Mysterious Snorkel Drownings Explained

Snorkel Safety Study
Interim Report
July 2020

Prepared by:
Carol Wilcox, Project Manager
in collaboration with
Philip R. Foti, M.D., Principal Investigator
Ralph S. Goto, Project Administrator

In Cooperation with:
Hawai'i State Department of Health
Hawaiian Lifeguard Association
Hawai'i Tourism Authority
Honolulu Medical Examiner Office
The four County First Responder and Emergency Medical Service agencies
Friends of Hanauma Bay

Table of Contents

Executive Summary

In October 2017, the Hawai'i State Department of Health established the Snorkel Safety Sub-Committee to address public concern about snorkel-related drownings. In January 2019, the Hawai'i Tourism Authority funded the Sub-Committee's Snorkel Safety Study (Study). The purpose was "to determine the causes and risk factors associated with snorkel-related fatal and non-fatal ocean drownings in Hawai'i and develop appropriate safety messages." The Snorkel Safety Study has four components--the Snorkel Airways Resistance Analyzer (SARA) Investigation, the Medical Examiner's Office Reports Investigation, Case Studies Investigation, and the Snorkel Safety Survey.

In the first year the Study:

- Convened two Snorkel Safety workshops (March 2018 and February 2020)
- Designed and conducted a survey of "snorkelers who have gotten into trouble"
- Tested snorkels for resistance
- Examined Medical Examiner's Office reports
- Interviewed individuals who experienced non-fatal drowning
- Investigated physiological effects of immersion in water
- Investigated physiological effects of recent travel
- Identified health issues that might make snorkelers more vulnerable

Going forward, the Study will focus on expanding participation in the Snorkel Safety Survey and education.

Summary of Findings

Hypoxia induced by Rapid Onset Pulmonary Edema (ROPE) is the cause of some, probably most, snorkel related fatal and near fatal drownings. ROPE has not been associated with snorkeling in the past. This unravels the mystery of previously inexplicable snorkel-related drownings. It is an important discovery with significant implications.

Certain factors increase the risk of ROPE:

- Snorkel resistance and horizontal immersion are predisposing factors that can contribute to the onset of ROPE
- Certain health issues increase the risk of developing ROPE
- Recent prolonged air travel may be a contributing factor

Conclusions of the Snorkel Resistance investigation:

- Snorkels and full-face masks have a wide range of airflow resistance
- High resistance adds to the risk of developing ROPE

- The more you exert, the greater the resistance
- You can't judge a snorkel by its looks
- Full-face masks pose no inherent advantage or disadvantage compared to other devices in terms of resistance to inhalation of air

Conclusions from a review of the Coroner's Office Records:

- Autopsies are not a conclusive source of useful information for differentiating the mechanism of drowning
- Cardiac disease, in particular Left Ventricle End Diastolic Pressure (LVEDP), is a probable risk factor

Conclusions from conducting individual Case Studies:

- Cardiac disease, in particular LVEDP is a probable risk factor that can lead to ROPE
- ROPE-induced hypoxia was a factor in most fatal and non-fatal snorkel drownings

Summary of Snorkel Safety Survey Results:

- Some, probably most, fatal and non-fatal drowning were by hypoxia induced by Rapid Onset Pulmonary Edema (ROPE)
- Full-face masks may be a risk factor

Full-face masks:

- Cannot assess their resistance by visual inspection
- Cannot be removed easily in urgent situations even with quick release features
- Cannot "spit out" mouthpiece in urgent situations
- Cannot clear water from tube with sharp expiratory force maneuver
- Cannot dive beneath the surface safely
- Valve malfunction may lead to serious aspiration consequence

