Mn, hence it confirmed saltwater origin as expected. In contrast, the white shell bead nucleus was found to contain much higher Mn levels and lower Sr levels, which proved it was fashioned from FW shell. Moreover, the artificial coating on the shell bead did not reveal any elements typically expected in pearl or shell analysis (Krzemnicki, 2005), but did show high levels of bismuth (Bi) (figure 9), thus proving that an artificial substance had been used to coat the nucleus.

Raman analysis of the white shell bead nucleus (figure 10, green line) and residual nacreous area (figure 10, yellow line) showed typical aragonite features at 701, 704 and 1085 cm^{-1} as expected for pearls and shells, while the Raman spectrum of the artificial coating on the shell bead was of higher intensity and produced noticeable features around 650, 1042, 1295, 1450, 1602 cm^{-1} (figure 10, red line). These features do not relate to aragonite (Urmos et al., 1991; Buzgar and Apopei, 2009) nor are they indicative of any color pigments in naturally-colored pearls and shells (Karampelas et al., 2009; Cartier and Krzemnicki, 2016; Bergamonti et al., 2011); therefore, the Raman result confirmed the artificial nature of the coating.

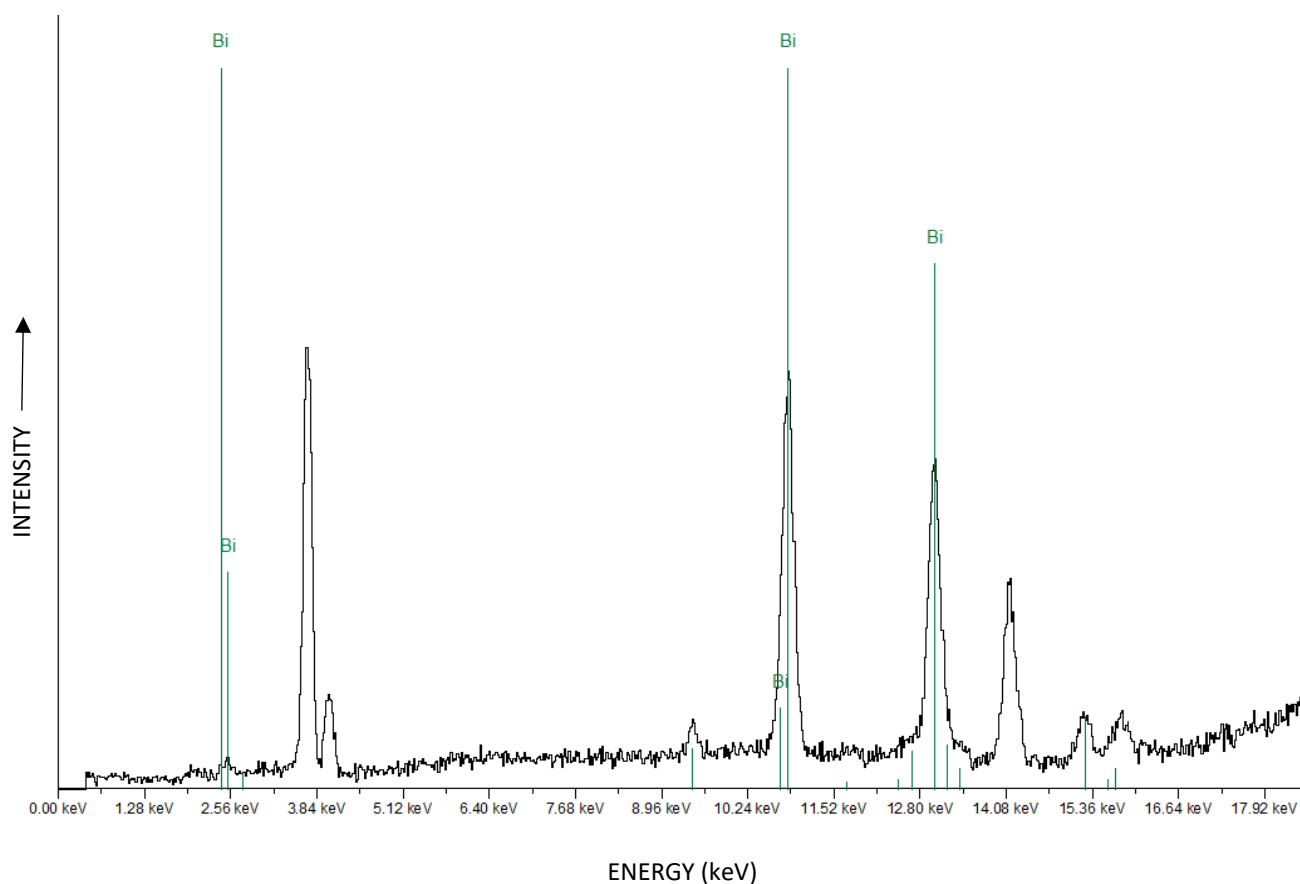


Figure 9. EDXRF analysis of the artificial coating on the shell bead of sample 3 post-process showed high levels of bismuth (Bi). This element is not found in pearls or shells and proved the artificial nature of the coating.

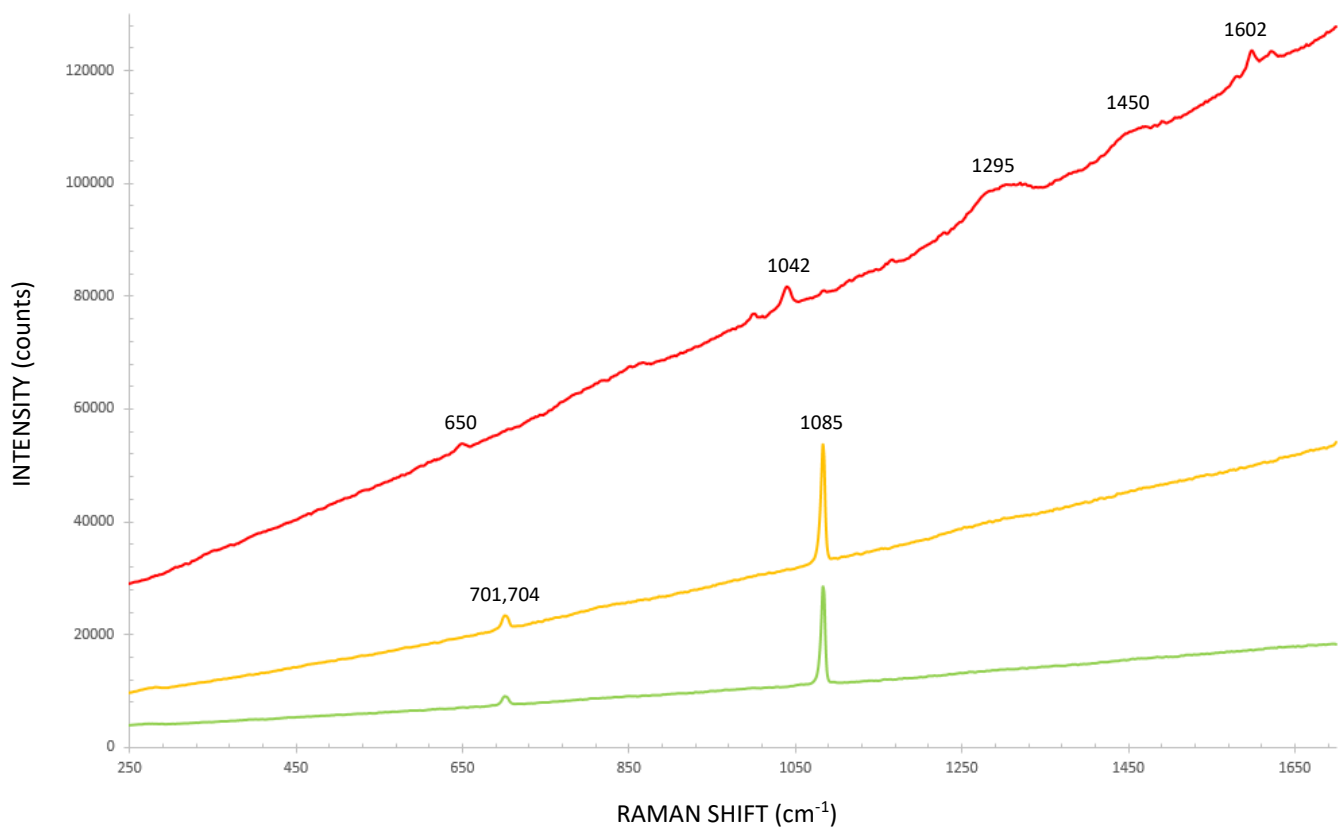


Figure 10. The Raman spectra of sample 3 post-process on the original white shell bead nucleus (green line) and residual nacreous area (yellow line) showed typical aragonite features at 701, 704, 1085 cm^{-1} . The spectrum of the artificial coating on the shell bead was higher intensity and exhibited distinct features around 650, 1042, 1295, 1450, 1602 cm^{-1} (red line) characteristic of an artificial product.

