Rethinking Proactive Dental Care: Examining the Impact of QLF on Dental Motivation and its Potential as an IoT Home Product

Elvis Lee
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Imperial College London Design Engineering

Abstract—There is a conspicuous lack of dental care products in the current market that give quantifiable data to users for better management of oral hygiene. Relying on routine maintenance and the occasional sign of problem in looking after our teeth, dental healthcare as a reactive realm emerges as the norm. This in turn has clear implications on general dental health and patient motivation. Taking plaque as the main indicator for dental issues and motivation, the paper introduces a phone-mounted QLF (quantitative light fluorescence) prototype to investigate its effect on dental motivation. It then discusses the future of QLF dental care products, and the potential transition towards a more proactive tele-dental health system.

Keywords—QLF, dental motivation, plaque, prototype, fluorescence

I. INTRODUCTION

The dental industry has always been a reactive field. This could be attributed to various reasons such as negative past experience, relative invasiveness or high treatment cost, but by far the largest factor appears to be simply that we only visit the dentist when it is necessary. Although how often one should visit their dentist depends on their evaluated dental risk, it is generally good practice to have a dental check-up at least once a year to maintain dental hygiene [1]. Yet, initial interviews with 18 participants between the ages of 19 and 24 revealed that 89% frequent less than once a year, and 31% of those people only go when they experience pain and require professional help. Aligning with the retroactive connotations of healing or restoration to good health in words like 'therapy', 'medicine', and 'treatment', this study highlights a lack of proactiveness and motivation in maintaining dental health.

This lack of proactiveness and motivation can often be inferred from one's ability to manage dental plaque, given that plaque is one of the biggest indicators of the three most common dental issues (tooth decay, tooth sensitivity, and gum disease) [2]. The accumulation of plaque can be prevented by proper brushing and good hygiene, but small quantities of plaque are invisible and can be difficult to accurately remove. Without the dental motivation to maintain good oral hygiene, plaque can build up to eventually become larger issues. This paper aims to propose and test a dental scanner with QLF capabilities built for home-use and examine how it affects dental motivation, to investigate whether QLF technology has a place in promoting future preventive dental products at home.

II. BACKGROUND

A. Dental Motivation

One of the most fundamental steps to achieving good oral health is to have the motivation to clean our teeth properly. In an interview with orthodontist Dr. Clement Lau, he emphasised that motivation is key to maintaining dental hygiene ('Brushing [people's] teeth isn't hard', he said, 'but getting them to brush it is.'); he also highlighted that the lack of it is closely associated with plaque build-up and periodontal disease[1]. Not only can plaque appear on any tooth surface and become difficult to remove, there are also areas which the average toothbrush cannot reach, allowing plaque to develop more easily in those concentrated spots. Dr. Lau continued to stress that removing plaque build-up is even more difficult without an electric toothbrush, which also adversely impacts dental motivation over time, because having the proper tools (high-quality or electric toothbrush) for the job is the best way to be motivated to maintain oral hygiene.

An important factor in individual dental motivation is the presence of clinical feedback from a dental professional. Naturally, the person delivering clinical feedback is critical, as seen in a study investigating OHI (Oral hygiene instructions) and patient motivation. The study looked at dental systems such as Belgium, in which the role of dental hygienist does not exist, and concluded that dental hygienists, or further trained dentists with hygienist knowledge, is highly beneficial for patients and their overall motivation [3]. This is supported by Uitenbroek et al.'s study, which found that patients who continually received professional feedback by a dental hygienist score significantly better than those who are not [4] on a scale which evaluated knowledge, attitude, self-care, and motivation. As a result, an important link can be drawn between dental feedback and its level of professionalism, showing the impact both factors have on an individual's dental motivation.

Another factor affecting motivation is the different types of clinical feedback. Within the U.K., the NHS have implemented a 'Red, Amber, Green' (RAG) dental risk evaluation system in hopes of 'encouraging [the public] to take ownership and responsibility for their own oral health' [5]. The importance of various forms of feedback is illustrated in a study evaluating a patient's "willingness to pay" (WTP) for feedback information, in parallel with the RAG traffic light system [5]. The study found that patients are willing to pay up to 20 pounds per session for verbal feedback, 18.8 pounds for QLF (quantitative light-based fluorescence), a light-based plaque identifier, and only 10 pounds for "traffic light" (TL) [5]. Additionally, a positive correlation can be identified between higher willingness to pay and improved oral hygiene during subsequent appointments, indicating a link between high-value feedback and dental motivation. Another form of feedback explored involved the use of intra-oral cameras in conjunction with verbal communication. A study found that patients were more driven to take steps to improve their oral health and 'agreed more quickly to a course of treatment' under the combination of intra-oral camera feedback and communication with the dentist [6]. Although this finding could be influenced by the physical presence of a dental

[1] periodontal disease is the inflammation of the gums and bone that surround and support the teeth (CDC, 2018)

professional, it nonetheless suggests that these patients gained increased dental motivation from tailored dental feedback.

