TESE DE DOUTORAMENTO

DROWNING AND CARDIOPULMONARY RESUSCITATION. RELEVANCE OF THE PROBLEM AND EFFECT OF PHYSICAL TRAINING ON RESUSCITATION QUALITY

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DECLARACIÓN DO AUTOR DA TESE

DROWNING AND CARDIOPULMONARY RESUSCITATION. RELEVANCE OF THE PROBLEM AND EFFECT OF PHYSICAL TRAINING ON RESUSCITATION QUALITY

D. Cristian Abelairas Gómez

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DROWNING AND CARDIOPULMONARY RESUSCITATION. RELEVANCE OF THE PROBLEM AND EFFECT OF PHYSICAL TRAINING ON RESUSCITATION QUALITY

D. Antonio Rodríguez Núñez

INFORMA:

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CONFLITO DE INTERESES

DROWNING AND CARDIOPULMONARY RESUSCITATION. RELEVANCE OF THE PROBLEM AND EFFECT OF PHYSICAL TRAINING ON RESUSCITATION QUALITY

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Asdo. Cristian Abelairas Gómez

A todas.

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Nothing happens unless with hard work

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- Gracias -

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MAIN PUBLICATIONS

Manuscript 1: *Narrative review*

Authors: **Abelairas-Gómez C**, Tipton MJ, González-Salvado V, Bierens JJLM.

Title: **Drowning epidemiology, prevention, pathophysiology, resuscitation, and hospital treatment.**

Journal: Emergencias (ISSN: 1137-6821) – Revista Científica de la Sociedad Española de Medicina de Emergencias.

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Manuscript 2: *Original contribution*

Authors: **Abelairas-Gómez C**, Rey E, González-Salvado V, Mecías-Calvo M, Rodríguez-Ruiz E, Rodríguez-Núñez A.

Title: **Acute muscle fatigue and CPR quality assisted by visual feedback devices: A randomized-crossover simulation trial.**

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ADDITIONAL PUBLICATIONS

Manuscript 3.1: *Letter to the Editor*

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Title: **Response to the letter concerning the article "The effect of strength training on quality of prolonged basic cardiopulmonary resuscitation" published in "Kardiologia Polska" 2017; 75, 1: 21-27.**

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ABBREVIATIONS

[La]: Blood lactate concentration

AED: Automated external defibrillator

AHA: American Heart Association

AMF: Acute muscle fatigue

BMI: Body mass index

CA: Cardiac arrest

CPR: Cardiopulmonary resuscitation

CRH: Cardiac rehabilitation

CO-CPR: Compression-only CPR

CV-CPR: Compression: ventilation CPR

Dm: Radial displacement

EAD: Early afterdepolarisations

ECMO: Extracorporeal membrane oxygenation

EMG: Electromyography

EMS: Emergency medical services

ERC: European Resuscitation Council

HR: Heart rate

ICU: Intensive Care Unit

IQR: Interquartile range

JCR: Journal Citation Reports

LQTS: Long QT Syndrome

MaxVO₂:	Maximum oxygen consumption
MV:	Mechanical ventilation
MVC:	Maximum voluntary contraction
NIV:	Non-invasive ventilation
OHCA:	Out-of-hospital cardiac arrest
PEEP:	End-expiratory positive pressure
Tc:	Contraction time
Td:	Delay time
Tr:	Relaxation time
Ts:	Sustained contraction time
TMG:	Tensiomyography
Vc:	Contraction velocity
VF:	Ventricular fibrillation
VNS:	Vagal never stimulation
VT:	Pulseless ventricular tachycardia
WHO:	World Health Organization

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0. SPANISH SUMMARY

0.1. INTRODUCCIÓN

El ahogamiento es un problema de salud pública a nivel mundial. A pesar de su relevancia en términos de morbilidad y mortalidad, se trata de un área temática en la que la información científica disponible es escasa desde diferentes perspectivas: epidemiología, prevención, fisiopatología, tratamiento inmediato y cuidados continuados.

En primer lugar, debe quedar claro lo que se entiende en la actualidad como *ahogamiento*: el proceso de sufrir dificultades respiratorias por sumersión/inmersión en un líquido. Definición que nació en 2002 en el Congreso Mundial de Ahogamiento celebrado en Ámsterdam (Holanda) y se ha consolidado. Con la definición del término tras un procedimiento de consenso de diferentes expertos del ámbito, también se abogó por la supresión de determinados términos más ambiguos o que pudieran dar lugar a confusión: *dry/wet-drowning*, *near-drowning*, *active/passive/silent-drowning* y *secondary-drowning*.

De este modo, la terminología aceptada respecto al ahogamiento incluye:

- ✓ *Ahogamiento mortal*: si la persona muere en cualquier momento a causa del ahogamiento.
- ✓ *Ahogamiento no mortal*: si la persona es rescatada y el proceso de ahogamiento interrumpido.
- ✓ *Rescate acuático*: si la persona es rescatada antes del comienzo de aspiración de agua.

- ✓ *Ahogamiento presenciado/no presenciado*: aquel en el que la inmersión/sumersión ha sido presenciada o no respectivamente.
- ✓ *Inmersión*: evento en el que las vías respiratorias se mantienen por encima de la superficie del agua.
- ✓ *Sumersión*: evento en el que las vías respiratorias están por debajo de la superficie del agua.

En cuanto a la epidemiología, si bien se registran como fallecidos a nivel mundial casi 400.000 personas al año, la Organización Mundial de la Salud (OMS) estima que las cifras reales pueden ser mucho más altas (hasta un 50% más elevadas en países desarrollados y multiplicarse incluso por cinco en países en vías de desarrollo) siendo diversas las causas de esta pérdida de casos detectados, notificados y diagnosticados. Por esto es preciso realizar estudios epidemiológicos, para conocer las cifras reales del problema, las circunstancias, factores de riesgo y desencadenantes en función del contexto.

La prevención se considera la clave para la reducción de las muertes por ahogamiento. A pesar de la importancia del tratamiento de la víctima ahogada y de la formación del personal con "el deber de asistir", con las medidas preventivas oportunas se considera que la mayor parte de los ahogamientos y sus consecuencias a corto y largo plazo podrían ser evitados. Entre las medidas de prevención del ahogamiento destacan: la instalación de barreras para la restricción del acceso al agua; ofrecer lugares seguros alejados del agua para niños en edad preescolar; la enseñanza de natación, actividades acuáticas y socorrismo en edad escolar; la capacitación en socorrismo y reanimación cardiopulmonar (RCP) a la sociedad; además de leyes y reglamentos de seguridad para la navegación y mejora de la gestión de riesgos en inundaciones.

La fisiopatología del proceso de ahogamiento tampoco es del todo conocida a pesar de tratarse de una “causa clásica” de morbilidad y mortalidad. En parte es debido a que ocurre generalmente en circunstancias poco controlables, lo que hace muy difícil llevar a cabo estudios experimentales y ensayos clínicos específicos. Sin embargo, todo conocimiento que se tenga sobre la fisiopatología del ahogamiento facilitará la mejora en el tratamiento pre- y hospitalario por lo que se trata de un campo en el que debería profundizarse.

Una vez comenzado el proceso de ahogamiento y avanzado hasta la parada cardiorrespiratoria (PCR), uno de los principales factores de supervivencia libre de secuelas neurológicas es la RCP in situ, bien sea por testigos legos o por profesionales con “el deber de asistir” como socorristas acuáticos. Además del inicio inmediato de la RCP, es esencial que dicho procedimiento se realice con criterios de calidad, por lo que los profesionales que atienden a estas víctimas deben estar formados y entrenados de forma adecuada.

Desde el punto de vista físico, realizar maniobras de RCP de calidad es una tarea de intensidad relativamente exigente, sobre todo si se realiza en un entorno adverso como es el medio acuático o si se realiza después de un esfuerzo físico importante, como el caso del rescate de la víctima en el agua. En cualquier caso, la RCP como actividad física en sí genera fatiga en el rescatador independientemente del esfuerzo previo realizado, lo que implica fatiga también en condiciones de reposo. Dada la importancia pronóstica de mantener la calidad de la RCP a lo largo del tiempo y la realidad de la fatiga durante la RCP, es esencial investigar este aspecto y, si fuera necesario, poner en práctica pautas y estrategias adecuadas de entrenamiento.

De este modo, se ha estudiado la fatiga desde diferentes perspectivas: diferentes relaciones compresión:ventilación; protocolo estándar (CV-RCP) vs. protocolo compresión-continua (CC-RCP); influencia del cambio de profundidad de las guías de resucitación de 2010 respecto a las de 2005; secuencia temporal del cambio de reanimadores; etc. Por otro lado, también se ha pretendido estudiar la fatiga que provoca la RCP desde una perspectiva fisiológica, analizando su repercusión sobre parámetros fisiológicos del reanimador como la frecuencia cardíaca y la fuerza muscular, o sobre parámetros bioquímicos como las concentraciones de lactato; aspectos de gran relevancia práctica ya que la condición física del rescatador podría ser un factor pronóstico positivo en caso de parada cardíaca.

En cuanto a la implicación muscular en el esfuerzo, principalmente con el uso de electromiografía (EMG), se han estudiado los grupos musculares a los que se exige más activación durante la RCP, con resultados variados en función del tipo de estudio y sus condiciones. El hecho de que en la mayoría de las investigaciones realizadas relativas a la RCP no se hayan normalizado los datos de la EMG en relación a la contracción máxima voluntaria de los participantes puede ser una explicación a esta disparidad de resultados. Hasta la fecha no se han publicado trabajos en los que se haya analizado con tensiomiografía (TMG) la intervención muscular, una técnica sencilla y no invasiva para la medición de parámetros de contracción muscular.

Los hechos comentados justifican la realización de este proyecto de investigación que trate de obtener evidencias y respuestas a las lagunas del conocimiento e incógnitas planteadas.

0.2. HIPÓTESIS

1. Existen evidencias científicas suficientes para hacer recomendaciones firmes en la prevención y tratamiento del ahogamiento.

2. El protocolo CC-RCP genera más fatiga en el rescatador que el protocolo CV-RCP.
3. Un programa de entrenamiento de fuerza contribuye a mantener una calidad de reanimación óptima durante más tiempo.

0.3. OBJETIVOS

1. Realizar una actualización científica sobre los principales factores a considerar en el estudio del ahogamiento: epidemiología, prevención, fisiopatología y tratamiento de la víctima ahogada.
2. Estudiar de forma cuantitativa la fatiga muscular generada por la realización de compresiones torácicas de calidad en los protocolos CC-RPC y CV-RCP.
3. Analizar los efectos de un programa de entrenamiento de fuerza sobre la calidad de las compresiones torácicas de durante la CV-RCP.

0.4 METODOLOGÍA

Objetivo 1. Se realizó una revisión bibliográfica sobre ahogamiento a través de los motores de búsqueda PubMed y Scopus haciendo uso de los operadores booleanos así como palabras clave y términos MeSH (Factores de riesgo; mortalidad; síndrome de dificultad respiratoria del adulto; parada cardiaca; manejo de atención al paciente; reanimación cardiopulmonar; pronóstico; supervivencia; ahogamiento; epidemiología; fisiopatología; prevención). La revisión se centró en los principales aspectos implicados en el ahogamiento: epidemiología, prevención, fisiopatología y resucitación de la víctima ahogada, desde el momento y lugar del evento hasta su atención a nivel hospitalario.

Objetivo 2. Se realizó un análisis descriptivo del estado de la musculatura tras la realización de la RCP. Para ello se contó con una muestra con formación previa que tuvo que superar un pre-test para ser incluida. Se tomaron registros mediante tensiomiografía del tríceps braquial y recto abdominal en condiciones basales y tras cada uno de los cinco ciclos de dos minutos de RCP que tuvieron que realizar los participantes. Esta metodología se realizó tanto con el protocolo CC-RCP como con el protocolo CV-RCP.