Discussion

The orient and overtone observed on the surfaces of many pearls are optical effects produced by the diffraction of white light from the pattern of nacreous platelets present on nacreous pearls. The resulting intensity is one of the factors used in determining a pearl's desirability and to some extent value (Snow et al., 2004). The more obvious the effect, generally the more desirable the pearl. This also applies to the surface quality, since the smoother and less blemished a pearl, the higher the desirability and hence, value. With this in mind, it is worth noting how the processing of each pearl impacted these features. Pre-process, sample 1 exhibited a dull luster and lacked any overtone, but post-process its luster improved and it developed an orient. Whether the orient appeared because the frosty imperfections were removed to reveal the underlying nacre or arose because the nacreous platelets were modified as a result of the process is not clear. Moreover, the pearl lost about 2.16 carats, which is quite a sizeable amount, and large enough to create some concern for pearl traders since weight (size) is one of the pearl factors that also impacts a pearl's value (Gemological Institute of America, 2011). This clearly illustrates that while the processing of pearls may improve some factors, it may on the other hand impact other factors such as the weight. All potential scenarios need to be taken into account in order to determine whether processing is warranted and value creation is likely.

Furthermore, the banded features visible in an area of sample 1 post-process indicated that the nacre was very thin. This allowed the banded structure of the FW shell bead nucleus beneath to manifest itself through the translucent layers (Cartier and Krzemnicki, 2013). Such banding relates to the deposition of calcium carbonate as growth layers in shell that relate to annual seasonal and environmental factors (Brey and Mackensen, 1997; Nehrke et al., 2012). The RTX results confirmed the thin nacre thickness with an average measurement of 0.24 mm, which falls below the typical range of *Pinctada maxima* bead cultured pearls². Thin nacre influences the quality and durability of pearls (Gemological Institute of America, 2011) and is not a desirable factor when it comes to determining the value of pearls.

Likewise, the broken yellowish brown organic areas on the surface of sample 2 showed uneven colored layers in some areas (table 3E). These layers likely resulted from the alternate deposition of aragonite and organic matter termed conchiolin (Fremy, 1855) as a consequence of the growth conditions during the pearl's formation (Snow et al., 2004; Wehrmeister et al., 2007; Ma et al., 2009).

Sample 3's surface showed numerous fine white irregular fibrous veins beneath the broken yellowish brown organic-rich layers and nacre (table 4, D and E). Some literature states that the yellowish brown organic matter is a result of disease and originally formed on the nacreous surfaces of the shell before subsequently spreading to the pearls (Southgate and Lucas, 2008). Moreover, the numerous fine veins within the pearl's nacre may be evidence of parasite or worm intrusions. The larvae stages of these organisms may bore into the shell (Menzel, 1991) and impact pearl formation, which would result in low-quality pearls (Bondad-Reantaso et al., 2007) as shown in sample 3.

The appearances and identities of samples 2 and 3 changed completely after processing. Prior to processing, they were nacreous bead cultured pearls but they ended up essentially being imitation "pearls" with only artificially coated shell beads. Typically bead cultured pearls only contain white FW shell beads (Cartier and Krzemnicki, 2013), so it is unusual to find artificially coated examples. Artificial coatings are sometimes used to imitate nacre and improve the appearance of blemished nacreous pearls (Gemological Institute of America, 2011; CIBJO 2017). However, the purpose of using artificially-coated shell nuclei in cultured pearls is still unclear, although possible reasons for their use include influencing the bodycolor of the pearl where colored coatings are used, concealing surface imperfections and uneven coloration of the shell beads, or improving the apparent surface luster. The owner of the samples claimed that the coated shell bead may also have some influence on the luster and surface quality of the pearl produced by the mollusks.