Chapter 1: The Snorkel Safety Study

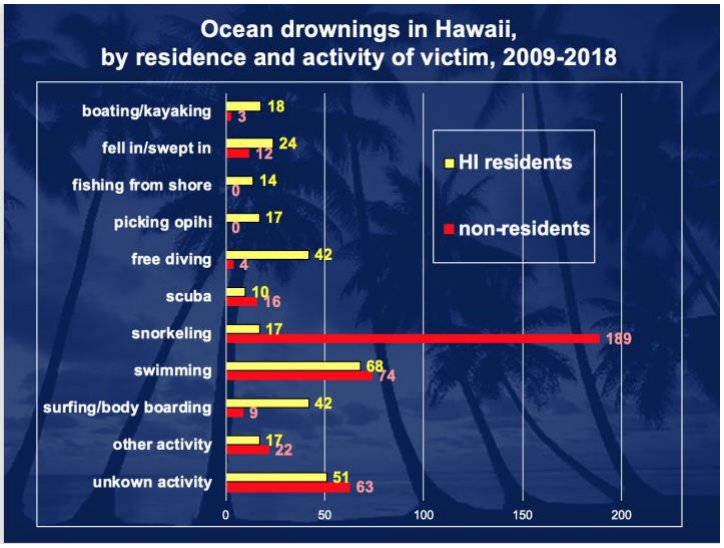
In 2016, Nathan Eagle, reporter for online Hawai`i newspaper "Civil Beat," published a five-part series with the heading, "State Health Department Records over the Past Decade Show that Hawaii's Visitor-Drowning rate is 13 Times the National Average and 10 Times the Rate of Hawai'i Residents."

These drownings during a seemingly benign activity and the disparity between visitor and resident have been a mystery. Why are visitor snorkel-related drownings ten times that of residents? The widely held explanations is that visitors generally lack ocean swimming and snorkeling experience. Is this really the case? Are there other factors? Even more mysterious, why do so many snorkel-related drownings occur without signs of distress?

In September 2016, Nancy Peacock drowned while snorkeling off Poho'iki, the now land-locked small boat harbor on the Big Island. Nancy was recruited as a pro water skier when she was 11 years old. She organized rafting trips in California, swam in a pool every day. She had been coming to Hawai'i to snorkel for the last 20 years. She was 70 years old.

Her husband, Guy Cooper, could not understand how this could have happened to Nancy, on a calm day, to someone so accustomed to snorkeling. When he discovered that similar unexplained snorkel-related drownings were not all that uncommon in Hawai'i, he launched a vigorous campaign to focus public attention and government action on this question. Mr. Cooper felt that "What hasn't been looked at, near as I can tell, is what exacerbation the equipment might add to the mix, specifically these new full-face masks."

The high incidence of inexplicable snorkel-related drownings was no surprise to Hawai'i State government. The Department of Health had collected data on drownings in Hawai'i for decades.



Given public concern, in October 2017 the Department of Health established a Snorkel Safety Sub-Committee under the leadership of Bridget Velasco, Emergency Medical Services & Injury Prevention System Branch, and chairman Ralph Goto, retired Ocean Safety Administrator. Committee members were Dan Galanis, State Epidemiologist, DOH; Dr. Philip Foti, Pulmonologist and Principal Investigator; Carol Wilcox, snorkel drowning survivor and Project Manager; and Jeremy Burns, Technical Advisor. Numerous others from ocean safety, first responders, the medical profession, community groups, and interested individuals joined in.

The Snorkel Safety Sub-Committee proposed a two year **Snorkel Safety Study (Study)** to "determine the causes and risk factors associated with snorkel-related fatal and non-fatal drownings and develop appropriate safety messages." In January 2019, the Hawai'i Tourism Authority funded the Study**.**

In the first phase, which was concluded in March, 2020, the Study:

- Convened two Snorkel Safety workshops (March 2018 and February 2020)
- Designed a Snorkel Safety Survey for those who have "gotten into trouble while snorkeling"
- Assessed Survey responses from 36 participants
- Designed the Snorkel Airways Resistance Analyzer (SARA)
- Tested 50 snorkels with SARA
- Examined Hawaii Medical Examiner's Office's autopsies and reports for drownings in 2017, 2018, and 2019
- Interviewed individuals who experienced non-fatal drowning
- Examined medical records of fatal drownings
- Investigated physiological effects of immersion in water
- Investigated physiological effects of recent travel
- Identified health issues that might make snorkelers more vulnerable

The Snorkel Safety Study concluded that some snorkel-related drownings are from **Hypoxia induced by Rapid Onset Pulmonary Edema (ROPE)**. In this report, we will explain what ROPE is, how we arrived at this conclusion, potential risk factors, precautions a snorkeler might take, and what more we need to learn.