Objetivo 3. Se diseñó específicamente un programa de entrenamiento de fuerza y se evaluaron sus efectos sobre la calidad de la RCP en un escenario simulado con maniquís con sensores de calidad de las compresiones torácicas y las ventilaciones. Los componentes de la muestra seleccionada realizaron un test basal de un minuto de RCP (criterio de inclusión: superar 70% de calidad). Posteriormente hicieron un test de 10 minutos de RCP en la modalidad CV-RCP. En una tercera fase, los participantes que superaron el punto de corte de calidad de la RCP (70% en el primer minuto) se dividieron en dos grupos (control y experimental). El grupo experimental realizó el entrenamiento de fuerza (3 sesiones/semana durante 4 semanas), mientras que el grupo control realizó su actividad diaria normal. Tras el periodo de entrenamiento, ambos grupos repitieron el mismo test de 10 minutos de RCP en el modelo simulado.

0.4.1. Centros de realización:

1. Facultad de Enfermería, Universidade de Santiago de Compostela.
2. Facultad de Ciencias de la Educación y del Deporte, Universidad de Vigo

3. Facultad de Ciencias de la Salud, Universidad Europea del Atlántico, Santander.

0.4.2. Medios y recursos:

1. Grupo de investigación en Enfermería Clínica, Urgencias, Simulación e Innovación Docente (CLINURSID), Universidade de Santiago de Compostela.
2. Grupo de Investigación en Rendimiento y Motricidad del Salvamento y Socorrismo (REMOSS), Universidad de Vigo.
3. Parte de esta investigación fue financiada a través de un proyecto de investigación en concurrencia competitiva: Sociedad para el Desarrollo de Cantabria (SODERCAN) (Ref. RH16-XX-023).

0.4.3. Aspectos éticos y legales:

Los estudios realizados cumplieron los principios éticos contemplados en la declaración de Helsinki. Todos y cada uno de los participantes cumplimentaron un consentimiento informado autorizando su participación en el estudio y la cesión de sus datos, que fueron manejados de forma anónima. Además, podían retirarse siempre que lo considerasen oportuno sin necesidad de dar explicaciones al equipo de investigación.

0.5. RESULTADOS

Los principales resultados de la presente tesis doctoral se muestran en forma de compendio de publicaciones científicas, que incluyen una Revisión de la Literatura Científica, dos Artículos Originales y una Carta al Editor.

0.5.1. Revisión de la Literatura Científica: El ahogamiento: epidemiología, prevención, fisiopatología, reanimación de la víctima ahogada y tratamiento hospitalario (Original en castellano).

Referencia: **Abelairas-Gómez C**, Tipton MJ, González-Salvado V, Bierens JJLM. El ahogamiento: epidemiología, prevención, fisiopatología, reanimación de la víctima ahogada y tratamiento hospitalario. **Emergencias 2019;31(4):270-80.**

El objetivo de esta revisión narrativa fue elaborar un documento que tratara los aspectos clave del ahogamiento de acuerdo con la evidencia científica disponible. El ahogamiento se define como el proceso de sufrir dificultades respiratorias por sumersión/inmersión en un líquido. El tiempo de sumersión es un factor clave en la supervivencia y daño neurológico. Aunque la dificultad respiratoria y la hipoxia conforman el cuadro predominante, pueden presentarse otras manifestaciones y complicaciones que afecten a distintos sistemas y aparatos. El ahogamiento es una de las principales causas de muerte accidental en el mundo. Sin embargo, la mortalidad por ahogamiento está infraestimada y su morbilidad total es desconocida. La prevención es el factor clave para la reducción de la mortalidad y morbilidad, pero si esta falla, la rapidez y calidad del tratamiento tanto prehospitalario como hospitalario determinarán el pronóstico. Por tanto, resulta fundamental conocer los factores y mecanismos particulares implicados en esta emergencia.

Palabras clave: Factores de riesgo; mortalidad; síndrome de dificultad respiratoria del adulto; parada cardiaca; manejo de atención al paciente; reanimación cardiopulmonar; pronóstico; supervivencia.

0.5.2. Artículo Original: Fatiga muscular aguda y calidad de la RCP asistida por mecanismos de feedback: un estudio randomizado-cruzado (Original en inglés: Acute muscle fatigue and CPR quality assisted by visual feedback devices: A randomized-crossover simulation trial).

Referencia: **Abelairas-Gómez C**, Rey E, González-Salvado V, Mecías-Calvo M, Rodríguez-Ruiz E, Rodríguez-Núñez A. Acute muscle fatigue and CPR quality assisted by visual feedback devices: A randomized-crossover simulation trial. **PLoS ONE 2018;13(9):e0203576.**

Objetivo: Analizar la fatiga muscular aguda en el tríceps braquial y recto abdominal durante la RCP (CC-RCP & CV-RCP) realizada por personal formado en soporte vital básico.

Material y métodos: Veintiséis participantes fueron aleatoriamente divididos en dos grupos de acuerdo a los músculos analizados; 18 cumplieron finalmente los criterios de inclusión (9 en cada grupo). Ambos grupos realizaron 2 test de RCP (CC-RCP & CV-RCP) de 10 minutos divididos en 5 periodos de 2 min con otros 2 min de recuperación inter-test. El método de ventilación fue elegido por cada participante (boca a boca, mascarilla o balón auto-inflable). Los participantes disponían del feedback reportado por el maniquí durante los dos test. La fatiga muscular se midió mediante tensiomiografía en condiciones de reposo y tras la realización de cada ciclo de 2 minutos de RCP.

Resultados: El tiempo de contracción del recto abdominal aumentó significativamente durante el quinto ciclo de RCP ($p = 0.020$). El desplazamiento radial del vientre muscular del tríceps braquial ($p = 0.047$) así como la velocidad de contracción ($p = 0.018$) fueron menores durante la CC-RCP que durante la CV-RCP. Los participantes que entrenaron previamente con mecanismos de retroalimentación alcanzaron mejores índices de calidad en ambos protocolos. La mitad de los participantes escogieron ventilar con el balón auto-inflable pero obtuvieron menor calidad de ventilación que el resto de participantes.

Conclusiones: La CC-RCP induce mayor fatiga muscular que la CV-RCP. Se encontraron mayores índices de fatiga durante el quinto ciclo de RCP independientemente del protocolo. Parece ser que unos índices de fuerza muscular suficientes podrían ser un requisito para la realización de una RCP de mayor calidad. Además, la formación debería focalizarse más en la correcta realización de las ventilaciones.

0.5.3. Artículo Original: Efecto de un entrenamiento de fuerza en la calidad de la reanimación cardiopulmonar de larga duración (Original en inglés: The effect of strength training on quality of prolonged basic cardiopulmonary resuscitation)

Referencia: **Abelairas-Gómez C**, Barcala-Furelos R, Szarpak Ł, García-García Ó, Paz-Domínguez Á, López-García S, Rodríguez-Núñez A. The effect of strength training on quality of prologed basic cardiopulmonary resuscitation. **Kardiol Pol 2017;75(1):21-7.**

Introducción: La realización de compresiones y ventilaciones de calidad es el elemento clave para una reanimación cardiopulmonar (RCP) efectiva.

Objetivo: Investigar los efectos de un entrenamiento de fuerza en la calidad de la RCP realizada en un maniquí.

Material y métodos: Estudio cuasi-experimental en el que participaron 39 participantes con formación previa en soporte vital básico. Fueron aleatorizados en dos grupos (control y experimental). Ambos grupos realizaron un test de 10 minutos de CV-RCP. Posteriormente, el grupo experimental fue sometido a un entrenamiento de fuerza de 4 semanas

(3 sesiones/semana) focalizado en la principal musculatura implicada en la RCP. Tras el periodo de entrenamiento, ambos grupos volvieron a realizar un test de 10 minutos de RCP.

Resultados: Tras el entrenamiento, el grupo experimental aumentó significativamente la profundidad de compresión (53.7 ± 2.3 mm vs. 49.9 ± 5.9 mm; p = 0.003) y el porcentaje de compresiones correctas (68.2 ± 21.0% vs. 46.4 ± 29.1%; p = 0.004). Los participantes entrenados mantuvieron una calidad de compresiones superior al grupo control a lo largo de los 10 minutos. El volumen de aire por ventilación fue superior en el grupo experimental (701.5 ± 187.0 ml vs. 584.8 ± 113.6 ml; p = 0.040) y superior a lo recomendado. En el segundo test, las ventilaciones con volumen excesivo fueron superiores en el grupo experimental (31.5 ± 19.6% vs. 15.6 ± 13.0%; p = 0.007).

Conclusiones: Un entrenamiento de fuerza específico y sencillo supone un impacto importante en la calidad de las compresiones torácicas durante un test de 10 minutos de RCP. Se debe mejorar la formación en la realización de las ventilaciones para evitar la hiperventilación.

Palabras clave: reanimación cardiopulmonar; calidad; condición física; entrenamiento de fuerza.

0.5.4. Carta al Editor: Respuesta a la carta referente al artículo “Efecto de un entrenamiento de fuerzo en la calidad de la reanimación cardiopulmonar de larga duración” (Original en inglés: Response to the letter concerning the article “The effect of strength training on quality of prolonged basic cardiopulmonary resuscitation” published in “Kardiologia Polska” 2017; 75, 1: 21–27)

El profesor Oh JH escribió una carta al editor en relación a nuestro artículo “The effect of strength training on quality of prologed basic cardiopulmonary resuscitation" centrándose en tres apartados: 1) la antropometría como factor determinante en la RCP; 2) la utilidad del entrenamiento de fuerza para la mejora de la calidad de la RCP; 3) el diseño de programas de entrenamiento sin material específico.

De este modo, desde la revista Kardiologia Polska nos concedieron la oportunidad de réplica:

Diferentes estudios mostraron una asociación positiva entre el índice de masa corporal y la calidad de la RCP. Teniendo en cuenta esto, un entrenamiento de fuerza podría ser especialmente beneficioso para aquellas personas con un menor peso/índice de masa corporal. Sin embargo, una de las problemáticas que entraña el programa de fuerza utilizado fue el uso de máquinas de fitness. Esto podría generar poca adherencia ya que supone el entrenamiento en un gimnasio. Por tanto, desarrollar programas de entrenamiento con ejercicios calisténicos podría ser una alternativa. Una vez el efecto del programa de entrenamiento de fuerza ha sido testado, es necesario continuar investigando en qué tipo de entrenamiento contribuye en mayor medida al objetivo planteado.

Consideramos que el aumento de la investigación en cuanto a entrenamiento de fuerza y RCP será útil para evitar la sobre-ventilación descrita en nuestro estudio. Podría argumentarse que la sobre-ventilación no es un gran problema para personal lego al recomendarse la realización del protocolo sin ventilaciones, pero consideramos que lo ideal es encontrar una estrategia que mejore la calidad de las compresiones sin comprometer las ventilaciones. Sería importante estudiar específicamente las diferencias entre ambos protocolos. En el caso del protocolo CC-RCP, los efectos de la fatiga aparecen antes, lo que se traduce en un descenso de la calidad. Como se observó en nuestro estudio, un entrenamiento de fuerza mejora y mantiene la calidad de la RCP. En nuestro estudio se utilizó CV-RCP, pero resultados similares se obtendrían con el protocolo CC-RCP.

En conclusión, consideramos que la investigación relativa al entrenamiento de fuerza y RCP debería continuar de la siguiente manera: 1) comparando programas de entrenamiento con y sin material específico; 2) midiendo las diferencias en los efectos entre protocolo CC-RCP & CV-RCP; 3) evitando la sobre-ventilación causada por el entrenamiento; y 4) incluyendo la RCP en el propio entrenamiento.