B. Causes of Poor Dental Health

Most dental complications begin with plaque build-up. There are over 700 different types of bacteria within the oral cavity in humans, some of which adheres to the surfaces of teeth to form, initially, thin biofilms [7,8], which eventually harden to become tartar (calculus) in as little as 48 hours. Whilst plaque is natural and contributes to the development and defence of our bodies [9], the formation of tartar (semi-permanent plaque buildup) can lead to more serious health concerns, particularly because it can only be removed by a dental professional [10]. Bacteria within plaque have been found to be directly associated with cariogenicity[2] and the capability to demineralize enamel [11]. The result of this is hyper-sensitive teeth that trigger discomfort or pain when in contact with cold foods and beverages. It can also compound existing dental issues such as the weakening of the gum-tooth structure which can lead to periodontitis, encouraging further development of plaque and cavities [12], or even necessary tooth extraction [2]. These dental issues take time to develop, making plaque build-up a clear indication of lower levels of dental motivation.

C. Quantitative Light Fluorescence (QLF)

The aforementioned QLF (quantitative light fluorescence) is a method of plaque detection that utilises the natural red fluorescence of specific bacteria in the biofilm, which occurs under excitation by the light of blue-violet wavelength. However, the excitation of this biofilm is a sign of maturity instead of cariogenicity [13], meaning that the existence of red fluorescence indicates general plaque buildup, instead of dental issues such as cavities due to cariogenic bacteria. As the desired wavelength encompasses both the blue light as well as some ultraviolet light, a small range of wavelengths between 380-405nm all appear to excite plaque to emit red fluorescence [14-16]. The technology was adapted by Waller, van Daelen, and van der Veen to create the QLF-D Biluminator™ 2 [15], which utilised a larger camera and a QLF attachment containing the UV LEDs and optical filters. Their study shows that this natural fluorescence can be captured by any camera with a high pass optical filter for dental feedback, which blocks the initial blue-violet light from obscuring the fluorescence.

The more commonly known plaque identification methods include teeth staining tablets, or professional dental examinations. In comparison, QLF is a new technology, and a google search for plaque and UV shows no QLF-related plaque identification articles written before 2020. Nevertheless, QLF has been used extensively to research oral biofilms [17-18], and for clinical use and development of intra-oral scanners such as the products from Inspektor Research Systems [19-20]. Inspektor also mentions on their website that ‘prevention is better than cure’ and emphasises that ‘Up to 70% of oral health problems suffered by you and those around you can be avoided if prevention is taken seriously’, supporting the need for proactive dental health [21]. Their products all contain QLF capabilities and optical filters, allowing users to see plaque easily, but are relatively expensive and mostly geared towards clinical and research use. While it seems likely that home-use products will be the next step, they currently do not have any product available in the market yet, a potential reason being the long FDA medical kit approval duration [22]. Other products have also started to incorporate QLF technology, such as toothbrushes from Miharu-kun [23], Prophix by Onvi [24], and Sonicare by Phillips [25] (figure 1).

Fig. 1. Current QLF devices. (top left) Sonicare. (top right) LumiO. (bottom left) Prophix. (bottom right) Miharu-kun

A prototype called LumiO created by the IIS lab in Japan references both Miharu-kun and the QLF-D Biluminator™ 2 [15], integrating QLF in the toothbrush head [14]. The paper provides detailed description of its functionality and an illustration of how a QLF-capable device can be built. Though the fluorescence can be seen by eye, 3D visualisation products have also been created such as Sonicare’s app [25], the I-tero element [26]. Visualisation without QLF has already proven its link to motivation such as Park and Chintal’s intra-oral scanner based on confocal laser scanner microscopy, as they all demonstrate the capability to inform patients on their cleaning methods and help maintain good oral health [27]. As QLF information is a strong form of dental feedback, it provides a clear link to dental motivation and shows prominent potential in the self-care home product market.

III. Method

A. QLF Prototype Study

For the purpose of this study, a prototype with QLF capabilities has been made. An ethics form was submitted and approved by the Dyson school of Design Engineering at Imperial college, detailing the prototype, potential risks, and study activities (appendix section A). Three main things were investigated.

Firstly, the effects of having a QLF device on an individual’s brushing habit will be investigated. This will look at whether the existence of a dental health aid affects the participants in any way. The data received will come from interviews in which participants will be asked for their opinion

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[2] The potential for producing carries (cavities/tooth decay) (Medical dictionary)

on the prototype's ease of use, usefulness, functionality, and overall experience.

Secondly, the prototype will be evaluated on how well it can help participants reduce plaque content every time they brush their teeth. A total of four participants were given the prototype and asked to photograph the front of their teeth four times a day for a total of eight days (once before brushing, once after brushing, twice a day). Data was separated into two groups – Group A (days 1-4) and Group B (days 5-8) – the latter of which included plaque feedback. Participants received the python GUI (graphical user interface) and image analysis interface once they have submitted the 16th image marking the end of day four. All collected data will then be analysed using the paired T-test statistical method, looking for any significant difference between pre and post brushing images for both groups.

Finally, feedback will be introduced to measure the effects it has on dental motivation. A reduction in plaque would suggest higher levels of motivation, as well as more informed brushing with the help of the QLF device. It will be expected that having the participants use a device alongside their current brushing routine will introduce observer bias in both halves of the study, which is why the additional variable of feedback will be the only point of investigation in the second half of the study (days 5-8). Participants will use a python based tkinter* GUI to upload their images for analysis. Subsequently, in real time, participants will be able to get both a plaque percentage and an image analysis of where the red fluorescence is, thereby indicating where the plaque is. After the study, the data will also be analysed using the paired T-test analysis method, which will look at whether feedback has any significant effect on plaque reduction, and hence the participant's dental motivation.