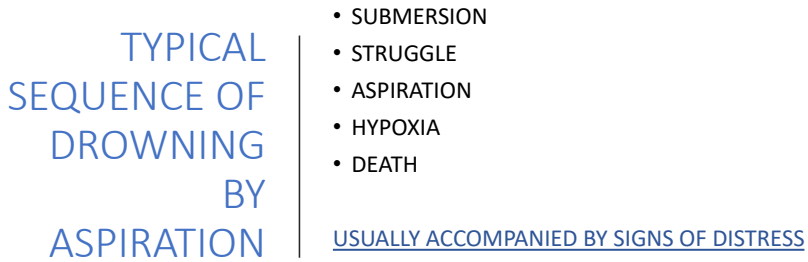
Chapter 2: Drowning by Rapid Onset Pulmonary Edema (ROPE)

Snorkel-related drownings are often a mystery. It is not unusual to find a snorkeler motionless, close to shore, in calm conditions, and not very long after entering the water. Often there are no signs of distress. Understanding why this is so could go a long way in averting future drownings. The Snorkel Safety Study hypothesized that this quick and quiet pattern of drowning was consistent with hypoxia induced by **Rapid Onset Pulmonary Edema (ROPE).** (Briefly, the infusion of bodily fluid into the lungs reducing its capacity to deliver oxygen to the blood). This hypothesis has been borne out by the evidence. This is a new and important discovery. Until now, ROPE has not been associated with snorkeling.

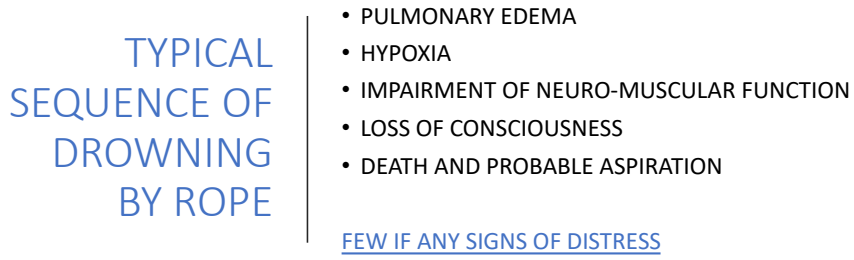
We understand "Drowning" to mean death due to submersion in and inhalation of water. This is *Drowning by Aspiration.* In 2005, the World Health Organization developed an additional definition: "Drowning is the process of experiencing respiratory impairment from submersion/immersion in liquid." This expanded the meaning of drowning as a process that could be both fatal and non-fatal. It still was contingent upon submersion in and inhalation of liquid.

D*rowning by ROPE* is different. It does not need either submersion in or inhalation of liquid. Rather it is respiratory impairment that can be triggered by snorkeling. Its progression is quick and quiet. In either case death is by hypoxia (lack of sufficient oxygen), but the path there and the person's experience is very different. Externally, the primary difference is the presence or absence of struggle. Rescue can happen almost anywhere along either of these trajectories resulting in a non-fatal drowning.

Drowning by Aspiration sequence: Submersion, Struggle for Air, Involuntary Aspiration (inhalation of liquid), Hypoxia (lack of oxygen), Cardiac Arrest, Clinical Death. Usually accompanied by signs of distress.



Drowning by ROPE sequence: Sudden Shortness of Breath, Weakness, Loss of Strength, Confusion/Sense of Doom, Unconsciousness, Death. Few if any signs of distress.



ROPE Explained

- *Pulmonary*: relating to the lungs
- *Edema*: swelling caused by excess fluid accumulated in the body's tissues
- *Pulmonary Edema*: the infusion of fluids into the lungs
- *Rapid Onset*: If negative pressure persists, oxygen is blocked from entering the blood by the edema fluid. This can happen in a matter of minutes.