0.6. DISCUSIÓN

0.6.1. El ahogamiento

0.6.1.1. Epidemiología y prevención

El ahogamiento es considerado por la OMS como un problema mundial de salud pública descuidado en el que la epidemiología y prevención son los principales damnificados. De este modo, las cifras de muertes por ahogamiento están totalmente infra-estimadas. Cabe recordar también que el ahogamiento engloba, principalmente y entre otras posibilidades, al ahogamiento mortal y al ahogamiento no mortal. En este sentido, el conocimiento epidemiológico sobre el ahogamiento no solamente está sub-representado por la falta de datos sobre las muertes por ahogamiento. Las consecuencias del ahogamiento están también infraestimadas porque la mayor parte de los estudios se centran en el estudio de los ahogamientos mortales.

La prevención se considera la mejor de las medidas para la reducción de la mortalidad y morbilidad asociadas al ahogamiento, muy por encima del tratamiento. La OMS establece un total de seis intervenciones a nivel comunitario para la prevención del ahogamiento:

1. Proporcionar espacios seguros lejos del agua para niños en edad preescolar.
2. Instalar barreras para controlar el acceso al agua.
3. Enseñar a los niños en edad escolar (mayores de 6 años) a nadar y competencias para la seguridad en el agua.
4. Crear resiliencia y gestionar los riesgos de inundación y de otro tipo.
5. Formar a las personas del entorno en rescates seguros y reanimación.
6. Establecer y hacer cumplir reglamentos para las embarcaciones de recreo y transporte y los transbordadores.

0.6.1.2. Fisiopatología: el "conflicto autónomo"

De acuerdo con la definición de ahogamiento como problema respiratorio derivado de la inmersión/sumersión en un líquido, se entiende que la actividad cardíaca en la víctima adulta evoluciona desde un ritmo sinusal normal a una taquicardia ventricular, bradicardia extrema, actividad eléctrica sin pulso y, finalmente, asistolia. Parece lógico asumir que la PCR en el paciente ahogado es de origen respiratorio, y que finalmente conduce a la parada del corazón. De hecho, la mayor parte de las publicaciones que han mostrado resultados sobre ritmos cardíacos de pacientes ahogados hallaron ritmos no desfibrilables.

El denominado *conflicto autónomo* trata de explicar el mecanismo por el cual el número de ahogamientos con PCR de origen cardíaco podría ser mayor del esperado. El efecto de la sumersión en agua fría puede aumentar la incidencia de arritmias por la estimulación de ambas regiones del sistema nervioso (simpática y parasimpática). Para poder analizar y entender en mayor medida el *conflicto autónomo*, se han realizado investigaciones *in vitro*. Así, se observaron un gran abanico de arritmias tras la estimulación simultánea de ambas regiones del sistema nervioso: bloqueo auricoventricular, taquicardia, bradicardia, bigeminismo y *torsade de pointes*. Además, el *conflicto autónomo* podría verse acentuado por diferentes factores predisponentes entre los que se encuentra el síndrome del intervalo QT alargado, por lo que su repercusión podría estar subestimada por la incapacidad de conocer *post mortem* el ritmo cardíaco previo.

0.6.1.3. Controversia en el tratamiento(?): RCP compresión: ventilación vs. RCP compresión-continua

El protocolo de RCP para el paciente ahogado recomienda la realización de cinco ventilaciones previas a los ciclos de 30 compresiones y 2 ventilaciones. Recientemente se ha publicado un estudio en el que se concluía que la CC-CPR podría ser tan efectiva como la CV-CPR en víctimas ahogadas. En mencionado estudio, aspectos tan determinantes en el ahogamiento como el tiempo de sumersión o la temperatura del agua no han sido registrados. Además, la edad media de los casos evaluados fue superior a los 70 años, algo que contrasta enormemente con otras publicaciones que reportaron datos de ahogamientos mortales en los que los niños eran la principal población de riesgo, en los que la edad media estaba muy alejada de los 70 años o con porcentajes de ahogados >65 años por debajo del 40%. Con la edad aumenta el riesgo cardiovascular y la prevalencia de enfermedad coronaria, la cual es uno de los factores predisponentes del *conflicto autónomo*. Teniendo en cuenta esto, que ≈90% de los ahogamientos no fueron presenciados por testigos, y que en el 50% de los casos los tiempos de respuesta de los sistemas de emergencias médicas fueron superiores a 9 minutos, cabe suponer que podrían haberse dado muchos casos en los que, aunque el origen de la PCR fuese cardíaco (*conflicto autónomo*), no se encontrase un ritmo desfibrilable en el momento de la RCP con monitorización cardíaca. Esto explicaría también los bajos índices de pronóstico favorable en ambas cohortes (CC-CPR & CV-CPR). Por tanto, quizás resulta apresurado plantearse la realización de CC-CPR en el paciente ahogado en lugar de focalizar la atención en el buen manejo de la vía aérea, la ventilación (con o sin instrumental) y la reducción de las interrupciones en la RCP.

0.6.1.4. Tratamiento: ventilación no invasiva y presión positiva al final de la espiración

Se han publicado pocos estudios que puedan esclarecer qué métodos de manejo de la vía aérea y soporte de la ventilación serían los ideales en el caso del paciente ahogado. Del mismo modo que en la RCP en otras víctimas, es probable que la intubación endotraqueal no aporte ventajas cuando es realizada por personal no experto, lo que es habitual en la RCP inicial. Por otra parte, el uso de dispositivos supraglóticos podría no ser del todo apropiado para víctimas ahogadas debido al descenso de la distensibilidad pulmonar y el aumento de la resistencia de la vía aérea. Por ello, la utilización de la mascarilla facial o bolsa autoinflable con un adecuado posicionamiento del cuello y apertura manual de la vía aérea parece ser el método con mejor relación beneficio/riesgo en el paciente ahogado.

La aplicación de ventilación no invasiva (VNI) en el paciente ahogado frente a la ventilación mecánica invasiva (VMI) también es un tema que ha despertado el interés de los investigadores tanto en el ámbito prehospitalario como en el hospitalario. La aplicación de VNI permitiría una más temprana oxigenación además del uso complementario y precoz de sistemas de presión positiva al final de la espiración, y ya existen evidencias de la seguridad y efectividad de la ventilación sin intubación en el ámbito prehospitalario. La VNI se presenta por tanto como una opción real de tratamiento ventilatorio en el paciente ahogado, evitando la necesidad de intubación endotraqueal, el uso de dispositivos mecánicos no siempre sencillos y también las posibles complicaciones asociadas a la VMI.

0.6.2. Tratamiento: La RCP desde el ejercicio físico

0.6.2.1. RCP: calidad, fatiga y entrenamiento

Se ha pretendido estudiar la fatiga a nivel neuromuscular mediante el uso de la TMG para describir los efectos de mencionada fatiga a nivel interno (rescatador) y no externo (calidad de RCP). Al final de cada período de CC-RCP se encontraron valores más bajos del desplazamiento del vientre muscular y de velocidad de contracción en el tríceps braquial, lo que se traduce en mayores índices de fatiga. En nuestro estudio no se observaron diferencias en las variables reportadas por la TMG a lo largo de los períodos en el tríceps braquial, algo que podría ser explicado por el hecho de que en ambos protocolos los participantes intercalaban 2 min de RCP con 2 min de descanso.

Sí que se encontraron diferencias significativas en el tiempo de contracción en el recto abdominal. En un análisis más profundo, el tiempo de contracción fue superior en el quinto período de RCP que en el resto. La implicación del recto abdominal en la RCP ya ha sido reportada previamente y categorizada como una intensidad moderada-alta.

Tras el análisis de la activación muscular por medio de la EMG se ha propuesto la programación de ejercicio físico para aquellos músculos más implicados. De este modo, se ha diseñado un programa de entrenamiento de fuerza de 12 sesiones (3 sesiones x 4 semanas) en el que se ha tenido en cuenta la musculatura más implicada en la RCP. Nuestros resultados, en los que se muestra una clara mejora en la calidad de la RCP en el grupo de entrenamiento en comparación con el grupo control, concuerdan con otras investigaciones en las que se asociaba una mayor fuerza muscular con la calidad de la reanimación. Sin embargo, el hecho de que la calidad de las ventilaciones haya disminuido tras el programa de entrenamiento, hace que no haya que olvidarse que deben entrenarse al mismo tiempo ambos factores: fuerza y RCP.

0.7. CONCLUSIONES

1. La evidencia científica existente en relación al ahogamiento es suficiente como para la elaboración de un documento de recomendaciones para su prevención y tratamiento.
2. El tríceps braquial desarrolla más fatiga muscular en la realización del protocolo CC-RCP.
3. Un programa de fuerza de 12 sesiones (3 sesiones x 4 semanas) contribuye a aumentar y mantener la calidad de la reanimación durante 10 minutos.

1. ABSTRACT, RESUMEN & RESUMO

1.1. ABSTRACT

According to the article 41 of the doctoral studies Normative of the Universidade of Santiago de Compostela, this doctoral thesis fits the modality of research articles compendium. In addition to other additional results, three publications in journals indexed in the *Journal Citation Reports* are present.

The first publication broaches one of the leading causes of death worldwide: drowning. A narrative review was carried out about its main aspects: epidemiology, prevention, pathophysiology and treatment. Drowning evidenced-base is much enough to write specific recommendations.

Taking into account that cardiopulmonary resuscitation is one of the main early-recommended treatments in drowning, the two next investigations caught up this topic. Neuromuscular fatigue associated to resuscitation was analysed in triceps brachii and rectus abdominis. Moreover, a strength training program was designed in order to study its effect on resuscitation quality.

Keywords: Drowning, prevention, pathophysiology, treatment, cardiopulmonary resuscitation, acute muscle fatigue, physical fitness, training.

1.2. RESUMEN

De acuerdo al artículo 41 del Reglamento de estudios de doctorado de la Universidade de Santiago de Compostela, esta tesis doctoral se ajusta a la modalidad de Tesis por compendio de artículos de investigación. De este modo, y entre otros resultados adicionales, se presentan tres trabajos de investigación interrelacionados publicados en revistas indexadas en el *Journal Citation Reports*.

La primera publicación aborda una de las principales causas de muerte a nivel mundial: el ahogamiento. Se redactó una revisión narrativa sobre los aspectos más destacados respecto a epidemiología, prevención, fisiopatología y tratamiento. La evidencia publicada es suficiente para redactar unas guías específicas que aborden esta causa de muerte.

Teniendo en cuenta que la reanimación cardiopulmonar es uno de los principales tratamientos precoces recomendados para la atención del paciente ahogado, las dos investigaciones restantes tratan sobre este tema. Se estudió la fatiga generada por la reanimación cardiopulmonar desde el punto de vista físico, analizando los cambios en la función contráctil muscular del tríceps braquial y del recto abdominal. Además, se diseñó un programa específico de entrenamiento de fuerza para estudiar su efecto sobre la calidad de la reanimación.

Palabras clave: Ahogamiento, prevención, fisiopatología, tratamiento, reanimación cardiopulmonar, fatiga muscular aguda, condición física, entrenamiento.

1.3. RESUMO

De acordo ao artigo 41 do Regulamento de estudos de doutoramento da Universidade de Santiago de Compostela, esta tese doutoral axústase á modalidade de Teses por compendio de artigos de investigación. Deste modo, e entre outros resultados adicionais, preséntanse tres traballos de investigación interrelacionados publicados en revistas indexadas no *Journal Citation Reports*.

A primeiras das publicacións aborda unha das principais causas de morte a nivel mundial: o afogamento. Fíxose unha revisión narrativa sobre os aspectos más destacados respecto á epidemioloxía, prevención, fisiopatoloxía e tratamento. A evidencia publicada é suficiente como para a redacción dunhas guías específicas que aborden esta causa de morte.

