Harmful Algae 57 (2016) 51–55

Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

Dietary assessment of domoic acid exposure: What can be learned from traditional methods and new applications for a technology assisted device

Carol J. Boushey [a,*], Edward J. Delp [b], Ziad Ahmad [b], Yu Wang [b], Sparkle M. Roberts [c], Lynn M. Grattan [c]

[a] Epidemiology Program, University of Hawaii Cancer Center, 701 Ilalo Street, Room 525, Honolulu, HI 96813, United States
[b] School of Electrical and Computer Engineering, Purdue University, 465 Northwestern Avenue, West Lafayette, IN 47907, United States
[c] Department of Neurology, Division of Neuropsychology, University of Maryland, School of Medicine, 110 S. Paca St. 3rd Floor, Baltimore, MD 21201, United States

ARTICLE INFO

Keywords:
Mobile technology
Domoic acid
Shellfish
Razor clam
Amnesic shellfish poisoning

ABSTRACT

Three Tribal Nations in the Pacific Northwest United States comprise the members of the CoASTAL cohort. These populations may be at risk for neurobehavioral impairment, i.e., amnesic shellfish poisoning, from shellfish consumption resulting in repeated, low-level domoic acid (DA) exposure. Previous work with this cohort confirmed a high proportion of clam consumers with varying levels of potential exposure over time. Since clams are an episodically consumed food, traditional dietary records do not fully capture exposure. Frequency questionnaires can capture accumulated doses over time and this data can be used to examine dose–response relationships with periodic studies of memory and learning. However, frequency questionnaires cannot be used to assess consumption and memory response in real time. To address this shortcoming, a modified technology assisted dietary assessment (TADA) iPod application was developed to capture images of the clam meal, sourcing data, and associated memory functioning within 24 h and seven days after consumption. This methodology was piloted with razor clam meals consumed by members from the CoASTAL cohort. Preliminary findings suggest that the TADA iPod application is potentially useful in collecting real-time data with respect to razor clam consumption, as well as one day and seven day memory outcome data. This technology holds promise for addressing the challenges of other HAB related dietary exposure outcome studies.
© 2016 Elsevier B.V. All rights reserved.

1. Introduction

For more than 25 years, there has been a dramatic increase in the number of harmful algal blooms in coastal waters throughout the world (Anderson et al., 2012). As a result, there are more toxic algal species, more algal toxins, and more geographic regions encroached upon than formerly documented. When these toxic species proliferate, they may cause massive kills of fish and shellfish; wildlife mortality due to consumption at higher trophic levels; and human illness or death. One algal toxin, domoic acid (DA) is a known neurotoxin that has been associated with amnesic shellfish poisoning in humans (see Grattan et al., 2016). In the United States, P*seudo-nitzschia*-producing blooms responsible for DA neurotoxins have been intermittently found in the coastal waters of the Pacific Northwest for nearly three decades (c.f. Trainer and Suddleson, 2005; Trainer et al., 2007). A primary mechanism for human exposure to DA is through razor clam consumption. Unlike other bivalve species, razor clams can harbor DA for an extended period of time. As a result, exposures may occur after consuming fresh, frozen, or canned razor clam products for up to one year after harvesting. Protective measures are in place as shellfish harvesting beaches are closed when DA levels rise to 20 ppm or greater. Although careful environmental monitoring and management has prevented outbreaks of amnesic shellfish

Abbreviations: DA, domoic acid; FFQ, food frequency questionnaire; mFR, mobile food record; SAS, seafood assessment survey; TADA, technology assisted dietary assessment.

* Corresponding author. Tel.: +1 808 564 5915; fax: +1 808 586 2982.
E-mail address: cjboushey@cc.hawaii.edu (C.J. Boushey).

http://dx.doi.org/10.1016/j.hal.2016.03.013
1568-9883/© 2016 Elsevier B.V. All rights reserved.

poisoning in the region, the long-term impact of repeated, low-level exposure (less than 20 ppm) is less well-known. Since a human biomarker for exposure remains to be identified, a critical component of human health studies are the capacity to measure dietary exposure.