There are many ways to measure the effect dental feedback has on motivation, but this quantitative method measuring plaque percentages was chosen instead of qualitative methods, as it offered an opportunity to introduce a product prototype with QLF capabilities. Whilst it is difficult to obtain any statistical significance from low participant numbers and basic plaque analysis (discussed in section C), this method aims to lay out some foundation for future QLF product research and explore how data can affect motivation.

B. Prototype Creation

The prototype is inspired by LumiO [13] and is a basic QLF functioning device which can be equipped for the iPhone (versions 6S and above) (figure 2). In general, a smartphone mounted product was chosen due to the high probability that participants will own one. Furthermore, the iPhone has been chosen to standardise prototype design and camera quality. The 3D-printed model contains an iPhone holder, a battery pocket and a blacklight (wavelength 405nm) which has been adapted from a small blacklight torch. The blacklight is powered by 4xAA batteries and is put on an angled surface of the device to properly illuminate the user's teeth instead of shining directly perpendicular to the face. Angling the light down also helps avoid any risk of shining the light into the user's eyes.

Typically, optical filters are incorporated in QLF devices to reduce excess light which would block the visibility of red fluorescence. Various optical filters were tested for the initial stage prototypes (figure 3, Left to right: 495nm, 550nm, 600nm). The early prototypes utilised USB powered blacklights, powered through the output of a lightning port on the iPhone (figure 4). However, the blacklights did not function as the iPhone could not output enough power, and the effects of the optical filters did not significantly improve the visibility of plaque; instead, the higher wavelength filter colours became increasingly red (appendix section B). As a result, whilst the correct wavelengths are removed, the images captured had an additional red colour filter camouflaging with the plaque fluorescence. Another issue encountered in this prototype was that the inherent brightness and reflectiveness of the teeth often obscured the fluorescence and other details to be seen. Therefore, the actual prototype used in the study did not include the optical filters and the photos taken were raw images with just UV light and the iPhone camera.

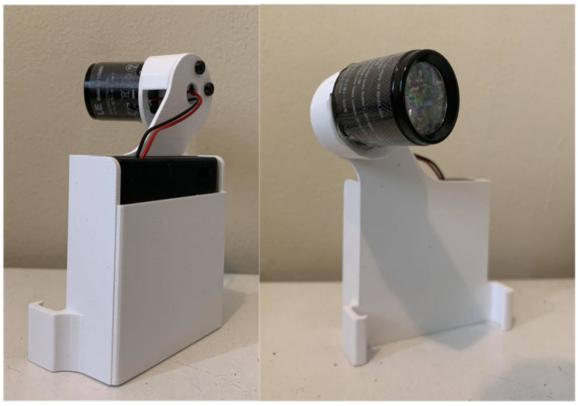

Fig. 2. Proposed QLF prototype

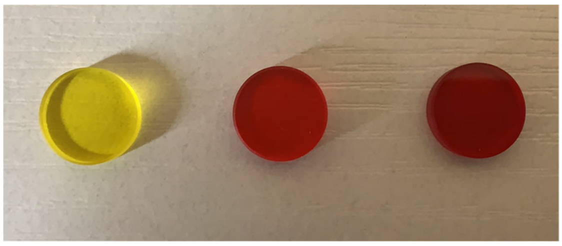

Fig. 3. Optical filters with increasing wavelengths (left to right) 495nm, 550nm, 600nm.

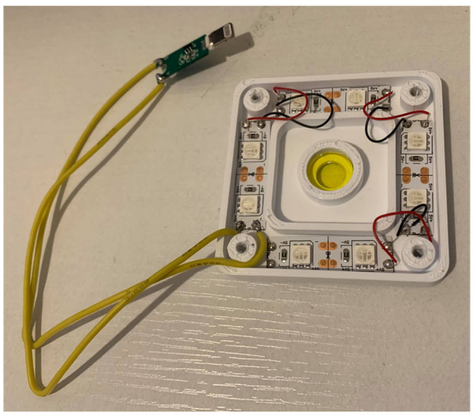

Fig. 4. Initial iPhone powered QLF prototype

C. Software and Plaque Analysis

To accompany the prototype, two things were needed: a way to analyse the QLF images, and an easy way for participants to get real time feedback. For this, a python program containing RGB pixel analysis and a tkinter GUI were created. The code was sent to participants, and the GUI was used to upload their images and get plaque feedback. The actual analysis method required a cropped image with as little non-oral cavity in the picture as possible (figure 5).

Fig. 5. Participant image before cropping, illustrating background

This was to help the analysis focus on the colour distribution around the teeth and gums instead of the background. To determine what areas of the teeth were plaque and fluorescing red, a value called 'Red_ difference' was created to determine what was 'red enough'. The formula for 'Red_difference' was (R-G) + (R-B), where G and B are the pixel intensity values of green and blue respectively. Greater values of Red_difference highlighted the 'redder', more intense pixels that are likely to be plaque. While this is a relatively simple way of achieving basic plaque analysis, initial tests proved to be effective at communicating plaque locations. This generates relatively accurate and reliable data, thus inadvertently increasing participants' faith in the prototype and potentially their motivation to use it as an informative dental tool. Figure 6 displays the accepted pixels which would be identified as plaque.