Tendo en conta que a reanimación cardiopulmonar é un dos principais tratamentos precoces recomendados para a atención ao paciente afogado, as dúas investigacións restantes tratan sobre este tema. Estudouse a fatiga xerada pola reanimación cardiopulmonar desde un punto de vista físico, analizando os cambios na función contráctil muscular do tríceps braquial e do recto abdominal. Ademais, deseñouse un programa específico de adestramento da forza para estudalo seu efecto na calidade da reanimación.

Palabras chave: Afogamento, prevención, fisiopatoloxía, tratamento, reanimación cardiopulmonar, fatiga muscular aguda, condición física, adestramento.

2. INTRODUCTION

2.1. Drowning. Our problem

More than 372,000 fatal drownings occur annually around the world, ensuring that drowning is considered a public health issue.[1] Therefore, the World Health Organization (WHO) has published a number of reports in which drowning was the sole topic or, in other cases, received significant attention (Table 1).

Table 1. Reports about drowning published by the WHO. [Own elaboration]

Year	Title	Main / Chapter
2006[2]	Guidelines for safe recreational water environments	Chapter 2: Drowning and injury prevention
2008[3]	European report on child injury prevention	Chapter 4: Drowning
2008[4]	World report on child injury prevention	Chapter 3: Drowning
2014[1]	Global report on drowning. Preventing a leading killer	Main
2017[5]	Preventing drowning: an implementation guide	Main

WHO: World Health Organization.

Although death rates related to drowning are alarming, different research and reports state that official data have underestimated the relevant figures.[1] Real numbers of drowning deaths in high-income countries could be up to 50% higher than current estimates,[1] whereas they could be five times higher in low- and middle-income countries.[1,4]

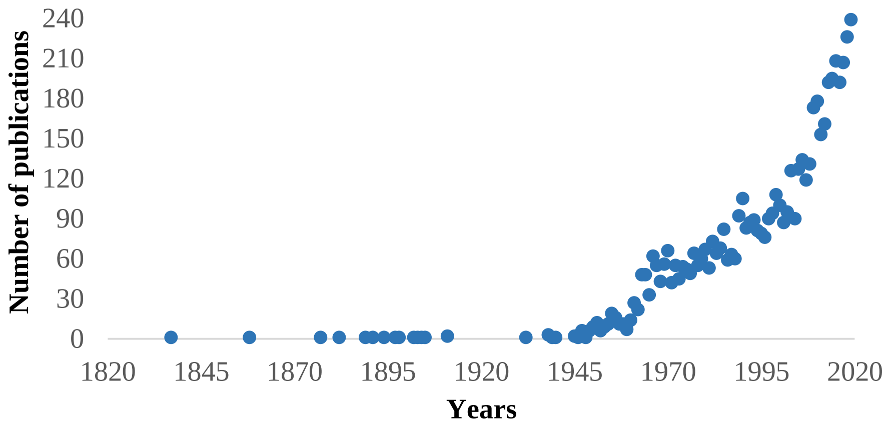


Figure 1. Number of publications per year in PubMed. Keyword: Drowning. [Original from the author]

A letter published in the *Journal of the American Medical Association* investigated the relationship between the frequency of 30 specific causes of death and the amount of funding each cause of death received and the volume of publications related to the issue.[6] According to the results, drowning was associated with less funding and fewer publications than would have been predicted based on mortality rates.[6] For this reason, and although it is a topic of study to which attention has increased considerably in recent years (Figure 1), there is a need for greater investment in the study of drowning from different perspectives: epidemiology, prevention, pathophysiology and treatment.

2.1.1. Terminology of drowning

Drowning is a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium.[7–9] This assumes that the liquid is introduced into the airway thus preventing breathing. The victim may survive or die, but regardless of the outcome it represents a case of drowning.[8,9] In case of death, it is defined as fatal drowning, and in case of survival, as non-fatal drowning.[10]

The need to define the term *drowning* has derived from the variability of existing definitions, which made it difficult to assess, analyze and compare studies.[11,12] The current definition was established by a consensus of experts following an arduous process of discussion at three international meetings, and also reviews and recommendations from other interested parties.[13,14] Finally, at the *World Congress of Drowning* (Amsterdam, Netherlands; 2002) the term *drowning* was defined as described in the previous paragraph and guidelines were developed for reported data related to drowning,[13,14] which were updated later.[8,9] This consensus also implied the recommendation to reject definitions considered obsolete, ambiguous and not based on evidence such as *dry/wet-drowning*, *near-drowning*, *active/passive/silent-drowning* or *secondary-drowning*. However, due to the publication of studies that continued to make use of definitions already considered invalid,[15] and with the aim of clarifying and explaining some of the existing myths about drowning, Szpilman *et al*[16] published the article *Dry drowning and other myths* in 2018.

Dry/wet-drowning: The term *dry-drowning* has been used referring to the appearance of drowned victims with apparently dry lungs. In this way, it allows a distinction between *wet-drowning* (water aspiration) and *dry-drowning* (non-water aspiration).[13,14] A cardiac arrest (CA) can happen in the water, just as it can on land, or possibly the victim may even fall into the water after their heart stops. This could offer an explanation why victims are sometimes found with dry lungs. However, in an animal study with two experimental groups that were introduced, post-mortem, in salt and fresh water containers, foam was found internally (throat and proximal trachea).[17] Therefore, as water can be introduced into the respiratory tract even after a death not caused by a drowning process, the term *dry-drowning* remains inaccurate and ambiguous.[18]

One of the most common explanations for dry lungs among drowned victims is laryngospasm. Although this phenomenon may occur as a defense mechanism preventing the entry of water into the respiratory tract, hypoxia will cause this reflex to cease. In a study conducted in Finland, less than 2% of the drowned victims analyzed did not show apparent signs of water aspiration, making it one of the studies that best justifies the rejection of the term *dry-drowning*.[19] By extension, the term *wet-drowning* would also be redundant.

Near-drowning: This term was used to refer to drowned people who had survived or had died after 24 hours. Returning to the example of CA, a person can die or survive following the CA, and in the latter case there is no expression *near-cardiac arrest*.[16] A person can die or survive an episode of drowning, but does not drown, recovers, feels good for a few hours or days and suddenly dies.[20] The definition of drowning sought a simple, inclusive, specific definition and in accordance with the Utstein style and with definitions of other medical conditions and diseases,[7] so the term *near-drowning* appears too imprecise.

Active vs. passive vs. silent drowning: *Active drowning* referred to those drownings that were witnessed in which the victim was seen moving. *Passive* and *silent drowning* were those in which the victim's movements were not observed. However, recordings of drowning with underwater cameras have shown that victims who appeared to be still, were, in fact, moving. In addition, weather and water conditions can make observation difficult, so the decision has been made to abandon these terms and make reference only to whether the drowning was witnessed or not. That is, if someone witnessed the immersion/submersion or not.[13,14]

Secondary drowning: This was used to refer to two situations. Firstly, those accidents that eventually resulted in a drowning (falls, cardiac arrests, serious injuries …). Secondly, to victims who developed adult respiratory distress syndrome after recovering.[13,14] Technically the term is inaccurate, since the victim does not suffer a second drowning episode. Also, as has already been noted, a drowned person does not recover and later die suddenly.[20] No case has ever been recorded in which symptoms have been alleviated, clinical evaluation has taken place and then the victim has died more than eight hours after the original drowning incident.[16] Consequently, it has been agreed that descriptions of events and their associated consequences must be explicit and that drowning is recognized as a primary process independent of the context and of other factors such as illnesses, injuries or intentional or unintentional immersion.[13,14]

In conclusion, the terms *dry/wet-drowning*, *near-drowning*, *active/passive/silent drowning*, and *secondary drowning* should be abandoned as a result of their being vague, ambiguous and confused.[7,13–16,18,20–22] In this way, *fatal drowning* can be defined as that in which the victim dies at any moment as a result of the drowning, before they are rescued or not. *Non-fatal drowning* is that in which the victim survives as a consequence of a rescue interrupting the drowning process. In cases where the victim is rescued before the water aspiration process begins, the appropriate term is a *water rescue*.[10] In Table 2 a summary of the obsolete and newly-recognized terminology is presented.

Table 2. Drowning terminology. Currently accepted and obsolete. [Original from the author]

Accepted	
Drowning	The process of experiencing respiratory impairment from submersion/immersion in liquid.
Fatal drowning	If the person dies at any time as a result of drowning.
Non-fatal drowning	If the person is rescued at any time and the process of drowning is interrupted.
Water rescue	Any submersion or immersion incident without evidence of respiratory impairment.
Witnessed	The episode is observed from the onset of submersion/ immersion.
Unwitnessed	The victim is found in the water and no one saw how he or she got there.
Immersion	Upper airway above water.
Submersion	Upper airway under water.
Obsolete	
Dry/wet-drowning	Near-drowning
Active/passive/silent drowning	Secondary drowning

2.1.2. Drowning: epidemiology, prevention, pathophysiology and treatment

Put briefly, the four main areas of study within the topic of drowning can be summed up as follows: epidemiology, prevention, pathophysiology and treatment. In accordance with different professional contexts, the knowledge of each of these will be different. For example, prevention measures will not be the same in a school as on a beach, and the knowledge regarding treatment will not be the same in case of a lifeguard compared with that of a medical doctor who is employed in an Intensive Care Unit (ICU). Also, in the case of the lifeguard, not only should training include the skills, procedures or protocols to be carried out when dealing with a drowned victim, but it is also necessary to include the rescue as part of treatment, and even vigilance as part of prevention. Following the creation of the current definition of drowning, and with the aim to reframe drowning, the *Drowning Timeline* has been created. The *Drowning Timeline* is a chronological chart that describes drowning, as a pathophysiological process, describing the triggers, actions, and interventions, with important attention to preventive measures (Figure 2).[23]

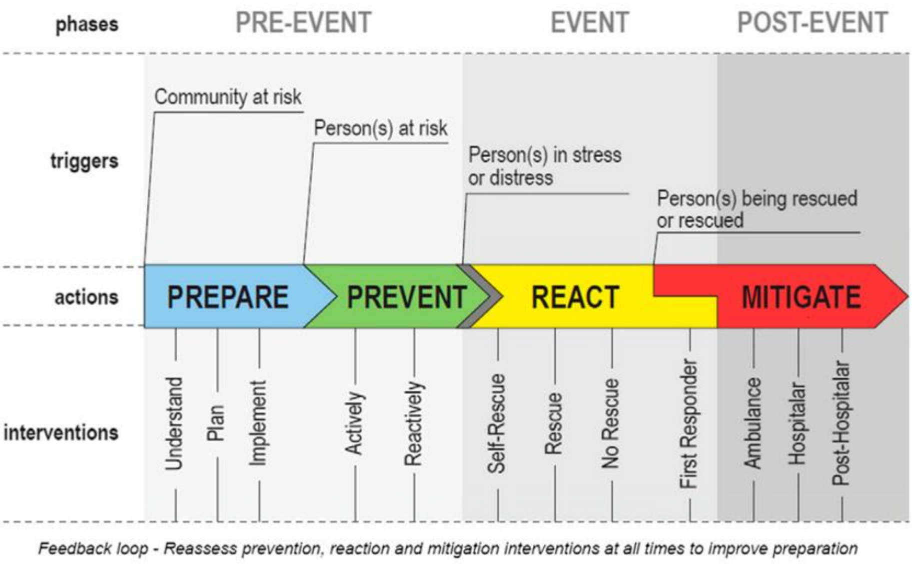


Figure 2. Drowning Timeline.[1]

[1] Reprinted from *The American Journal of Emergency Medicine*, 34(11), David Szpilman et al, *Drowning timeline: a new systematic model of the drowning process*, 2224-6, Copyright (2016), with permission from Elsevier. License number: 4734870164438[23]

The first section of the *Drowning Timeline* relates to preparation, including the general population's understanding not only of the drowning process itself, but also of its after effects in terms of mortality and morbidity. Epidemiology is present principally in this first section, allowing a view of drowning in different contexts and facilitating a way to implement preventive measures. The second phase is considered, along with the first, to be the most important in reducing the mortality/morbidity for drowning, and relates to prevention. Most of the deaths by drowning can be avoided by preventive measures[5,10,24] and these are considered to be the real key for the reduction of fatal cases.[25] Despite prevention is considered the most important factor in reducing drowning numbers, research into the efficacy of programs and interventions of a preventive nature is very scarce. At the *World Congress of Drowning Prevention* celebrated in Vancouver (Canada) in 2017, more than 300 abstracts were submitted, of which, around 20% tackled prevention. Nevertheless, only 8 of these abstracts featured some way of measuring the impact of the studied proposals and programs for prevention (unpublished results).