To facilitate the assessment of dietary exposure with respect to DA, the purpose of this brief report is twofold: (1) to summarize the current knowledge of razor clam consumption using traditional dietary assessment methods in a cohort of Native Americans at risk of DA exposure and (2) to introduce the adaptation of a novel measure to capture dietary intake using mobile technology.

2. Methods

2.1. Dietary assessment of the CoASTAL cohort

The CoASTAL cohort (Communities Advancing the Studies of Tribal Nations Across the Lifespan) represents members from three Pacific Northwest coastal Native American reservations. The cohort was assembled for the purpose of studying the impacts of repeated exposure to low levels of DA over time (Grattan et al., 2016; Tracy and Grattan, 2016). In the absence of a human biomarker, robust dietary assessment is essential to studying the impact of long term exposure. To make the best use of available methods to capture dietary exposure, three dietary assessment methods were used to measure razor clam intake. This included the dietary record, a food frequency questionnaire (FFQ, Subar et al., 2001; Fialkowski et al., 2010b, 2012), and the study-specific Shellfish Assessment Survey (SAS, Fialkowski et al., 2010a). When Fialkowski and colleagues (2010a) compared the latter two methods; findings indicated that the SAS and the FFQ were similar in their ability to identify consumption levels in 518 adult participants. Specifically, the FFQ and SAS documented razor clam consumption rates in the cohort at 84% and 83%, respectively, over the course of one year (Fialkowski et al., 2010a). Although the FFQ has the capacity to assess a wider range of food and beverage consumption (including nutritional values) for the purpose of estimating relative exposures via shellfish intake, either measure could be used with reasonably good validity.

To determining relative exposure, both the FFQ and the SAS are based upon dietary recall for a time period immediately preceding assessment (e.g. 3 months, 6 months, or one year). In contrast, dietary records are based upon detailed daily food diaries. This method is most useful when the objective is to measure absolute rather than relative intake; such as for comparisons with dietary recommendations (Dietary Reference Intakes, 2000). Detailed real-time recordkeeping of consumed food and beverages removes the error of generalizing population intake to that of individuals. In the previously described CoASTAL cohort sample (Fialkowski et al., 2010a; Tracy and Grattan, 2016; Grattan et al., 2016), the proportion of individuals recording shellfish consumption over four days of dietary recordkeeping was 26%. Fig. 1 shows the pattern of razor clam consumption from these dietary records. This relatively low consumption rate may be expected from these daily records, compared to annual or seasonally based recall methods, as razor clams are an episodically consumed food (Tooze et al., 2006).

Capturing full penetration of a food product that is episodically eaten within a population is difficult to detect with only a few days of assessment. Increasing the amount of time participants are expected to complete daily written diaries is not typically useful due to loss of interest. Thus, this method is not useful on its own to assess exposure over time. Regardless of the dietary measure utilized to assess potential DA exposure and human neurotoxicity, linkages still need to be made with estimates of DA levels in the consumed clams (from sourcing data) and post-consumption memory ability (from standardized assessment). A mobile application was specifically developed for the CoASTAL cohort to collect all of this data with minimal participant burden in real-time.

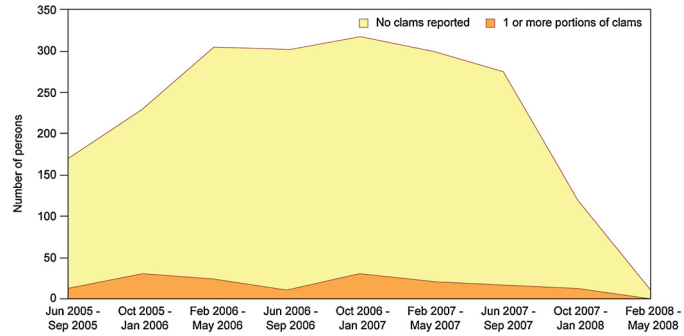

Fig. 1. Clam consumption from dietary records among members of the CoASTAL cohort by quarter from June 2005 to May 2008 (n = 566). Average number of records per person is 5.3 ± 2.8 (range 1–11).