Another part of the analysis is the GUI that participants will interact with to get feedback during the second half of the study (figures 7, 8, 9). A simple program was created along with an instructions page in attempts to standardize

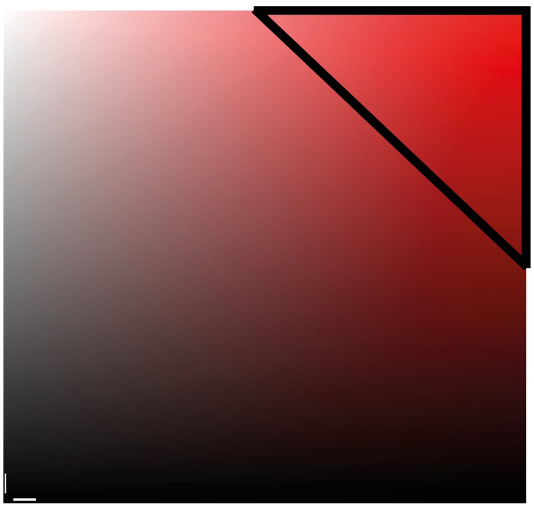

Fig. 6. Red_difference > 120 parameter example in RBG colour pallete

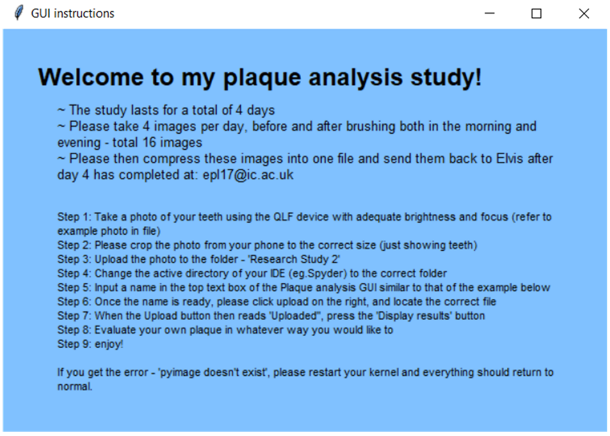

Fig. 7. GUI instructions page

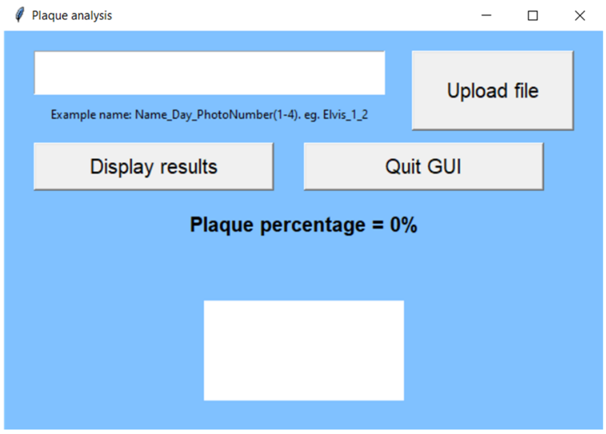

Fig. 8. GUI blank interface

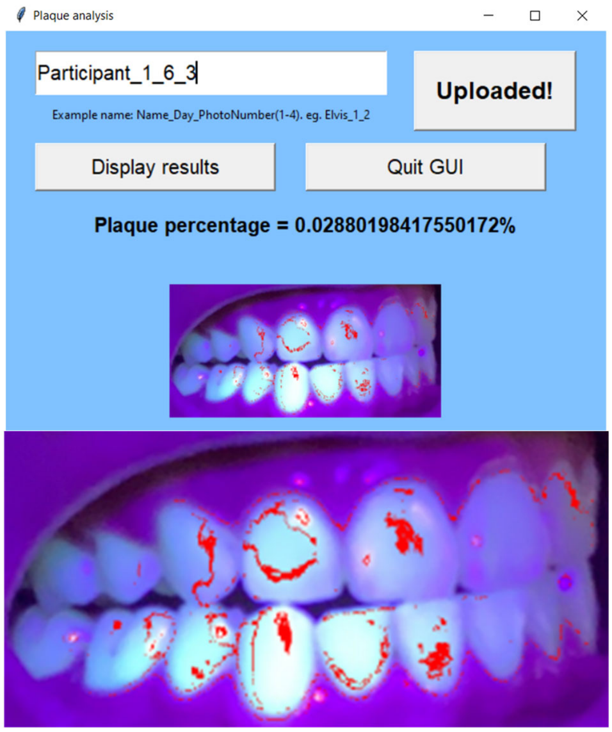

Fig. 9. GUI displaying plaque feedback. (top) GUI display. (bottom) Plaque image, plaque indicated as red (255,0,0) RGB pixels