The numerous minute glittering particles of the artificial coatings of these samples (table 3 and 4) resemble some artificial coatings on the surface of imitation pearls (Hanano et al., 1990; Hänni, 2004; Gemological Institute of America, 2011; Zhou and Zhou, 2014) and artificial coatings used on nacreous pearl surfaces (Hyatt, 2011; Lai, 2017; Chow, 2019). Artificial coatings used for imitation pearls are usually composed of fish scales combined with other coloring substances when applicable (Hanano et al., 1990). Unsurprisingly, the fluorescence reactions of samples 2 and 3 post processing in the DiamondView (table 7, right) were different from those observed for nacreous pearls (Zhou et al., 2016; Nilpetploy et al., 2018). The reactions were consistent with artificial coatings used to treat

² The typical nacre thickness range for bead cultured pearls grown in the *Pinctada maxima* mollusk is 1.50 mm to 3.00 mm.

nacreous pearls (Homkrajae, 2015; Nilpetploy, 2019) and other treated-color pearls recorded in GIA's database.

The EDXRF and Raman results of the artificial coating of sample 3 also showed some noticeable features consistent with artificial coatings in pearls and imitation pearls. The high concentration of bismuth (Bi) in the EDXRF results (figure 9) is typical of many artificial coatings (Krzemnicki, 2005; Hyatt, 2011; Zhou and Zhou, 2014). In addition, the feature at approximately at 1602 cm^{-1} in the Raman (figure 10) spectrum has also been noted in some artificial coatings (Krzemnicki, 2005; Lai, 2017; Chow, 2019). Given the results of samples 2 and 3, and an additional sawn pearl that was provided for examination, it is probably safe to assume that all the samples studied contained an artificially coated shell bead nucleus. However, under routine identification procedures they would still be considered bead cultured pearls as their internal structures are not in keeping with those of atypical bead cultured pearls (aBC) studied previously (Hainschwang, 2010; Hänni et al., 2010; Cartier and Krzemnicki, 2013; Cartier et al., 2013; Scarratt et al., 2017), and for the fact that destructive testing would be necessary to prove the existence of the coating under the nacre. When only the shell bead nucleus remains post-process, it is obviously an undesirable outcome, as all the pearl value factors disappear and it becomes an unmarketable product. This proves that such processing is not always straightforward; it usually requires care and effort in order to prevent such outcomes.

On the other hand, the results of samples 4 and 5 were improved in that they remained nacreous pearls; however, it is debatable whether their surface appearances were improved as the processing appeared to grind down the outer layers and allow the underlying imperfections to show more clearly. This was especially true of sample 4 where the color changed from white to cream and silver post-processing, and many unsightly veins and imperfections were revealed (table 5). Although all the tiny white surface spots of sample 5 were removed by the process, a cluster of imperfections became darker and hence more apparent (table 6). The results of samples 1, 4 and 5 clearly show that the pearl processing is not always successful, but some change may be evident and is generally better than no change at all or an outcome where the results are obviously detrimental.

Unfortunately, the exact nature of the methods used in processing these samples was not disclosed; however, the results provided some clues. Post-process, the visible nacreous surface layers and features of all relevant nacreous samples were altered to different degrees, and their nacre thickness decreased. Such results indicate that working (grinding) and/or surface peeling may have been applied to remove the outer poor-quality surface layers, or to re-shape the pearls in order to make them more symmetrical as well as improve their surface appearances. Additionally, the surfaces of samples 1, 4 and 5 looked much smoother and more lustrous, and exhibited fine polishing lines. Most of the nacreous surface platelets appeared to be modified and showed very faint and smooth edges, while many organic-rich surface areas and imperfections were ground down and revealed molten-looking smoothed edges. These surface features indicated that the samples had been polished to varying degrees in order to smooth out the underlying exposed layers and create a higher luster.

Furthermore, the fluorescence reactions of all the nacreous samples under LWUV radiation showed a stronger chalky/powdery greenish blue to varying degrees (figure 7D). These differed from the reactions observed pre-processing (figure 7C). The chalky/powdery appearance under LWUV is not typically seen in untreated South Sea cultured pearls (Elen, 2001; Strack, 2006), but is more commonly observed in akoya and FW cultured pearls which are routinely bleached (Roskin, 2002).