2.1.1. Technologically assisted exposure assessment

Since mobile phone use is ubiquitous to most people under the age of 65 (Pew Research Center, 2014) and taking pictures of food is a popular cell phone activity, CoASTAL cohort researchers examined ways to improve the accuracy of exposure and outcome assessment through mobile technology. Subsequently, the mobile food record (mFR) was modified and adapted for field use with the CoASTAL cohort. The application, running on the technology assisted dietary assessment (TADA) system for mobile devise use, assessed dietary intake via participant captured images of food and beverages they were about to consume (Boushey et al., 2009; Zhu et al., 2010, 2015; Xu et al., 2012, 2013a,b; He et al., 2013a,b; Wang et al., 2015). In addition to analyzing images of razor clam meals, the application was also designed to capture the source beaches for the consumed razor clams, and to collect real-time memory data.

Operationally, while the application runs on a mobile device, all data are sent to a central secure server, where investigators can view, analyze or download the data through a secure web application (Bosch et al., 2011; Ahmad et al., 2014). The TADA mFR system was modified to accommodate the situation of recording the food of interest i.e., razor clams, and identified as TADAd. Figs. 2–5 illustrate the record screens throughout the data collection process. These include prompts for taking a photograph of a razor clam meal (Fig. 2), a screen for documenting the source of the razor clams (Fig. 3), a procedures for completing the memory questionnaire (Fig. 4), and a mechanism for recording razor clam consumption that took place earlier in the day if the participant forgot to take a picture (Fig. 5).

The small colored checkerboard square seen in the lower left of each button on the opening screens shown in Fig. 2 represents a fiducial marker (Xu et al., 2012). The fiducial marker is about 2-inches square. This item is included in every image as a color and size reference to help with the reconstruction of a three-dimensional environment that allows for estimation of the volume of the foods and beverages (Lee et al., 2012; Xu et al., 2012, 2013b). In this study, the food items were calibrated to represent a variety of razor clam preparations, including clam chowder.

In order to monitor potential alterations in memory, the Everyday Memory Questionnaire (Royle and Lincoln, 2008) was adapted and installed into the TADAd system. The memory questionnaire was launched 24 h after a report of clam consumption and then again after 7 days. If an individual consumed clams several times a day or several times a week, the launch sequence

Fig. 2. The classic mobile food record (mFR) opening screen is on the left. The adaptation of the mFR for collecting a single food that is usually eaten in its entirety is the screen on the right.

was set so that questionnaires would be separated by enough time to prevent user fatigue.

Since clams are not eaten every day, a mechanism was developed to remind participants to take images of clams to be consumed using methods of ecological momentary assessment (EMA) as a guide (Dunton et al., 2012; Marszalek et al., 2014). During random morning hours, users received a message asking, "Can you remember to send us throughout the day pictures of meals that include razor clams?" The question was accompanied by response buttons of "yes" or "no." If the user selected, "no," they were asked to type an explanation into a dialog box, e.g., "I have a dental appointment". At a random time toward the end of the day, users received a second inquiry, "Did you eat any razor clams today, including mixtures containing razor clams (e.g., clam chowder, dip) and did not take a picture?" Again, the question was followed by a "yes" or "no" response request. If the user responded with "yes," the user was prompted with a short sequence of questions to record the clam eating occasion as shown in Fig. 5.