While the mechanics of ROPE are technical and complex, the concept is simple. When inhalation is impaired, as can happen when breathing through a narrow tube, lung pressure is

reduced. This is **Negative Transthoracic Pressure (NTP)**. The lungs become infused with edema (pulmonary edema) causing a loss of oxygen (hypoxia) which leads to death. This phenomenon is known by different names---in SCUBA as Immersion Pulmonary Edema (IPE), in anesthesiology as Acute Negative Pressure Pulmonary Edema (ANPPE), in long distance swimming as Swimming Induced Pulmonary Edema (SIPE), and in mountain climbing as High Altitude Pulmonary Edema (HAPE).

The lungs are defined by a fine, permeable membrane. Liquids and gasses travel in both directions through this complicated and exquisitely balanced membrane. During inhalation, oxygen is transferred from the lungs to the blood stream and then delivered to body tissue. In exchange, carbon dioxide that has built up in the blood (in capillaries carrying blood along one side of this membrane) is passed back to air spaces in the lungs and expelled during exhalation.

When inhalation results in significant NTP, as can happen when breathing through a narrow tube, a vacuum phenomenon develops within the lungs which draws fluid from surrounding capillaries into the air space of the lungs. The snorkeler experiences shortness of breath. If the negative pressure persists, each breath draws more fluid into the air spaces resulting in less and less oxygen intake into the capillary blood. Blood oxygen is critically reduced. If the snorkeler increases exertion, thus increasing rate of breathing, resistance, negative pressure,and hypoxia are hastened. Insufficient oxygen to the brain causes loss of muscle strength, confusion, and harbingers of death. The only thing left functioning is the heart, which tries desperately to pump oxygen. Loss of consciousness and clinical death ensues.

Chapter 3: Why Snorkelers?

Why do snorkelers get Rapid Onset Pulmonary Edema (ROPE) more than swimmers, surfers or everyday ocean frolickers? Two elements basic to snorkeling work in combination.

- Prone Immersion: Water pressure exerted on the chest needs to be overcome
- The Snorkel: Resistance to inhalation created by breathing through a narrow tube results in negative transthoracic pressure (NTP).

The Snorkel

A narrow tube generates resistance to inhalation. If the resistance is strong enough, and if it persists, it will result in reduced pressure in the lungs (NTP) which can lead to ROPE. This is an established physiological phenomenon. One of the Study's objective was to determine how much resistance a snorkel exerts.

Figure 2. *Snorkel design ranges from a simple basic tube to those with pleats, purging valves, pinched tubes, wet/dry apparatus and, more recently, masks with integrated snorkels, known as full-face masks.*

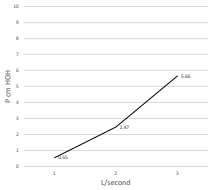
The Snorkel Airways Resistance Analyzer (SARA)

Dr. Philip Foti invented the **Snorkel Airway Resistance Analyzer (SARA)** to measure snorkel resistance during inhalation. He tested 49 snorkels, including 16 simple snorkels, 29 snorkels with wet/dry apparatus, and four full-face masks. Each snorkel was tested at three levels of air flow to simulate various levels of inhalation rates. Generally, the simpler the snorkel the less resistance it generated. However other factors, sometimes not visible, such as the size at the narrowest opening, or the design of the valves, made visual determination of resistance unreliable. In all cases, resistance increased with the increased level of air flow, signifying that ROPE will accelerate with increased exertion.

SARA is a small vacuum that measures a snorkel's resistance to airflow by analyzing the negative pressure required, tested at 1, 2, and 3 liters/second of air flow (flow=pressure/resistance). These are commonly utilized standards when testing lung volume air flow rates in the laboratory. Results showed that resistance is highly variable from one snorkel to the next. This is illustrated in the following graphs. The horizontal axis is the liters/second passing through the tube at the three different levels of air flow; the vertical axis is the resistance as measured in negative centimeters of water pressure. (-P cm HOH).