The following two phases, *React* and *Mitigate*, refer to an intervention when present at a drowning, including rescue and medical attention (both in the water and on land). This final part of the *Drowning Timeline* is focused mainly on knowledge of the pathophysiology of the victim, which allows an assessment of appropriate protocols and dictates the best form of action for treatment.

Complementing the *Drowning Timeline*, and taking into account that education on how to prevent or deal with drownings has not been guided by high-level evidence, the *Drowning Chain of Survival* has also been created (Figure 3).[26]

Figure 3. Drowning Chain of Survival.[2]

With five links, one more than the *Chain of Survival* dictating the response to a CA,[27] the *Drowning Chain of Survival* does not feature a series of fixed recommendations, but only a general guide to those aspects involved in the prevention of drownings and the correct intervention when dealing with a drowning. In this case, as with the *Drowning Timeline*, it is also possible to establish a relation between the links and the concepts of epidemiology, prevention, pathophysiology and treatment (Figure 4).

Since the *Drowning Timeline* and the *Drowning Chain of Survival* establish a series of concepts at a general level, one of the aims of the present doctoral thesis was to clarify in more detail, based on the scientific literature, the four key aspects related to drowning: epidemiology, prevention, pathophysiology and treatment.

[2] Reprinted from *Resuscitation*, 85(9), David Szpilman et al, *Creating a drowning chain of survival*, 1149-52, Copyright (2014), with permission from Elsevier. License number: 4744230302318[26]

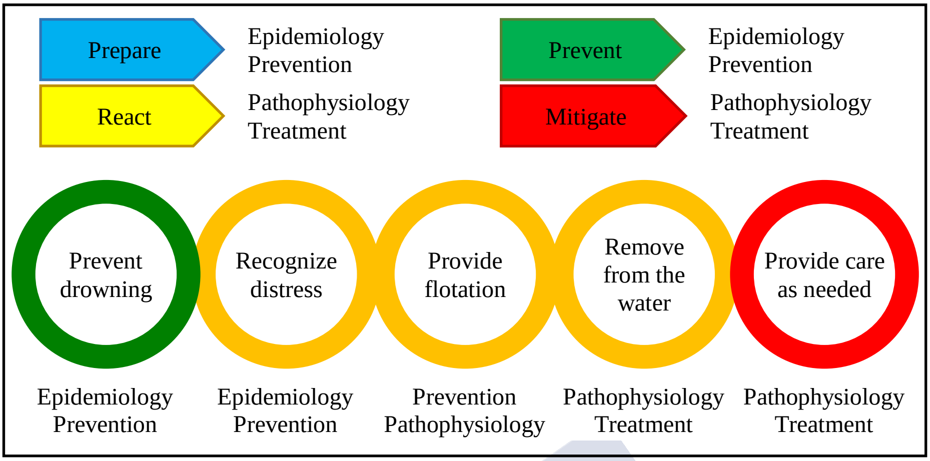


Figure 4. Relationship between the terms described in the *Drowning Timeline* and the *Drowning Chain of Survival* and epidemiology, prevention, pathophysiology and treatment. [Original from the author]

2.2. CHAIN OF SURVIVAL

Figure 5 shows the *Chain of Survival*, which sums up the vital links necessary for a successful resuscitation in case of CA.[27]

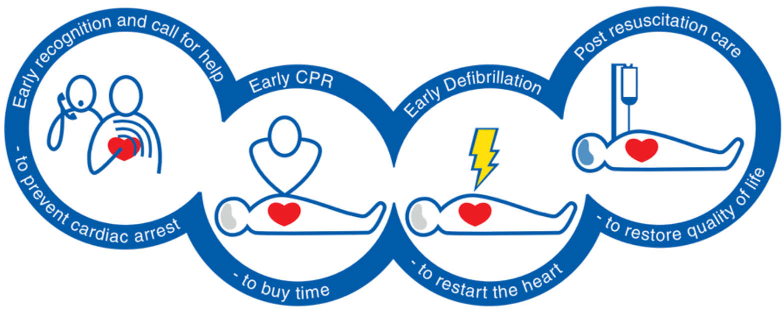


Figure 5. Chain of Survival.[3]

[3] Reprinted from *Resuscitation*, 95, Gavin D. Perkins et al, *European Resuscitation Council Guidelines for Resuscitation 2015 Section 2. Adult basic life support and automated external defibrillation*, 81-9, Copyright (2015), with permission from Elsevier. License number: 4744230362524[27]

If the links of the *Chain of Survival* are implemented appropriately, the survival rate for out-of-hospital CA (OHCA) attended and treated by the emergency medical services (EMS) increase greatly.[28–30]

In recent years, different modifications of the *Chain of Survival* have been proposed, as for case of drowning, the *Trauma Chain of Survival* has also been developed.[31] There has even been an initiative to create an independent algorithm for the recognition and treatment of hypothermia by means of extracorporeal membrane oxygenation (ECMO).[32] Nevertheless, in the latter case, said algorithm would form part of the fourth link of the initial *Chain of Survival*, *Post-resuscitation care*, without any need for the inclusion or modification of other links.

In Figure 5, it can be seen that the size of each link is exactly equal. Recently, two *Chains of Survival* have been published with links of different sizes (Figure 6).[33]

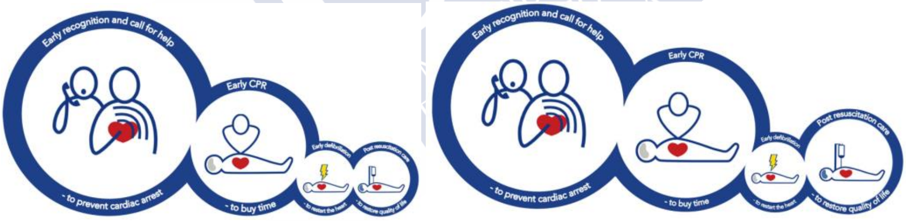


Figure 6. Chain of Survival for out-hospital (left) and in-hospital cardiac arrest (right).[4]

Taking the initial link as reference, the size of the rest of links are adapted according to the percentage of patients progressing to each one. Therefore, the size of the rest of the links indicates the percentage of patients reaching each point.[33] Although the author maintains that the intention is not to replace the original *Chain of Survival*, since "*it*

[4] Reprinted from *Resuscitation*, 126, Charles D. Deakin, *The chain of survival: Not all links are equal*, 80-2, Copyright (2018), with permission from Elsevier. License number: 4744230241878[33]

is still the optimal representation for emphasizing the importance of the overall chain concept or for educating the lay public", it is still possible that the erroneous message is communicated, unintentionally, that some links may be more important than others, even though the figure only shows, with all its limitations, the percentage of patients that reaches each of its links. For example, the size of the second link (*Early CPR*) of the chain shown in Figure 6 is calculated based on 60,000 OHCA cases registered by the National Health Service (UK), of which the EMS attended to 28,000; 28,000/60,000 = 0.47, granting this link a ratio of 0.47/1 compared to the size of the first link. What is not indicated is the outcomes in those remaining cases, and also whether the 28,000 EMS-attended cases has been previously attended by bystanders. This is a significant limitation during the calculation of each link's size and could lead to potential misunderstandings of what this new *Chain of Survival* suggests, especially bearing in mind the maxim that "*a chain is only as strong as its weakest link*".

With regard to the transmission of a potentially erroneous message, a similar issue occurred with the publication of the results of *Progetto Vita*, a study that evaluated the importance of time reductions in the application of automated external defibrillators (AED), but in which the volunteers did not apply cardiopulmonary resuscitation (CPR); even in cases where the AED was not recommending a shock, the volunteers were inactive until the arrival of the EMS.[34] Although the authors maintained that their article did not support the message of "*not doing CPR*", the discussion of the study minimized the importance of CPR,[35] even warning that after post-shock recovery, CPR could harm the chances of resuscitation, considering it *commotio cordis*. Therefore, while the scientific community claims that anybody can act when faced with OHCA, said article transmits a message, without being explicitly stated, in which the importance of the second link of the chain is minimized.

In 2018, a proposed *Survival Cycle* was published, in which the authors transformed the original *Chain of Survival* into a cycle, adding two links: one at the beginning and another at the end.[36] The beginning of the cycle, *CPR training and awareness campaigns* referred to the training of the general population. In reality, this information is already implicit in the first link of the original chain, *Early recognition and call for help*, since to be able to recognize a CA, it is necessary to have some prior education or awareness. The last link added by Martínez *et al*[36] was *Rehabilitation and monitoring*, referring to the importance of cardiac rehabilitation (CRH). In this respect, a circular version of the *Chain of Survival* had already been published previously, in which the promotion of healthy habits and the inclusion of CRH were considered as the *missing link* (Figure 7).[37,38]

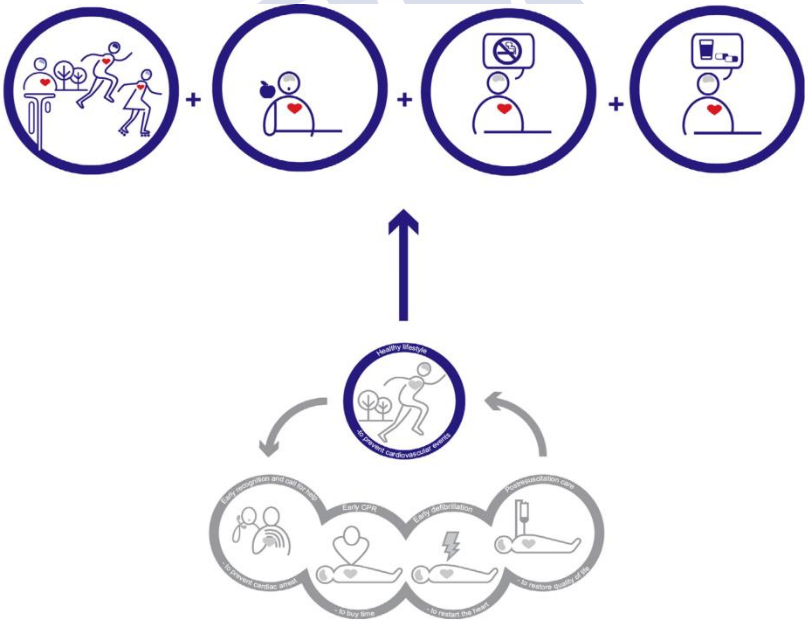


Figure 7. The “missing link” of the Chain of Survival and its details.[5]

[5] Reprinted from *Revista Española de Cardiología (English Edition)*, 72(1), Violeta González-Salvado et al, *From Prevention to Rehabilitation: Toward a Comprehensive Approach to Tackling Cardiac Arrest*, 3-6, Copyright (2018), with permission from Elsevier.[38]

2.3. CARDIOPULMONARY RESUSCITATION

CPR consists of a series of manoeuvres destined to cardiovert a CA. An unresponsive person who is not breathing normally is in CA and requires CPR.[27,28] Previously in this document, different explanatory models related to drowning and CA have been described, playing CPR an important part in all of these (Table 3).