The Apple iPod Touch 5th generation (with a rear facing camera) running on iOS6 was used for running the application. After receiving extensive training on the application, participants

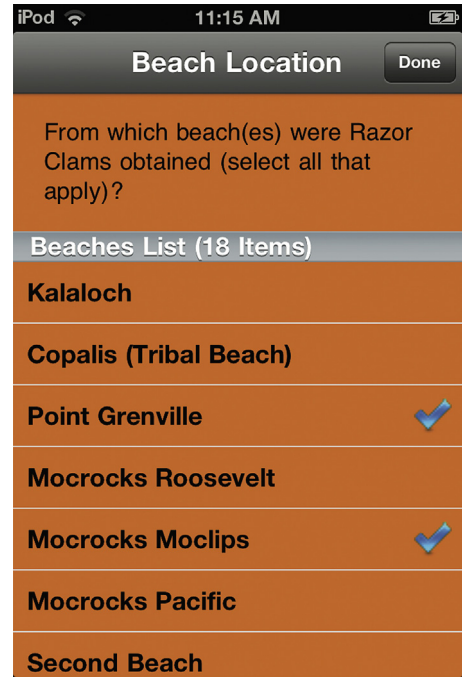

Fig. 3. The "Beach Location" screen is automatically displayed after an image is captured to allow the user to scroll through the list of 17 beaches plus an "unknown" choice to identify the clam source(s) by beach location. The user taps the beach name to select or deselect a beach. A check appears when a beach is selected (note: list shown is cut-off, the user scrolls through the list). Once finished, the user selects done and is returned to the opening screen.

used the device for a 30 day time period, seasonally. Throughout the field testing process, participants were asked to complete a feedback questionnaire regarding the usability of the application. Inquiries targeted the ease of using the application and associated procedures and were adapted from other studies using the TADA system (Daugherty et al., 2012; Six et al., 2010). Preliminary findings suggest that the measure has good face validity and participants were generally enthusiastic about using the application. It was considered easy to carry and the use of the fiducial marker was not burdensome. In some cases, the screens were thought to be difficult to read, but educating participants on how to adjust the brightness of the mobile screen or enlarge the font addressed this concern (Fig. 6).

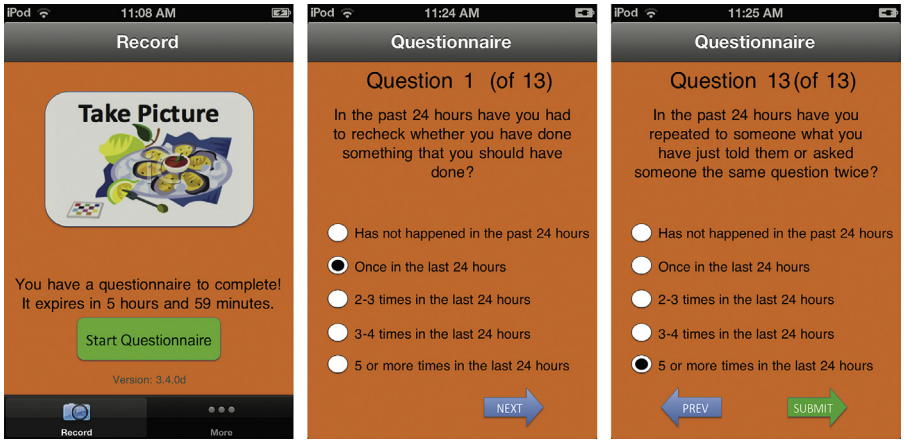

Fig. 4. Launching the memory questionnaire, questionnaire screens, and submit screen.