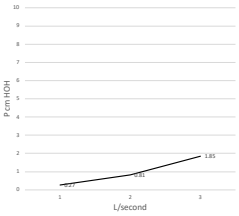
SARA RESISTANCE GRAPHS: CONVENTIONAL SNORKEL & MASK GEAR

Resistance Graph: High Resistance – Conventional Snorkel with Narrow Mouth Piece



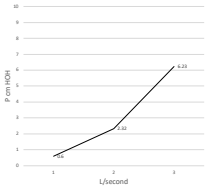
Simple Snorkel/Narrow Mouth Piece: Despite its simple unfettered appearance, this snorkel has a high resistance profile, probably because of the narrow mouthpiece.

Resistance Graph: Low Resistance – Conventional Snorkel



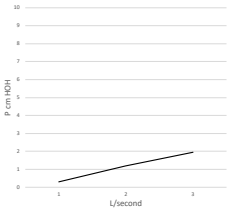
Simple Snorkel/Low Resistance: A snorkel with low resistance at every level. Shows a modest increase in resistance as airflow (or exertion) increases.

Resistance Graph: High Resistance – Conventional Snorkel



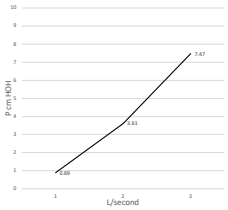
Simple Snorkel/High Resistance: This snorkel's resistance rises dramatically at increased flow rates, as occurs with increased exertion.

SARA RESISTANCE GRAPHS: FULL-FACE MASKS



Full-face Mask/Low Resistance: Low resistance at all levels of air flow.

Resistance Graph: High Resistance – Full Face Mask



Full-face Mask: High resistance at all levels of flow.

Conclusions of SARA investigation

- **Snorkels and full-face masks have a wide range of airflow resistance**
- **High resistance adds to the risk of developing ROPE**
- **The more you exert, the greater the resistance**
- **You can't judge a snorkel's resistance by its looks**
- **Full-face masks pose no inherent advantage or disadvantage compared to other devices in terms of resistance to inhalation of air**

Chapter 4: More Study Results

Why do snorkelers get in trouble so often? Why don't snorkelers in trouble exhibit distress? What does a drowning person experience?

Survivors of snorkeling incidents are uniquely positioned to answer these questions. They can report their own swimming ability, snorkeling experience, ocean conditions, equipment, recent travel, health, and things not yet considered. They can provide a detailed account of what happened leading up to and during the incident. Companions of fatal drownings can provide equally important information. These specifics often suggest whether they experienced Drowning by Aspiration or Drowning by ROPE.

Snorkel Safety Survey

To get these invaluable first hand reports, the Study designed the Snorkel Safety Survey for people "who get into trouble while snorkeling." The Survey can be taken on-line at Snorkelsafetystudy.com. Through a series of question and narratives, the Survey explores factors that may have contributed to a snorkeler's experience.

First posted in January 2019, thirty-six people completed the Survey by March 2020. Some of them described an incident that happened many years before, yet it was still as fresh in their minds as if it were yesterday.

The demographics of Hawai'i snorkel-related fatal drownings is mostly visitors and, among those, more middle age males. The Survey respondent group does not conform to that profile. Most respondents are Hawai'i residents, under 55 years of age, strong swimmers, and experienced snorkelers. Thus, the Survey currently does not shed any light about why visitors seem especially vulnerable. It does show that drownings happen to even the most experienced of watermen and women.