Table 3. Relationship between explanation models of drowning and CA, and CPR. [Original from the author]

Drowning Timeline	*Mitigate*
Drowning Chain of Survival	*Provide care as needed* (link 5)
Chain of Survival	*Early CPR* (link 2)

CA: Cardiac arrest; CPR: Cardiopulmonary resuscitation.

CPR consists of the application of 30 compressions in the center of the chest of a person in CA, to a 5-6 cm depth and with a rate of 100-120 com/min. For every 30 compressions, there should be 2 ventilations of 500-600 ml of air in not more than 10 s.[27,28] In cases of drowning, the assumption is that the arrest is of a respiratory and not cardiac origin and the protocol would begin with 5 ventilations followed by the cycles of compression and ventilation 30:2 (Figure 8).[39] CPR, like any physical activity, generates fatigue in the rescuer, therefore a change of rescuer is recommend every 2 minutes if possible.

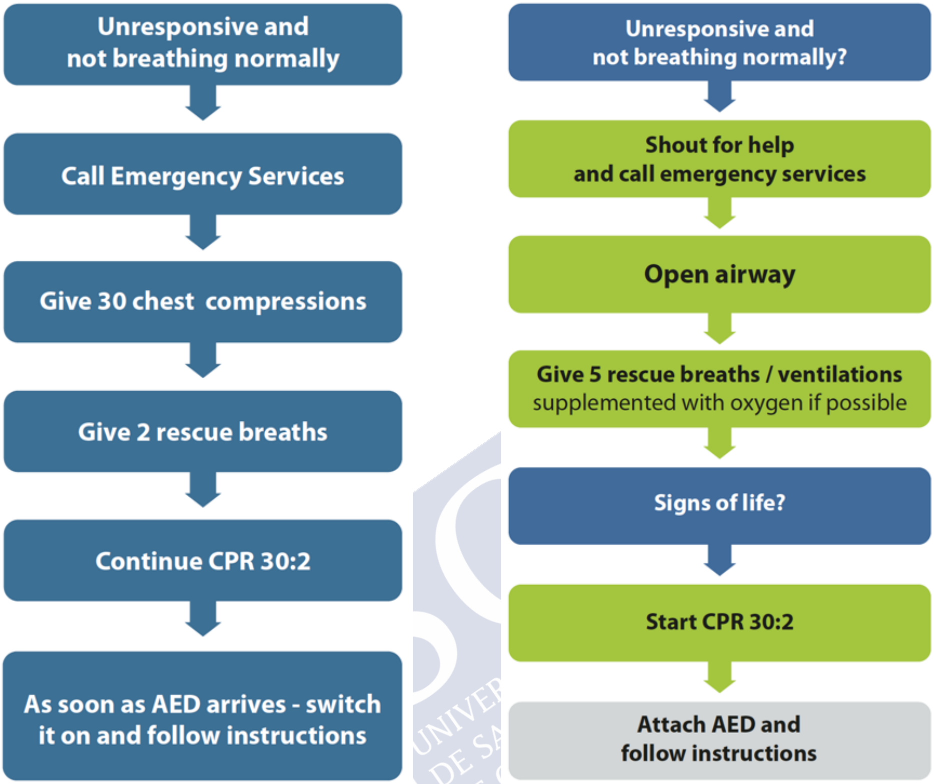


Figure 8. BLS/AED algorithm (left)[6] and drowning treatment algorithm for rescuers with a duty to respond (right).[7]
BLS: Basic life support; AED: Automated external defibrillator.

[6] Reprinted from *Resuscitation*, 95, Gavin D. Perkins et al, *European Resuscitation Council Guidelines for Resuscitation 2015 Section 2. Adult basic life support and automated external defibrillation*, 81-9, Copyright (2015), with permission from Elsevier. License number: 4758190640624[27]

[7] Reprinted from *Resuscitation*, 95, Anatolij Truhlář et al, *European Resuscitation Council Guidelines for Resuscitation 2015 Section 4. Cardiac arrest in special circumstances*, 148-201, Copyright (2015), with permission from Elsevier. License number: 4744230422725[39]

2.3.1. Cardiopulmonary resuscitation and physical fatigue

CPR quality has been the object of study for many years. By the 1990s, research that addressed the influence of fatigue on CPR had already been published.[40,41] Since then, a large number of studies have been published with the aim of analyzing the fatigue that CPR generates in the rescuer and the consequent decline of its quality. Fatigue generated by different ratios of compression:ventilation has been analyzed;[42–45] compression:ventilation CPR (CV-CPR) has been compared with compression-only CPR (CO-CPR);[42,46–49] also, the influence of the increase in the recommended depth of compressions following the publication of the European Resuscitation Council Guidelines for Resuscitation in 2010.[50] Consequently, as has already been mentioned in the previous paragraph, a change of rescuer is advisable every 2 min in order to minimize the effect of fatigue on the quality of CPR.[27,28]

In order to offset the effects of fatigue, while also improving the training of rescuers, different feedback devices have been designed which can report the quality of CPR and, in turn, encourage better execution. Different studies have demonstrated the utility of all kinds of devices: metronomes,[51,52] specific medical feedback devices,[53–56] low-cost devices,[57] smartwatches[58] and even songs to maintain the compression rate.[59] The effectiveness of feedback devices has been demonstrated to such a degree that its use in training and refresher courses is highly recommended.[60]

As well as feedback devices, automatic compression devices have also been designed. These eliminate the fatigue generated by CPR and allow the rescuer to perform other actions whilst CPR is in progress. However, as yet, no studies have shown improvements in outcome/survival rates in CA treated by automatic compression devices compared with manual CPR. Therefore, there is no evidence to recommend mechanical CPR for routine cases, except in those where chest compression is unfeasible[61–65] such as during ambulance transport.[66] Also, recent studies have shown strong association between the use of mechanical CPR and potentially life-threatening injuries.[67]

2.3.2. Physiological variables related to fatigue

Although fatigue that CPR generates has been studied extensively, most of the published literature describes fatigue in terms of CPR quality (with variables external to the rescuer), and not of variables directly related (intrinsic) to the rescuer. Weight, height and body mass index (BMI) have been established as factors which affect the quality of compressions,[68–74] causing some authors to suggest that rescuers with a BMI <25 $kg \cdot m^{-2}$ should be relieved after just one minute of CO-CPR.[68] Other studies suggest this should apply to those with <23 $kg \cdot m^{-2}$ BMI.[75] Differences between CPR quality of men and women have also been studied, demonstrating that differences between them disappear adjusting analysis by BMI and other variables related to physical fitness as maximum oxygen consumption ($MaxVO_2$) and muscle force.[70]

In 1999 a study was published which concluded that a certain level of physical fitness might be beneficial to deliver compressions of adequate quality.[76] In this study, physically active participants performed 18 minutes of CPR with a lower heart rate (HR) and using a lower rate of $MaxVO_2$.[76] HR has been one of the most studied physiological variables in the analysis of CPR fatigue. Hansen *et al*[77] registered HR over 90% of the max HR of the participants, who were asked to perform 15-min CO-CPR. Nevertheless, in the published literature, it is not common to find such high percentages of max HR, many publications concur with a range of 60-75%,[74–76,78–82] therefore giving compressions is rated equivalent to moderate-intensity physical activity.[76] What does seem to influence the mean HR during CPR is the physical fitness of the rescuer, and differences in HR have been found between physically active and sedentary people,[76] and also between medical students and physical education students, where the latter group demonstrating lower HR.[80] In another study in which three groups of rescuers were compared (sedentary vs. rugby players vs. swimmers) it was also observed that HR were lower in individuals who trained regularly, specifically with a higher peak work rate of the upper body.[83]

Blood lactate concentration ([La]) has also been analyzed. In general, the average [La] shown in the literature range between 2-4 $mmol{\cdot}l^{-1}$.[76,77,79,80] Nevertheless, maximum peaks as high as 8 $mmol{\cdot}l^{-1}$ have been registered after 15-min of CO-CPR, but no relation has been found between [La] and CPR quality.[77]

As has already been noted, physical fitness might be an important factor not only in delivering CPR whilst maintaining low levels of HR,[76,80] VO_2[76] or [La][80], but also in giving better CPR quality. Quality of CPR in the study of Lucia *et al*[76] was similar between a group of physically-active individuals with no CPR training and second group of trained but sedentary professionals. A later study showed correlation between a lower HR during a three-minute ramp protocol on a rowing ergometer at 75 watts and compressions delivered to a correct depth.[74] A relation has also been described between a lower $MaxVO_2$ and the quality of the compressions.[70] In addition, amongst a surveyed sample, those claiming to do sport or exercise ≈5 days per week with a total duration of ≈300 min per week reached higher indexes of CPR quality than those who did less physical activity (≈3 days/week; ≈120 min/week).[84]

Another significant variable related to physical fitness is muscular strength, which plays a fundamental role in the difficulty (or not) of maintaining an adequate depth during compressions.[75] As a result, the force applied by the rescuer may diminish over time as the number of compressions increases for each cycle of CPR (15:2 vs. 30:2 vs. 50:5).[82] The change of minimal depth of compression recommended by the 2010 guide (50 mm) as opposed to that of 2005 (38 mm) required in turn an increase in the minimal force of compression (44 kg vs. 32.5 kg).[74]. In this way, high levels of maximum isometric strength from the upper body (grip strength)[70,71] and a greater muscular mass in the upper limbs and trunk[85] have been associated to greater compression depth.

Although it is true that a relation has been described between muscular strength and the quality of compressions, primarily related to compression depth, as yet no published studies have quantified muscular fatigue across muscular parameters. Nor has it been established if a programmed and systematized strength training would influence the quality of CPR over time. Precisely, the las two objectives of this thesis are related to muscle fatigue and strength training, but to pursue them further it is first necessary to discuss about the musculature involved in CPR.

2.3.3. Muscles involved in cardiopulmonary resuscitation

During the last decade, different research has tried to analyze which musculature is key to delivering CPR. The most common instrument used was Electromyography (EMG). In order to guarantee consistent EMG readings for comparison between muscles, participants and time periods, a method of normalization is essential.[86–88] Without normalization of the information from the EMG, it is possible to establish that a certain muscle is activated, but not to express it in terms of "quantity of activation", since the activation during the maximum voluntary contraction (MVC) is unknown. As such, a comparison inter - and intramuscular, when the relative activation is not known, is highly limited. These limitations must be born in mind when analyzing muscular fatigue from CPR, as well as the musculature identified by means of the EMG, if no process of normalization of the readings is employed.

While Dainty *et al*[89], in their study which aimed to analyze muscular fatigue during CO-CPR and CV-CPR by means of EMG, managed to realize a process of normalization of the EMG data, almost all the publications that have tried to analyze fatigue or study the musculature involved in CPR failed to do so. In said study, the activation of left and right external oblique as well as triceps brachii declined significantly during CPR, suggesting approximately 3% of the MVC.[89] In the case of Tsou *et al*,[90] which also normalized the EMG readings, pectoralis major, rectus abdominis and erector spinae were the most activated muscles during chest compressions, with activation indexes over 45% of the MVC. Table 4 shows the musculature most often implicated in CPR according to the literature.

Table 4. Muscles with more activation during CPR. [Original from the author]

Triceps brachii	Trowbridge *et al*[91] Hasegawa *et al*[92] Yasuda *et al*[93] Dainty *et al*[89]
Pectoralis major	Tsou *et al*[90] Yasuda *et al*[93]
Anterior deltoid	Trowbridge *et al*[91]
Rectus abdominis	Tsou *et al*[90]
Biceps femoris	Hasegawa *et al*[92]
Erector Spinae	Tsou *et al*[90]
Brachioradialis	Yasuda *et al*[93]

CPR: Cardiopulmonary resuscitation.