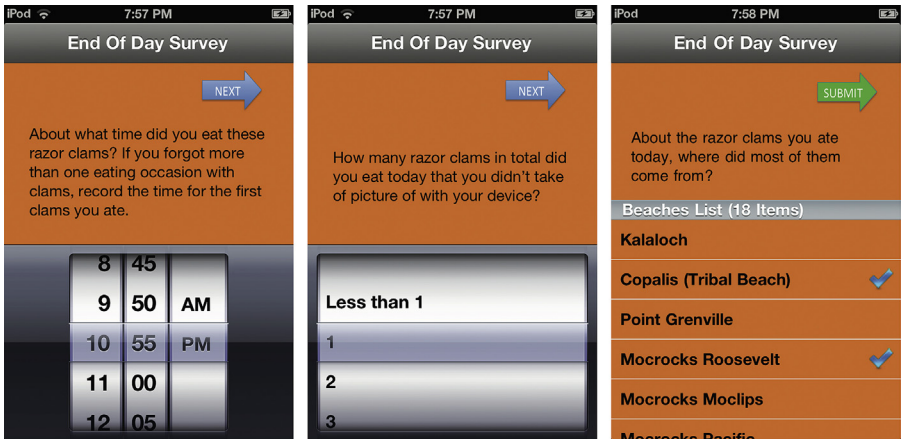

Fig. 5. The sequence of screens above is launched when a user answers that s/he forgot to capture an image of an eating occasion which included clams. Once completed the responses are sent to the secure server.

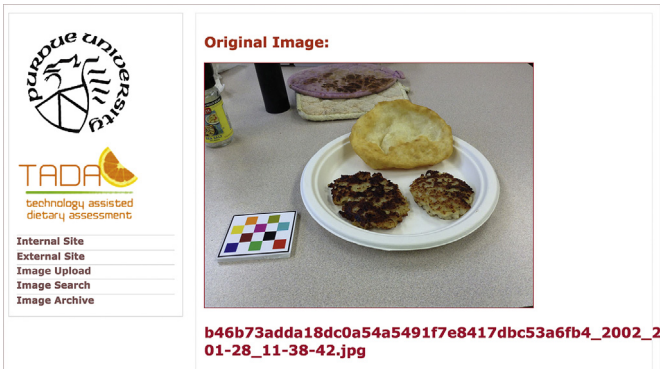

Fig. 6. A study participant's image of razor clam fritters as viewed on the web application. The GPS coordinates listed under the image name have been redacted.

3. Discussion/Conclusion

The CoASTAL cohort is at risk of exposure to low levels of DA through razor clam consumption. Accordingly, the Food Frequency Questionnaire and the Shellfish Assessment Survey identified razor clam consumption rates of up to 84%. For more detailed dietary assessments that were less dependent upon memory recall, daily records were used. However, similar to other studies, the daily diaries did not fully capture razor clam intake in the cohort. To minimize the burden of daily dietary food records on participants, a well-validated mobile dietary record, the mFR, was adapted for use with the cohort. Operating within the TADAd application, information on the clams' source(s), as well as the individual's memory functioning, was also able to be assessed in real time. To maximize the research utility of this measure, initial and ongoing education for using this application is essential for participants and field teams. With further adaptations, this technologically assisted device could potentially be used to facilitate the assessment of dietary exposure and human health outcomes associated with other HAB-related illnesses.

Acknowledgements

Funding/support: Support for this work came from a National Institute of Environmental Health Sciences grant (NIEHS: 5R01ES012459-05S1) awarded to Dr. Grattan. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIEHS. This project was also partially supported by the National Cancer Institute P30 C071789.

The authors thank the Quinault Indian Nation Tribal Councils; Joe Schumacker and Dawn Radonski from the Quinault Department of Fisheries; our tribal medical advisory board, Thomas Van Eaton of Makah Health Services, Robert Young of the Quinault Health Center, and Brenda Jaime-Nielson and Brad Krall of the Quileute Health Center; and our tribal advisory committee, Theresa Parker, Deanna Buzzell-Gray, June Williams, Melissa Peterson-Renault, Mary Jo Butterfield, and Edith Hottowe from the Makah Indian Nation; and Alena Lopez, Ervin Obi, and Carolyn Gennari from the Quinault Indian Nation for their contributions and participation in this study.[SS]

References

Anderson, D.M., Cembella, A.D., Hallegraeff, G.M., 2012. Progress in understanding harmful algal blooms: paradigm shifts and new technologies for research, monitoring, and management. Ann. Rev. Mar. Sci. 4, 143–176.