Of the thirty-six respondents,

- 60% exhibited symptoms clearly consistent with ROPE induced hypoxia
- 13% drifted away from safety
- 11% reported panic
- 8% cited ocean conditions
- Only one person reported possible aspiration
- No one cited lack of swimming or snorkeling experience as a contributing factor
- 66% of the Survey respondents were using full-face masks (FFM). Of these, 83% felt the FFM contributed to their problems

Summary of Snorkel Safety Survey Results:

- **Some, probably most, fatal and non-fatal drowning were by hypoxia induced by Rapid Onset Pulmonary Edema (ROPE)**
- **Full-face masks may be a risk factor**

Coroner's Office Investigation

The Study reviewed Coroner's Office drownings autopsies and reports for 2017, 2018 and 2019 to see if it was possible to differentiate between drowning by Aspiration or by ROPE. It was not. In either case the lungs are full of liquid and death is by hypoxia. However, clinical investigators' reports of autopsies were helpful in identifying pre-existing health conditions, and confirmed a significant correlation of drownings with cardiac disease, in particular Left Ventricle End Diastolic Pressure (LVEDP), which tends to start to manifest in older age groups and is most often asymptomatic when not severe. As a side note, there was very little indication of drug or alcohol being factors.

Coroner Report Investigation:

- **Autopsies are not a conclusive source of useful information for differentiating the mechanism of drowning**
- **Cardiac disease, in particular Left Ventricle End Diastolic Pressure (LVEDP), is a probable risk factor**

Case Studies

While survey participants weren't required to give their names, most did, and many were willing to be interviewed and to share their medical history. These case studies provided invaluable information especially in two areas: preexisting health issues and whether ROPE or aspiration occurred.

The suspected correlation between heart conditions, specifically Left Ventricle End Diastolic Pressure (LVEDP), and ROPE was corroborated in both men and women in these case studies. In several cases, the condition was not diagnosed until after the incident itself.

Results of Case Studies Investigations:

- **Heart Disease, especially Left Ventricle End Diastolic Pressure (LVEDP), is a probable risk factor that can lead to ROPE**
- **ROPE-induced hypoxia is a factor in fatal and non-fatal snorkel drownings**

CO2 Buildup

Attention has been given to the possibility that CO2 accumulation in the mask/snorkel and then the blood causes the snorkeler to become unconscious. CO2 buildup is not a physiologically viable explanation of snorkel-related drownings.

Visitors & Residents

In a parallel line of inquiry, the Study is considering the novel idea that recent and prolonged air travel may be relevant in explaining the disparity between residents and visitors in the number of snorkel-related drownings. Hawai'i is different from most other snorkel resort destinations in that almost all visitors have recently spent at least 5 hours on an airplane at cabin pressure equivalent to up to 8500 feet elevation. Visitors traveling from anywhere except the west coast

of the U.S. are often in the air much longer. There is evidence that exposure at these altitudes may alter permeability of the lung's mechanisms which normally blocks development of ROPE.

The idea that air travel may be a factor is hypothetical. We can only say that it has a credible basis in physiology. Sufficient visitor response to the Snorkel Safety Survey might provide useful data. In the end it will take scientific investigation beyond the capabilities of this Study to ascertain if extended exposure to altitude is indeed a risk factor.

Full-Face Masks

There are several features of FFMs to be aware of when choosing equipment:

- Cannot assess their resistance by visual inspection
- Cannot be removed easily in urgent situations even with quick release features
- Cannot "spit out" mouthpiece in urgent situations
- Cannot clear water from tube with sharp expiratory force maneuver
- Cannot dive beneath the surface safely
- Valve malfunction may lead to serious aspiration consequence

Chapter 5: Conclusion

By far the most important finding of the Snorkel Safety Study is the confirmation that Rapid Onset Pulmonary Edema (ROPE) is the trigger leading to hypoxia in some, possibly most, fatal and non-fatal snorkel-related drownings. This phenomenon, while identified in other activities such as SCUBA and swimming, has not before been associated with snorkeling. Yet the evidence is indisputable. It is borne out by physiology, case studies, medical records, and first hand accounts. ROPE explains previously mysterious fatal and non-fatal snorkel-related drownings.

Why this should be peculiar to snorkeling among all ocean recreational sports has to do with the activity and equipment itself. Inhaling through a narrow tube will cause resistance. Resistance to inhalation, in combination with horizontal immersion, will, under certain circumstances, lead to Rapid Onset Pulmonary Edema (ROPE).