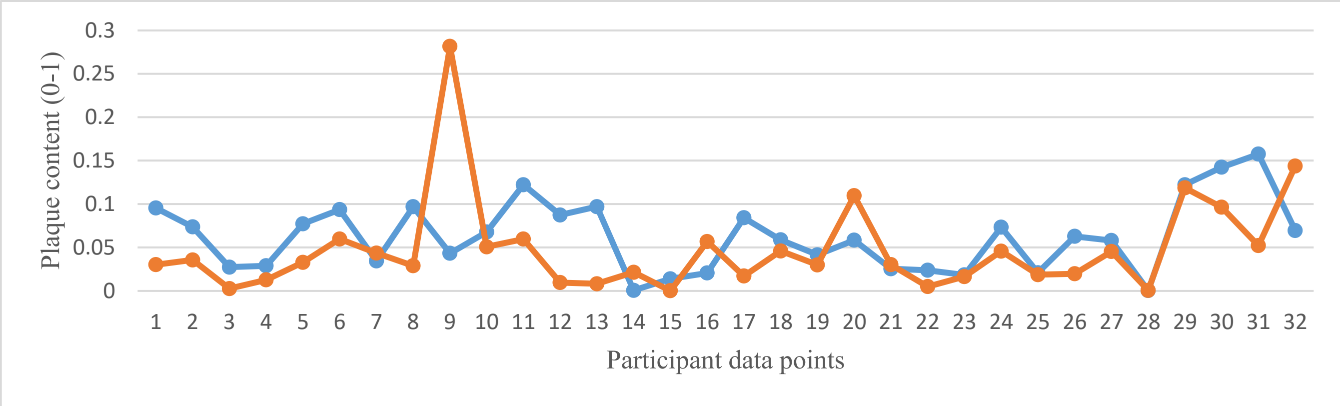

Fig. 10. Group A pre-brush and post-brushing plaque difference. (blue) Group A. (orange) Group B.

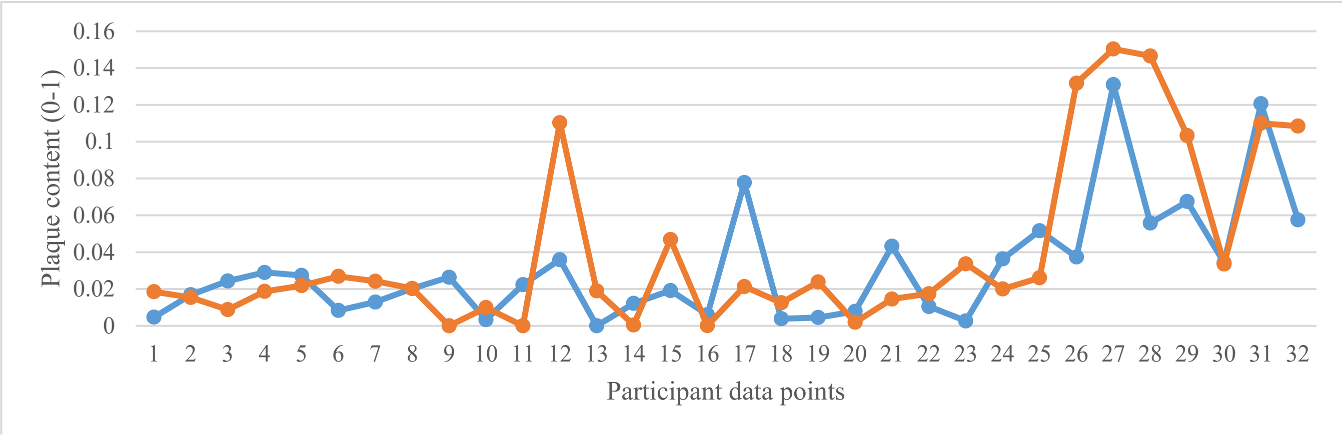

Fig. 11. Group B pre-brush and post-brushing plaque difference. (blue) Group A. (orange) Group B.

images in terms of brightness, the UV intensity, capture angle, and image clarity. The GUI contains a detailed instruction sheet which appears every time a participant wants to use it, allowing participants to follow the instructions clearly. The program also saves two more images in the same folder, one which highlights where areas of plaque are, and one which highlights where the program thinks the surfaces of the teeth are. After uploading an image of their teeth, participants can press the 'display results' button, allowing them to view their plaque (figure 9).

IV. RESULTS

Figure 10 displays plaque differences for each brushing period across the sample size of 32. Whilst 25% of the data points displayed that plaque levels were higher post-brushing, the average difference of plaque content was 0.0146, indicating that the prototype had a positive effect on plaque reduction. The calculated t value for group A was 1.493, which compared to the table value of 2.037 [28] for a study with sample size 32 and p = 0.05, indicates no significance.

Figure 11 displays the same plaque difference for group B. Here the discrepancy between post-brushing and pre-brushing