Ahmad, Z., Khanna, N., Kerr, D.A., Boushey, C.J., Delp, E.J., 2014. A mobile phone user interface for image-based dietary assessment. Proc. SPIE 9030 , http://dx.doi.org/10.1117/12.2041334.

Bosch, M., Schap, T., Khanna, N., Zhu, F., Boushey, C., Delp, E.J., 2011. Integrated databases system for mobile dietary assessment and analysis. In: Proc. of the IEEE Int. Conferen. on Multimedia and Expo, http://dx.doi.org/10.1109/ICME.2011.6012202.

Boushey, C.J., Kerr, D.A., Wright, J., Lutes, K.D., Ebert, D.S., Delp, E.J., 2009. Use of technology in children's dietary assessment. Eur. J. Clin. Nutr. 63, S50–S57.

Daugherty, B.L., Schap, T.E., Ettienne-Gittens, R., Zhu, F.M., Bosch, M., Delp, E.J., Ebert, D.S., Kerr, D.A., Boushey, C.J., 2012. Novel technologies for assessing dietary intake: evaluating the usability of a mobile telephone food record among adults and adolescents. J. Med. Internet Res. 14 (2), e58.

Dietary Reference Intakes, 2000. Applications in dietary assessment: a report of the Subcommittees on Interpretation and Uses of Dietary Reference Intakes and Upper Reference Levels of Nutrients, and the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. Food and Nutrition Board, Institute of Medicine, , pp. 151–152. Available from: http://www.nap.edu/read/9956/chapter/1.

Dunton, G.F., Liao, Y., Kawabata, K., Intille, S., 2012. Momentary assessment of adults' physical activity and sedentary behavior: feasibility and validity. Front. Psychol. 3, 260.

Fialkowski, M.K., McCrory, M.A., Roberts, S.M., Tracy, J.K., Grattan, L.M., Boushey, C.J., 2010a. Evaluation of dietary assessment tools used to assess the diet of adults participating in the Communities Advancing the Studies of Tribal Nations Across the Lifespan (CoASTAL) cohort. J. Am. Diet. Assoc. 110, 55–64.

Fialkowski, M.K., McCrory, M.A., Roberts, S.M., Tracy, J.K., Grattan, L.M., Boushey, .C.J., 2010b. Estimated nutrient intakes from food generally do not meet dietary reference intakes among adult members of Pacific Northwest Tribal Nations. J. Nutr. 140, 992–998.

Fialkowski, M.K., McCrory, M.A., Roberts, S.M., Tracy, J.K., Grattan, L.M., Boushey, C.J., 2012. Dietary patterns are associated with dietary recommendations but have limited relationship to BMI in the Communities Advancing the Studies of Tribal Nations Across the Lifespan (CoASTAL) cohort. Public Health Nutr. 15, 1948–1958.

Grattan, L.M., et al., 2016. Association between razor clam consumption and memory. Harmful Algae 57, 20–25.

He, Y., Xu, C., Khanna, N., Boushey, C.J., Delp, E.J., 2013a. Food image analysis: segmentation, identification and weight estimation. In: Proc. of the IEEE Int. Conferen. on Multimedia and Expo, http://dx.doi.org/10.1109/ICME. 2013.6607548.

He, Y., Xu, C., Khanna, N., Boushey, C., Delp, E., 2013b. Context based food image analysis. In: Proc. of 2013 IEEE Int. Conferen. on Image Process, pp. 2748–2752, http://dx.doi.org/10.1109/ICIP.2013.6738566.

Lee, C.D., Chae, J., Schap, T.E., Kerr, D.A., Delp, E.J., Ebert, D.S., Boushey, C.J., 2012. Comparison of known food weights with image-based portion-size automated estimation and adolescents' self-reported portion size. J. Diab. Sci. Tech. 6 (2), 428–434.