2.3.4. Tensiomyography

Figure 9. TMG protocol. [Original from the author]

Tensiomyography (TMG) is an innovative, simple and non-invasive method for muscular evaluation. This tool has been developed in the faculty of Electrical Engineering of the University of Ljubljana (Slovenia) with medical objectives in mind.[94] Strength is a basic parameter for the study of muscular function; by the end of the 1990s studies had already been published which illustrated the benefits of using TMG to measure parameters of muscular contraction.[95,96] Another advantage of TMG as opposed to other hardware is the ability to measure the action of a superficial muscle belonging to a major group, based on the radial displacement of the belly by means of a magnetic sensor.[96] One of the most positive aspects of TMG is that it allows rapid, precise evaluation, it does not interfere in normal daily tasks and it is not invasive.[97]

The muscular evaluation is carried out by means of a sensor placed perpendicularly in the most prominent area of the muscle belly, between two electrodes 3-5 cm apart (Figure 9). In isometric conditions, it measures the radial distortion of the muscle belly over time once it is being activated by an electrical stimulus of controlled intensity. After inducing the electrical stimulus, any possible distortion of the results by non-isometric contractions is avoided by restraining the relevant limb.[94,97]

The protocol of electrical stimulation can vary between studies. While it is true that a discharge of 1 ms is standard, not all publications use the same intensity. Carrasco *et al*[98] began with an initial discharge of 30 mA with increases of 10 mA up to a maximum of 110 mA. Whereas Rey *et al*[99] applied an initial discharge of 50 mA and two later ones of 75 and 100 mA, Morales-Artacho *et al*[100] preferred amplitudes of 40, 60, 80 and 100 mA. Where there does seem to be more consensus is in the recovery time between stimulations (10-15 s).[98,99,101,102]

The use of TMG provides multiple advantages when studying the contraction properties of the superficial musculature. Firstly, it is a non-invasive tool, of simple use, short duration and the participant is not required to produce any effort. In addition, as it is capable of analyzing a muscular group within a set, it offers more precise evaluation and analysis.[103] In Table 5 the variables analyzed by TMG are shown, and in Figure 10 this appears in graph form.

Table 5. Reported variables from TMG. [Original from the author]

Radial displacement (Dm)	Maximum radial displacement of the belly. A high Dm represents a lack of muscle tone, or muscular fatigue. A low Dm indicates excessive stiffness
Delay time (Td)	Time that passes from the original electrical impulse to the moment when 10% of the Dm is reached.
Contraction time (Tc)	Time taken to pass from 10% to 90% of Dm .
Sustained contraction time (Ts)	From the moment 50% Dm is reached to that when it is repeated during relaxation. It is interpreted as the duration time of the contraction.
Relaxation time (Tr)	Time passed during relaxation between 90% and 50% of Dm. High values for this variable indicate the existence of fatigue in the evaluated musculature.

TMG: Tensiomyography

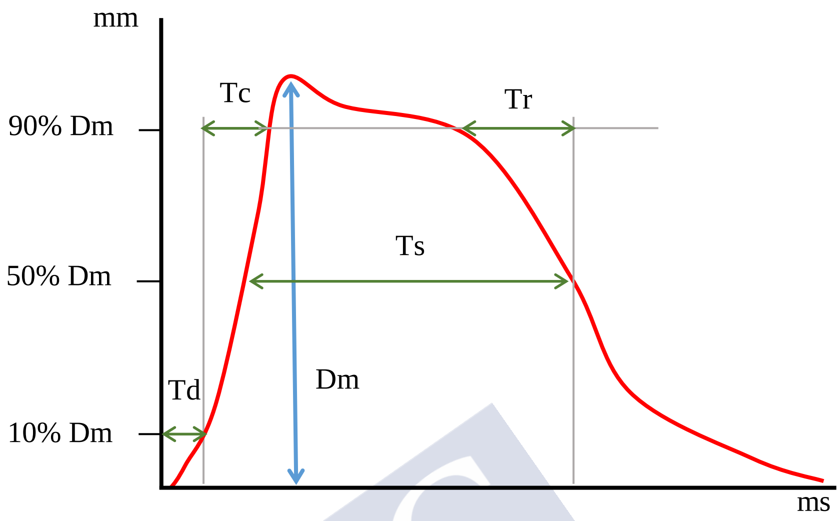


Figure 10. Graphic representation of TMG variables.
[Original from the author]
TMG: Tensiomyography

Out of the five reported TMG variables, Dm, Td and Tc are the three most reliable parameters, clearly defining TMG as a consistent method to assess muscle contraction properties.[104] Of these three, Dm and Tc are those with the highest level of reliability, the former for the measurement of the muscular stiffness, and the latter for the prediction of muscle fiber composition.[105]

3. HYPOTHESIS

H.0- Sufficient scientific evidence exist in order to write firm recommendations for the prevention and treatment of drowning.

H.1- Compression-only cardiopulmonary resuscitation leads to more acute muscle fatigue than compression-ventilation.

H.2- A strength training program helps rescuers to maintain optimum cardiopulmonary resuscitation quality over longer time.

4. OBJECTIVES

O.0- To carry out a scientific update on the main factors to be considered in the study of drowning: epidemiology, prevention, pathophysiology and the treatment of the drowned victims.

O.1- To study quantitatively the muscular fatigue generated by optimal chest compressions in the protocols of compression-only and compression-ventilation cardiopulmonary resuscitation.

O.2- To analyse the effects of a strength training on chest compressions during compression-ventilation cardiopulmonary resuscitation.

5. METHODOLOGY

The present doctoral thesis takes the format of a *Thesis by Compendium of Publications*. This supposes that the main body of the doctoral thesis consists of a series of articles that have been published or accepted by journals indexed in the *Journal Citation Reports*. A minimum of three publications is required.

Following this approach, three articles (a review of the literature and two originals) and a letter to the editor are featured. Each publication counts with its specific justification, objective, methodology, results, discussion and conclusions. Finally, there is a general discussion that covers all of the publications presented in this thesis.

Also, in a complementary way, there is a summary of other activities (see *Results* section) carried out by the PhD candidate that have contributed to his training as a researcher.

6. RESULTS

6. 1. PUBLICATIONS THAT FORM THE BODY OF THE PHD

6.1.1. Drowning epidemiology, prevention, pathophysiology, resuscitation, and hospital treatment

Type or article: Narrative review

Year of publication: 2019

Doi: -----

PMID: 31347808

Language: Spanish (Translated to English in Appendix 1).

Journal information

Emergencias (ISSN: 1137-6821): Emergencias is the journal of the Spanish Society of Emergency Medicine, being the most important journal (in terms of impact factor) in the area of emergencies in the Hispanic countries.

Reference: Abelairas-Gómez C, Tipton MJ, González-Salvado V, Bierens JJLM. Drowning epidemiology, prevention, pathophysiology, resuscitation, and hospital treatment. Emergencias. 2019;31(4):270-80.

Times cited up to February 2020: Not available

	Publication year JCR*	Last JCR (2018)
Impact factor	3.350	3.350
Impact factor without journal self cites	2.184	2.184
5-year impact factor	1.992	1.992
Decile	2	2
Quartile	1	1
Percentile	87.931	87.931
Category	Emergency medicine	
Rank	4/29	4/29

JCR: Journal Citation Reports.

*If the article was published in 2019 or 2020, publication year JCR shows data from the last JCR.

Link to the article:

http://emergencias.portalsemes.org/numeros-anteriores/volumen-31/numero-4/el-ahogamiento-epidemiologa-prevencin-fisiopatologa-reanimacin-de-la-vctima-ahogada-y-tratamiento-hospitalario/

6.1.2. Acute muscle fatigue and CPR quality assisted by visual feedback devices: A randomized-crossover simulation trial

Type or article: Original

Year of publication: 2018

Doi: 10.1371/journal.pone.0203576

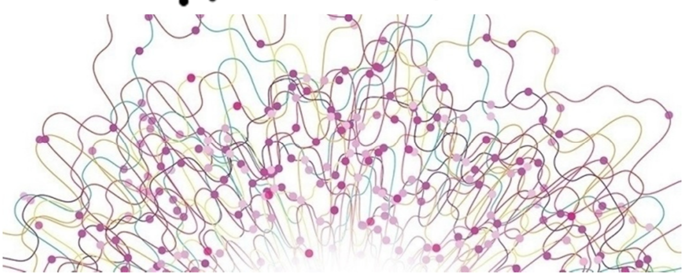
PMID: 30231037

Language: English

Journal information

PLoS ONE (ISSN: 1932-6203): PLoS ONE is an open-access multidisciplinary journal that publishes research about many different subject areas across science, engineering, medicine, and the related social sciences and humanities.

Reference: Abelairas-Gómez C, Rey E, González-Salvado V, Mecías-Calvo M, Rodríguez-Ruiz E, Rodríguez-Núñez A. Acute muscle fatigue and CPR quality assisted by visual feedback devices: A randomized-crossover simulation trial.. PLoS ONE. 2018;13(9):e0203576.



Times cited up to February 2020:

- Web of Science: 0
- Scopus: 0
- Google Scholar: 3

	Publication year JCR*	Last JCR (2018)
Impact factor	2.776	2.776
Impact factor without journal self cites	2.633	2.633
5-year impact factor	3.337	3.337
Decile	4	4
Quartile	2	2
Percentile	65.942	65.942
Category	Multidisciplinary sciences	
Rank	24/69	24/69

JCR: Journal Citation Reports.
*If the article was published in 2019 or 2020, publication year JCR shows data from the last JCR.

Link to the article:

https://doi.org/10.1371/journal.pone.0203576

6.1.3. The effect of strength training on quality of prolonged basic cardiopulmonary resuscitation

Type or article: Original

Year of publication: 2017

Doi: 10.5603/KP.a2016.0165

PMID: 27878801

Language: English

Journal information

Kardiologia Polska (ISSN: 0022-9032): Kardiologia Polska is the official journal of the Polish Cardiac Society since 1957. Its scope broads cardiology, from basic science to translational and clinical research on cardiovascular diseases.

Reference: Abelairas-Gómez C, Barcala-Furelos R, Szarpak Ł, García-García, Paz-Domínguez Á, López-García S, Rodríguez-Núñez A. The effect of strength training on quality of prolonged basic cardiopulmonary resuscitation. Kardiol Pol. 2017;75(1):21-7.

Times cited up to February 2020:

- Web of Science: 16
- Scopus: 14
- Google Scholar: 26

	Publication year JCR*	Last JCR (2018)
Impact factor	1.213	1.674
Impact factor without journal self cites	0.980	1.239
5-year impact factor	0.950	1.231
Decile	9	8
Quartile	4	3
Percentile	16.016	26.838
Category	Cardiac & Cardiovascular systems	
Rank	108/128	100/136

JCR: Journal Citation Reports.
*If the article was published in 2019 or 2020, publication year JCR shows data from the last JCR.

Link to the article:

https://doi.org/10.5603/KP.a2016.0165

6.2. OTHER PUBLICATIONS DIRECTLY RELATED TO PHD TOPIC

6.2.1. Response to the letter concerning the article "The effect of strength training on quality of prolonged basic cardiopulmonary resuscitation"

Type or article: Letter to the editor

Year of publication: 2017

Doi: 10.5603/KP.2017.0011

PMID: 28124792

Language: English

Journal information

Kardiologia Polska (ISSN: 0022-9032): Kardiologia Polska is the official journal of the Polish Cardiac Society since 1957. Its scope broads cardiology, from basic science to translational and clinical research on cardiovascular diseases.