With the fabrication and application of the Snorkel Airways Resistance Analyzer (SARA) the Study confirmed that snorkels are a source of resistance to inhalation. It was also determined that:

- A high resistance snorkel adds to the risk of developing ROPE
- The more energy exerted, the greater the resistance
- Snorkel efficacy cannot be determined by cursory visual inspection

Full-face masks pose no advantage or disadvantage in terms of resistance to inhalation of air compared to other devices. However, based on evaluation of design and first hand accounts there are several adverse features of full-face masks including:

- Cannot be removed easily in urgent situations even with quick release features
- Cannot “spit out” mouthpiece in urgent situations
- Cannot clear water from tube with sharp expiratory force maneuver
- Cannot dive beneath the surface safely
- Valve malfunction may lead to serious aspiration consequences

Heart Disease, especially Left Ventricle End Diastolic Pressure (LVEDP), is a likely risk factor that can lead to ROPE. This was confirmed in both autopsy reports and case studies. LVEDP is common in older age groups and is most often asymptomatic when not severe.

<u>Going forward</u>

In this coming year the Study will 1) Submit an article in a peer reviewed journal; 2) Stimulate interest in the Survey; 3) Build a robust website; 4) Develop appropriate messaging.

Message to Snorkelers

Recreational snorkeling is not a benign low-risk activity. This is true both for inexperienced and experienced swimmers and snorkelers

- Always swim with a buddy
- If you can't swim, don't snorkel
- The risk of drowning is relatively higher among visitors
- Choose snorkel devices thoughtfully. Avoid constrictions in mouthpiece caliber, which may increase airway resistance to inhalation
- Learn to use the simplest snorkel device safely before trying more complex models and before venturing to depths beyond one that allows standing with water at chest level
- If in doubt about your cardiovascular heath – don't go out
- It may be prudent to wait until several days after arrival in Hawai'i by air to attempt a snorkel venture
- Shortness of breath can be a sign of danger. Stay calm, stand up, remove snorkel, get out of water immediately
- Beware of drifting away

Chapter 6: Acknowledgements & References

Acknowledgements

The authors wish to express appreciation for those who contributed their expertise, assistance, guidance, enthusiasm and knowledge to this study. We are deeply grateful for your contributions, and with apologies to those we have missed, Mahalo: Laola Lake Aiu, Ronald Bregman, Dr. Alvin Bronstein, Jeremy Burns, Guy Cooper, Dr. Patrick Fujimoto, Daniel Galanis,Tina Hamayasu, James Howe, Dr. Christopher Happy, Alan Hong, Gerald Kosaki, Dr. John Mickey, Audrey Newman, Jessica Lani Rich, Tammie Smith, Kaala Souza, John Titchen, Bridget Velasco, Kalani Vierra, Colin Yamamoto
Snorkel Safety Survey participants
Kauai, Maui, and Hawaii Island Fire Departments
Ocean Safety and Lifeguard Services Division, City and County of Honolulu
Friends of Hanauma Bay

References

Branco, J. 2017. *Silent Snorkel Syndrome and the Researchers Trying to Prevent Great Barrier Reef Deaths*. Brisbane Times (Dec 3).

Eagle, N. and M Riker. 2016. *Death In Paradise Is All Too Frequent For Visitors To Hawaii*. Civil Beat.

Eagle, N. 2017. How One Woman's Snorkeling Death Might Help Save Lives. Civil Beat (March 8)

Foti, P.R., 2019. Searching for Answers to Unexplained Snorkeling Deaths, Civil Beat, May 16, 2019

Foti, P. R. 2020. SARA Presentation, February, 2020 (PPT)

Foti, Philip R., M.D., Coroner's Office Presentation, February 2020, (PPT)

Galanis, Daniel. 2020. Snorkel-related incidents and fatalities, 2010-2019, (PPT)

State of Hawaii Department of Health, EMS & Injury Prevention System Branch, website.

van Beeck, E.F., C.M Branche, D. Szpilman, J.H. Modell, & J.J.L.M. Bierens. 2005. "A new definition of drowning: towards documentation and prevention of a global public health problem." Bulletin of the World Health Organization, November 2005, 83(11)