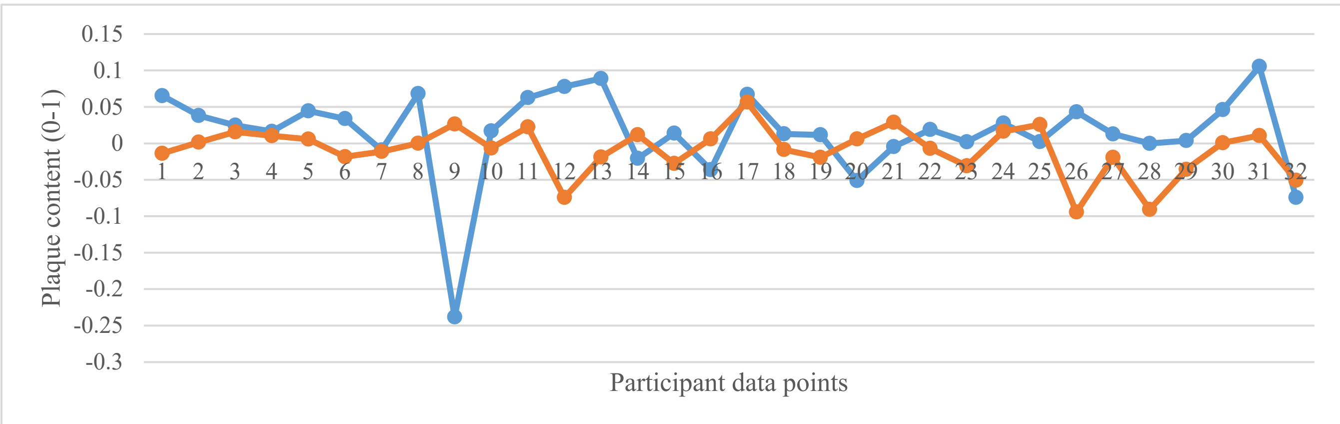

Fig. 12. Plaque difference between Groups A and B. (blue) Group A, (orange) Group B

is ambiguous, and the average plaque difference was -0.009, meaning measured plaque increased post brushing. The calculated t value was -1.694 for group B compared to the same 2.037 table value previously and shows no evidence of either value of pre or post brushing being significantly larger or smaller than the other (two-tailed test). However, in terms of plaque percentage, data from group B shows a reduction of overall plaque, up to 50% or more.

Figure 12 shows how the plaque differences compared between groups A and B. The expected result is that group B will have a slightly average plaque difference due to there being feedback and therefore less overall plaque. The average plaque content analysed per image was 0.032 pre-brushing, and 0.041 post-brushing compared to that of 0.062 pre-brushing and 0.048 post-brushing for group A. Indicating a general decrease of 0.031 between pre-brush results, and 0.0073 between post-brushing data. Figure 13 displays this and clearly shows that there is reduction in plaque content before brushing between A and B. Table 1 shows the calculated t values and the table value for significance.

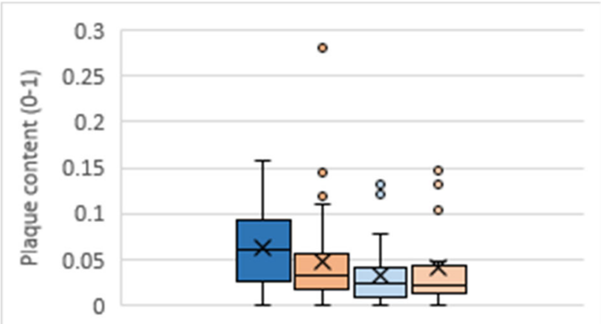

Fig. 13. Measured plaque content distribution (left to right) group A pre-brush, group A post-brush, group B pre-brush, group B post-brush

TABLE I. STUDY SIGNIFICANCE AND T VALUES

Chosen samples from Groups A, B	Calculated T value	Table T value	Significance
Plaque difference	0.060	2.037	Not-significant
Pre-brush plaque	0.129	2.037	Not-significant
Post-brush plaque	0.018	2.037	Not-significant

Figure 13 also displays the plaque content across all four stages of brushing (pre and post for both group A and B) in a boxplot diagram. The largest outlier was a plaque percentage of 28% post-brushing in group A. The average plaque content across the entire study was measured at 4.56%.

A. Participant Results

Although the study overall did not show significance in plaque reduction, a closer look into participant data reveals future study potential given better control of variables and higher participant numbers. Figure 14 shows participant 1 and their plaque percentage pre and post brushing during the first 4 days. The images were relatively consistent, and the average plaque reduction was 0.035. This was likely due to the fact that participant 1 took pictures in the same way every time, and the successful outcome of this was better accuracy in plaque analysis.

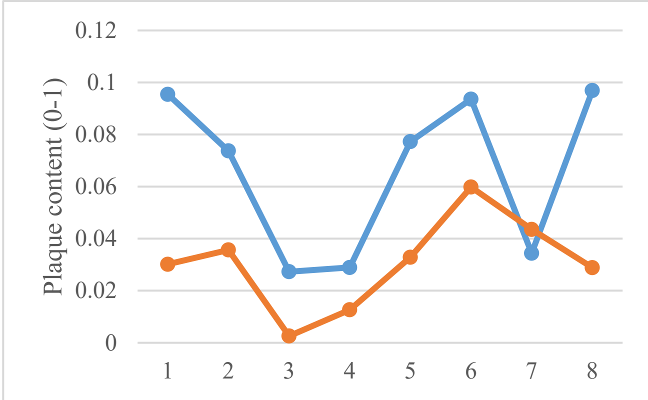

Fig. 14. Participant 1 data, Group A. (blue) pre-brush. (orange) post-brush

V. Discussion

A. Objectives and Limitations

The objective of this study is to firstly introduce a QLF prototype with phone attachment capabilities built for home use, and evaluate the effect it can have on dental motivation. In the current dental health market, there are very few QLF-embedded products and even fewer products which are non-toothbrush related. As thus, an important part of this paper is to introduce this possibility of incorporating clinical analysis technology into everyday homes, to see whether it increases dental proactiveness. This level of motivation was measured through plaque reduction using the image analysis program, the accuracy of which will also play a part in dictating the effect it has on motivation (i.e. if a user realises after prolonged use that the analysis is not quite accurate, their motivation to improve brushing will possibly decrease along with their faith in the product and its results). However, the balance between how accurate the plaque data needs to be to measure QLF, and the extent to which it affects dental motivation is something not explored and requires further research.