Therefore, bleaching was most likely another method used in the processes applied to these samples. However, the LWUV reactions of the samples were not in keeping with known akoya and FW cultured pearls, and bleaching is not as routinely applied to South Sea cultured pearls (CIBJO, 2017).

Samples 4 and 5 also showed stronger bluish white reactions around surface imperfections under ultra-shortwave UV radiation in the DiamondView (table 7, red arrows). This might indicate that chemicals were applied during processing and residues were trapped around these imperfections. The results were consistent with the reactions observed under LWUV and point towards the application of other chemical substances beyond those typically used in standard bleaching processes.

Conclusions

Pearls typically selected for processing are usually of lower quality with low values. There is no guarantee that the processor will benefit from the procedures applied (Koivula et al., 1993) and they might even take a complete loss. The results of this study prove that pearl processing does not always improve a pearl's appearance and by default increase its value; rather, it might decrease the value and impact the appearance negatively. All the samples in this study were low-quality pearls when first submitted. Two of them possessed dull cloudy lusterless surfaces while the others exhibited rough unsightly surfaces with obvious imperfections and organic-rich features. After processing, it was debatable whether any could be classified as higher-quality pearls, since some pearl value factors were improved but other defects remained, or their conspicuousness increased. However, two samples lost all their pearl value factors since only shell bead nuclei remained after processing.

Samples 1 and 5 fared best from the processing. Their surfaces became more lustrous and smooth, but the very thin nacre covering on the base of sample 1 decreased durability and increased the chances of damage, while imperfections on the surface of sample 5 became more visible, thereby bringing into doubt whether their quality actually improved. Samples 2 and 3 could not be classified as pearls after processing and lost any value they may have processed as a result. Even though sample 4 retained its nacre, its quality and appearance decreased post-processing. Its appearance worsened and it lost what little beauty it had before, owing to the increased visibility of the imperfections that were previously masked.

Nevertheless, the results show that pearl processing has an impact, whether negative or positive, but requires experienced staff, effort, and a degree of care from those involved in order to obtain optimal results and reduce the chances of failure. Although the majority of pearl dealers are no doubt aware of the various processes that can add value to pearls, this study will serve as a useful reminder, and clearly illustrates that durability is an important factor to consider. Even though it is challenging to prove which processing methods were applied, surface features on sample 5 indicated that it was subjected to significant polishing. Yet other methods may also have been used in conjunction that were masked by the polishing, making it hard to identify them. Therefore, it is the producer's responsibility to disclose when any form of processing has been applied, so as to be transparent with clients and increase their trust. Such integrity is also important when it comes to ensuring clients understand the value of the products they are purchasing and any potential long-term changes to the pearls' appearance that may develop. For their part, the manufacturers have to evaluate how they can obtain maximum benefits from their processing and counterbalance the pros

and cons that result. When considering which pearls are suitable candidates for processing, the most important factors would be size, and by default weight, since they decrease as a result of processing, and the severity and type of blemishes. Some types of blemishes no doubt respond better to processing than others and that is where the selectors' experience likely proves invaluable.

While pearl processing may be of some concern to the buyers, some specific techniques nonetheless have the potential to greatly improve or repair a pearl's surface appearance. It may, therefore, be the best option to use when reinstating the beauty and apparent value of pearls with broken or damaged nacre such as the example featured by Mr. Nava-Romo (McLaurin-Moreno [Video], 2008) undergoing a transformation during a peeling process.

Artificially coated shell bead nuclei are not typically seen in bead cultured pearls and the reason for their use is still not fully understood. However, these nuclei are of no concern to pearl testers since they are classified as bead cultured pearls when overgrown by nacre. The results of this study showed that only three samples were still classified as bead cultured pearls after processing. This meant that only a limited study on the characteristic surface features of the pearls that remained intact was possible, hence more samples are needed for a more comprehensive study. It would also be of interest to study cultured pearl samples produced by other mollusk species such as *Pinctada fucata martensii* (akoya) or *Pinctada margaritifera* (Tahitian) and compare the differences observed between them post processing. Upon completion of this study, all the samples were returned to the owner but it is doubtful they will ever find their way into the market given the results detailed. The processing of pearls using multiple techniques, including polishing, heavy polishing, working, heavy working, peeling, or a combination of these and other possible undeclared procedures, is currently used in the trade to improve the appearance, and as a result, value, of both cultured pearls and natural pearls of all types.

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