Marszalek, J., Morgulec-Adamowicz, N., Rutkowska, I., Kosmol, A., 2014. Using ecological momentary assessment to evaluate current physical activity. BioMed. Res. Int. 2014,, Article ID 915172.

Pew Research Center, 2014. Older Adults and Technology Use. Available in: http://www.pewinternet.org/2014/04/03/older-adults-and-technology-use/

Royle, J., Lincoln, N.B., 2008. The Everyday Memory Questionnaire-revised: development of a 13-item scale. Disabil. Rehabil. 30, 114–121.

Six, B.L., Schap, T.E., Zhu, F.M., Mariappan, A., Delp, E.J., Ebert, D.S., Kerr, D.A., Boushey, C.J., 2010. Evidence-based development of a mobile telephone food record. J. Am. Diet. Assoc. 110, 74–79.

Subar, A.F., Thompson, F.E., Kipnis, V., Midthune, D., Hurwitz, P., McNutt, S., McIntosh, A., Rosenfeld, S., 2001. Comparative validation of the Block, Willett, and National Cancer Institute food frequency questionnaires. Am. J. Epidemiol. 154, 1089–1099.

Tooze, J.A., Midthune, D., Dodd, K.W., Freedman, L.S., Krebs-Smith, S.M., Subar, A.F., Guenther, P.M., Carroll, R.J., Kipnis, V., 2006. A new method for estimating the usual intake of episodically consumed foods with application to their distribution. J. Am. Diet. Assoc. 106, 1575–1587.

Tracy, K., Grattan, L.M., 2016. Communities Advancing the Studies of Tribal nations Across the Lifespan: design, methods, and baseline of the CoASTAL Cohort Study, wave 1. Harmful Algae 57, 9–19.

Trainer, V.L., Cochlan, W.P., Erickson, A., Bill, B.D., Cox, F.H., Borchert, J.A., Lefebvre, K.A., 2007. Recent domoic acid closures of shellfish harvest areas in Washington State inland waterways. Harmful Algae 6, 449–459.

Trainer, V.L., Suddleson, M., 2005. Monitoring Approaches for Early Warning of Domoic Acid Events in Washington State. Available in: http://www.tos.org/oceanography/archive/18-2_trainer.pdf.

Wang, Y., Xu, C., Boushey, C., Zhu, F., Delp, E.J., 2015. Mobile image based color correction using deblurring. Proc. SPIE 9401 , http://dx.doi.org/10.1117/12.2083133.

Xu, C., Zhu, F., Khanna, N., Boushey, C.J., Delp, E.J., 2012. Image enhancement and quality measures for dietary assessment using mobile devices. Proc. SPIE 8296 , http://dx.doi.org/10.1117/12.909949.

Xu, C., He, Y., Khanna, N., Boushey, C.J., Delp, E.J., 2013a. Model-based food volume estimation using 3-D pose. In: Proc. 2013 IEEE Int. Conferen. Image Process, pp. 2534–2538, http://dx.doi.org/10.1109/ICIP. 2013.6738522.

Xu, C., He, Y., Parra Pozo, A., Khanna, N., Boushey, C., Delp, E., 2013b. Image-based food volume estimation. In: Proc. of ACM 5th Int. Confer. Multimedia, pp. 75–80, http://dx.doi.org/10.1145/2506023.2506037.

Zhu, F., Bosch, M., Woo, I., Kim, S.Y., Boushey, C.J., Ebert, D.S., Delp, E.J., 2010. The use of mobile devices in aiding dietary assessment and evaluation. IEEE J. Sel. Top. Signal Process 4 (4), 756–766.

Zhu, F., Bosch, M., Khanna, N., Boushey, C.J., Delp, E.J., 2015. Multiple hypotheses image segmentation and classification with application to dietary assessment. IEEE J. Biomed. Health Inform. 19 (1), 377–388.