The second objective is, to the best possible fidelity, evaluate plaque using the prototype. The quality of the QLF imagery that the prototype can capture will be limited in its accuracy and quality. To properly capture accurate QLF images, a device would require both stronger and more UV lights, on top of an optical filter to eliminate wavelengths below red light (<490nm – yellow/green optical filter for lower interference of red fluorescence), and a general light filter such as neutral density filters* to reduce overall exposure and brightness. With the added intensity of UV lights, the quantity of UV may start to be more harmful if exposed for longer periods of time, and a method to mitigate this risk would need to be built into the system as well. This could be in the form of a quick flash use of UV during the actual capture of the image, exposing the user to only milliseconds of UV per image. Other variables which affect image quality and standardisation include factors such as image angle, area of lighting, and even the participant's smile (figure 15).

Fig. 15. Image inconsistency example (a) lighting (b) angle (c) reflectivity

Under more optimal conditions, with the ability to do in-person studies (precluded in this paper due to COVID-19), the best way to gather data would be to physically take the photographs for each participant myself. This could also be done with a chin-rest rig setup (figure 16), which would result in almost identical photographs. The images in this ideal scenario should also be clearer, where plaque would be seen in more detail, allowing for better analysis and interpretation of results.

Fig. 16. Head rest (chin). Commonly used for eye examinations

An example of the discrepancy between the images and what QLF feedback should look like, is the difference between what the eye can see in the mirror with blacklight, compared to what is seen through a camera. As the prototype does not contain the two layers of optical filters which would improve the accuracy of plaque detection, it captures too much unwanted light 'noise'. A good example of QLF imagery are ones taken with the QLF-D Biluminator™ 2 [15]. These images show clear red fluorescence in relatively precise quantities, and the difference in fluorescence clarity is clear when the two pictures put next to each other (figure 17). This is one factor which explains how group B results for post-brushing plaque were higher than pre-brushing (0.0410 post-brushing compared to 0.032 pre-brushing), which is most likely an accuracy issue in both the image quality as well as image consistency. This will have some effect on the validity of the study as it directly affects the link between plaque analysis accuracy and dental motivation. Further research will need to be done to evaluate the extent of this relationship as it will depend on factors such as study duration; nevertheless, the lack of clarity in plaque location will introduce a level of invalidity in the results.

The measured data on plaque content had high variance due to the discussed limitations of both the prototype and human factors. This describes features such as the slight increase in plaque content in figure 11 towards the end of the

Fig. 17. QLF image difference between (top) QLF-D Biluminator [14] and (bottom) QLF phone mounted prototype. (circles in red) identified areas of plaque

study can only be explained by the lack of consistency. In an ideal situation, both figures 10 and 11 would show much more consistent levels of plaque across the eight days. The expected fluctuation would be slight increases in plaque between post-brushing results and the next pre-brushing result.

B. Positive Outcomes

Whilst there can be no statistical significances drawn from the study due to low values of n, the study was still a success in other areas. Participants in the study mentioned post study that the use of the prototype helped them focus on their brushing more and changed the experience of brushing from routine to 'targeted cleaning'. All 4 participants also mentioned that the use of the prototype was not an annoyance, but instead they all looked forward to the next time they could see plaque on their teeth. This link to increased dental motivation from interest in the prototype was an unforeseen connection which aligns well with the trends of self-care, tracking self-data and their motivational value [29]. The prototype also succeeded as a means of illustrating how QLF would work and how users should expect to use such a device, meanwhile providing QLF data which enabled the potential for any change in dental motivation.

Furthermore, the lack of significance between pre-brushing and post-brushing plaque content is not necessarily a negative outcome. Despite some inaccuracy in plaque detection, the detection of little to no plaque might simply indicate that participants had less plaque. As the participants from this study were not recruited from a clinic and are reasonably healthy, the expected plaque contents would not be very high. Furthermore, prolonged and correct use of the product and QLF technology should also lead to gradually decreasing levels of plaque being displayed, at which point the device should only show the fluorescence of the thin biofilm built up during the time between daily brushings (approximately 10-12 hours).

C. Next Steps and Technology Potential

Though this paper introduces QLF as a phone-mounted device, the technology is straightforward and can be adapted easily for other products and uses. Looking at the future of phone-mounted QLF devices, some options for development could be a compact QLF device which is easily clipped on any phone and can take high quality pictures. These devices would be similar to my initial prototype design, but would potentially include a rechargeable battery pack and a transparent cover that can also act as the optical filters. Still within the realm of phone accessories, QLF can even be embedded in an automatically charging phone case. Whilst the QLF technology would add some size to the case, it would be more compact than an external device, and the blacklight could have a secondary use for sanitary check.

However, as the product aims to be a proactive dental health product, bathroom-related products should be considered. Smart mirrors are starting to become more common, and will have more diverse functionalities integrated into our daily routines [30]. An embedded QLF system could be built into the smart mirror, allowing for an even simpler way to check for plaque. To integrate some IoT (Internet of things) into the system, the smart mirror could automatically be blacklight-ready for plaque scanning as soon as the user picks up their toothbrush, allowing the mirror to capture dental data as you brush.

In parallel to QLF devices, tele-dental health can be introduced by sending QLF imagery taken from home directly to the dentist, acting as one's dental medical record. Any scanned imagery can be automatically uploaded to a shared cloud space so that dentists can remotely raise concerns to their respective clients after examining their QLF plaque images. The advantage of such a system is that it allows more frequent and seamless communication between patient and dentist, raising the possibility of early diagnosis, hence saving both time and money. This would also eliminate the need for patients to manually scan and upload images for their dentist. As tele-dental health becomes commonplace, dental care moves away from the binary of proactive and reactive dental healthcare, to promote shared responsibility towards dental health. Figure 18 shows a diagram of a proactive response system.

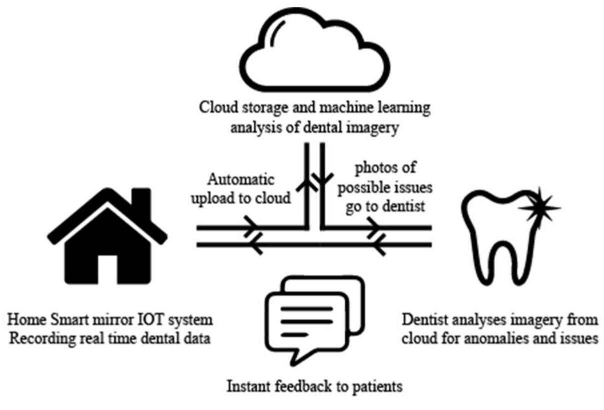

Fig. 18. Proactive response QLF dental health system

D. *Proactive Healthcare and Economic Incentive*

The benefits to using a product like the QLF prototype can be clearly linked to better dental health and greater proactivity in oral hygiene maintenance, due to increased motivation and understanding of individual dental needs. There is also an economic incentive within proactive healthcare as a whole [31]. With advancing technology and improved accuracy of diagnosis, health data can be automatically analysed, so that earlier detection and treatment will become standard practice [32]. The more proactive dental care becomes, the more cost-effective patient treatment will be, not because the actual treatment decreases in cost, but because earlier diagnosis would help minimise the need for costly, complex treatments.

VI. Conclusion

This paper has investigated the use of QLF in home-based devices by proposing a research method for measuring plaque reduction and its impact on motivation. Whilst the research outcomes did not show statistical significance, the learning process and findings highlight the value of adapting the technology to more controlled environments in future studies.

Having tried to incorporate QLF technology into devices through prototyping, it can be said that the core technology of QLF is easy to replicate. Though research shows that QLF has mainly been used in clinical products, it demonstrates great potential to penetrate the larger market as an everyday dental care product. This is also supported by the impact of QLF briefly researched within the NHS framework of dental feedback [5]. On this basis, it would be fair to predict that QLF will become more common in the future despite its current scarcity. As more IoT devices are assimilated into our daily lives, the same can be said about dental care IoT devices [33]. In combination with the growth of telehealth [34], the imminent development of a QLF embedded dental IoT system within our homes might just be on the horizon.

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APPENDIX

A. *Ethics approval form link:*

Notion logbook – sidebar – Ethics form approval – ethics form.xlsx

B. *QLF imagery using optical filters:*

Fig. 19. Plaque identification using blacklight with optical filter (495nm)

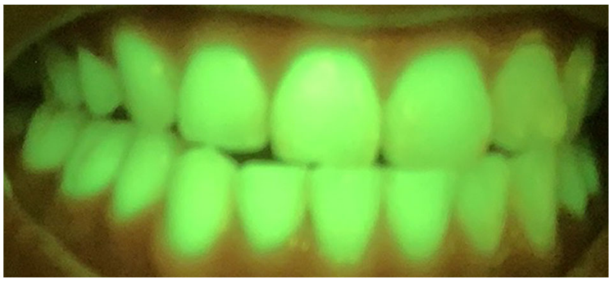

Fig. 20. Plaque identification image (none visible) using blacklight with optical filter (495nm)

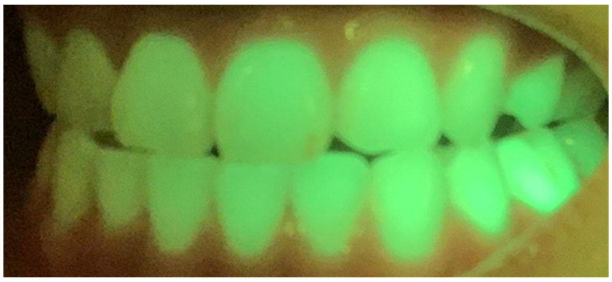

Fig. 21. Plaque identification image 2 (none visible) using blacklight with optical filter (495nm)

C. Notion Logbook Invitation Link:

https://www.notion.so/invite/a435885cdd424dcc081af1170ba4c4eb642ee15b