Reference: Abelairas-Gómez C, Barcala-Furelos R, Szarpak Ł, García-García, Paz-Domínguez Á, López-García S, Rodríguez-Núñez A. Response to the letter concerning the article "The effect of strength training on quality of prolonged basic cardiopulmonary resuscitation" published in "Kardiologia Polska" 2017; 75, 1: 21-27. Kardiol Pol. 2017;75(1):88-9.

	Publication year JCR*	Last JCR (2018)
Impact factor	1.213	1.674
Impact factor without journal self cites	0.980	1.239
5-year impact factor	0.950	1.231
Decile	9	8
Quartile	4	3
Percentile	16.016	26.838
Category	Cardiac & Cardiovascular systems	
Rank	108/128	100/136

JCR: Journal Citation Reports.
*If the article was published in 2018 or 2019, publication year JCR shows data from the last JCR.

Link to the article:

https://doi.org/10.5603/KP.2017.0011

6.3. OTHER RESULTS THAT CONTRIBUTED TO THE PHD CANDIDATE LEARNING AND TRAINING

6.3.1. Publications of the PhD candidate during the PhD period (indexed in JCR)

Original contribution

1. ***Abelairas-Gómez C***, Carballo-Fazanes A, López-García S, Martínez-Isasi S, Rico-Díaz J, Rodríguez-Núñez A. Knowledge and attitudes on first aid and basic life support of Primary and Preschool teachers and the parents. An Pediatr (Barc). In press. Doi: 10.1016/j.anpedi.2019.10.010.
2. Barcala-Furelos R, ***Abelairas-Gómez C***, Aranda-García S, Lorenzo-Martínez M, Martínez-Isasi S, Durán-Álvarez C, …, Rodríguez-Núñez A. Is it feasible "scoop and run while playing" resuscitation on a Rescue Water Craft? A randomized simulation study with lifeguards. Am J Emerg Med. In press. Doi: 10.1016/j.ajem.2019.10.045.
3. Carballo-Fazanes A, Barcala-Furelos R, Eiroa-Bermúdez J, Fernández-Méndez M, ***Abelairas-Gómez C***, Martínez-Isasi S, …, Rodríguez-Núñez A. Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high. A pilot study. Am J Emerg Med. In press. Doi: 10.1016/j.ajem.2019.12.048.
4. Tipton MJ, ***Abelairas-Gómez C***, Mayhew A, Milligan GS. The thermal demands of flood rescue and impacts on task performance. Ergonomics. 2020;63(1):109-118.
5. González-Salvado V, Rodríguez-Ruiz E, ***Abelairas-Gómez C***, Ruano-Raviña A, Peña-Gil C, González-Juanatey JR, Rodríguez-

Núñez A. Training Adult Laypeople in Basic Life Support. A Systematic Review. Rev Esp Cardiol (Engl Ed). 2020:73(1):53-68.

6. Aranda-García S, Herrera-Pedroviejo E, ***Abelairas-Gómez C***. Basic life support learning in undergraduate students of Sports Sciences: Efficacy of 150 minutes of training and retention after eight months. Int J Environ Res Public Health. 2019;16(23):4771.

7. Fernández-Méndez F, Otero-Agra M, ***Abelairas-Gómez C***, Sáez-Gallego NM, Rodríguez-Núñez A, Barcala-Furelos R. ABCDE approach to victims by lifeguards: How do they manage a critical patient? A cross sectional simulation study. PLoS One. 2019;14(4):e0212080.

8. Rodriguez-Ruiz E, Guerra Martín V, ***Abelairas-Gómez C***, Sampedro Vidal F, Gómez González C, Barcala-Furelos R, Rodríguez-Nuñez A. A new chest compression technique in infants. Med Intensiva. 2019;43(6):346-51.

9. Rodriguez-Ruiz E, Martínez-Puga A, Carballo-Fazanes A, ***Abelairas-Gómez C***, Rodríguez-Nuñez A. Two new chest compression methods might challenge the standard in a simulated infant model. Eur J Pediatr. 2019;178(10):1529-35.

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Letters to the Editor

1. ***Abelairas-Gómez C***, Carballo-Fazanes A, López-García S, Martínez-Isasi S, Rodríguez-Núñez A. Schoolteachers should know how and teach to Save Lives to the Kids. The inclusion of basic life support training in university degrees whose aim is to train teachers. An Pediatr (Barc). In press. Doi: 10.1016/j.anpedi.2019.11.010.

2. ***Abelairas-Gómez C***, López-García S, Martínez-Isasi S, Carballo-Fazanes A, Rodríguez-Núñez A. Basic life support knowledge of the future of the Infant and Primary School teacher. An unresolved problem in university study plans? An Pediatr (Barc). 2019;91(5):344-5.

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6.3.2. Research stays during the PhD period

Centre

Extreme Environments Laboratory – Department of Sport and Exercise Science – University of Portsmouth (UK)

Brief information

The Extreme Environments Laboratory works to understand, evaluate and enhance human comfort and performance.

It researches in the areas of sport, industry, emergency services, military and for expeditions to the ultimate extremes.

Researchers from the laboratory have assisted athletes preparing for the Olympic and Paralympic Games. They are internationally recognised for the impact of our research (i.e. survival sea; thermal environment; working at altitude; search and surveillance, and expedition support).

With

Professor. Dr. Michael J. Tipton

Date

4^{th} October 2017 – 19^{th} January 2018

&

1^{st} September 2018 – 2^{nd} November 2018

Activities

The work programme involved research in the area of flood rescue (protocol development, lab set up, experimentation, analysis & write up).

Results

- Tipton MJ, Abelairas-Gómez C, Mayhew A, Milligan G. The Thermal Demands of Flood Rescue and Impacts on Task Performance. Ergonomics. Ergonomics. 2020;63(1):109-118.
- Abelairas-Gómez C, González-Salvado V, Tipton MJ, Bierens JJLM. Drowning epidemiology, prevention, pathophysiology, resuscitation, and hospital treatment. Emergencias. 2019;31(4):270-80.
- Drowning prevention research: quantity and quality. Analysis of papers published in the proceeding of the World Conference on Drowning Prevention 2017 (Vancouver - Canada). Under review.

Centre

Institut Nacional d'Educació Física de Catalunya – University of Barcelona

Brief information

The INEFC is the higher education centre created by the Catalan Government that has as its mission, according to the Law on Sport, the training, specialization and improvement of graduates in physical education and sport, as well as for scientific research and the dissemination of their work or studies for training.

The two academic centers have teaching staff with recognized experience in the field of teaching and in the professional exercising of the various areas of physical education and sport. The INEFC also has a workforce of administration and services staff to guarantee the operational functioning of the institution.

With

Dr. Silvia Aranda García

Date

12th November 2018 – 13th January 2019

Activities

Three activities were developed during this period: 1) to start multi-centre research project about the changes of performing cardiopulmonary resuscitation with different chest resistances; 2) to collaborate in a study about the cardiopulmonary resuscitation training of sport students; 3) to advise in the development of a new water rescue device for lifeguards (QuickRescue).

Results

- Aranda-García S, Herrera-Pedroviejo E, Abelairas-Gómez C. Basic life support learning in undergraduate students of Sports Sciences: Efficacy of 150 minutes of training and retention after eight months. Int J Environ Res Public Health. 2019;16(23):4771.
- Abelairas-Gómez C, Barcala-Furelos M, Aranda-García S, López-García S, Barcala-Furelos R. Cardiopulmonary resuscitation quality as a function of chest resistance: and ongoing research project. In: International Life Saving Federation editor. World Conference of Drowning Prevention; 2019 Oct 08-10: Durban, South Africa; 2019. p. 306.
- Report about QuickRescue.

6.3.3. Young Investigator award in the Ian Jacobs Young investigators competition of the European Resuscitation Council

The late Ian Jacobs, former paramedic and nurse, led the Australian Resuscitation Council for over 15 years and ILCOR from 2011-14. Ian is remembered for his dedication, kindness and compassion. His enthusiasm for life and for his achievements that motivated all around him to strive harder to further the science of resuscitation. The Ian Jacobs Young Investigator Award is awarded annually to the best non-physician researcher.

A young investigator will be considered someone under the age of 35 years old on the 1st day of the congress or within 5 years of the award of a postgraduate research thesis (Masters, MD, PhD).

Young investigators are invited to submit a free text summary of research (300 words) that they have undertaken in the field of resuscitation. Young investigators submit their body of work as sole authors and finalists are selected by the session organizers. The best researchers are invited to present at the meeting. Presentations last 15 minutes with 5 minutes for questioning.

In the European Resuscitation Council Congress 2017 [28-30 September 2017 – Freiburg (Germany)], the Ian Jacobs Award was given, for first time, to two researchers: Cristian Abelairas-Gómez (Spain) and Ben Beck (Australia) (Figure 11).

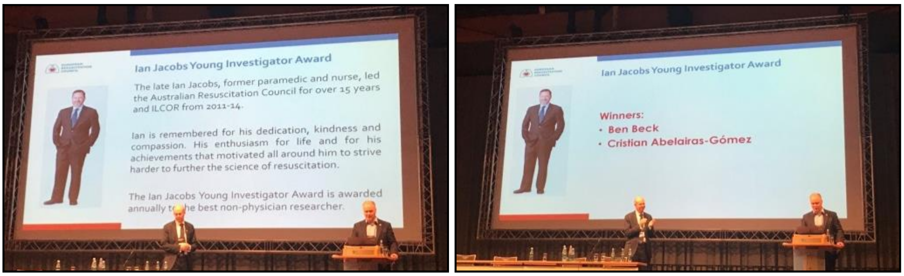

Figure 11. Ian Jacobs Young investigators competition of the European Resuscitation Council [28-30 September 2017 – Freiburg (Germany)]. [Original from the author]

7. DISCUSSION

The present doctoral thesis addresses a worldwide public health issue, *drowning*, and one of its most immediate and effective treatments, CPR. Drowning has been tackled from a methodological perspective with a narrative review, collecting in one document the scientific evidence published regarding epidemiology, prevention and treatment. Moving on to CPR, this has been dealt with whilst focusing on training and physical exercise. From this perspective, the discussion tries to tackle the key points and questions related to drowning, and discuss the results obtained in the analysis of muscular fatigue in the CPR and the effect of physical training on the quality with which it is applied.

7.1. Drowning

7.1.1. Epidemiology and prevention

Drowning is considered by the WHO to be a neglected public health issue.[1] Epidemiology and prevention of drowning are the issues most affected by the low quality of drowning data. The under-reporting of fatal drownings, especially in low- and middle-income countries where the official figures are estimated to be 90% below actual levels,[106] is the result of different factors:[1] 1) the records often exclude intentional deaths by drowning (suicide or murder); 2) the consequences of natural disasters (tsunamis, floods…) are also often excluded, as are accidents at sea (shipwrecks…); 3) many victims of drowning never receive medical attention, and it is generally the medical services that register the information.

It is also necessary to remember that drowning includes, mainly and among other possibilities, fatal drowning and non-fatal drowning. In this regard, the epidemiologic knowledge of drowning is not only under-represented due to the absence of information on deaths by drowning, but also because most of the studies focus on the study of fatal drownings.[106] As well as a lack of epidemiology for fatal drownings, there has been even less study into morbidity associated with non-fatal cases. It is believed that for every fatal drowning, 4-5 people receive in-hospital treatment for non-fatal drowning.[10,107]

Tools for recording information and statistics related to drowning should be standardised and unified, and they should include not only fatal drownings but also non-fatal cases and even aquatic rescues. Different local, national and international agencies should also collaborate in the registration of cases in order to provide improved data relating to the epidemiology of drowning.[108] This would simplify the design and implementation of preventive measures to reduce the morbid-mortality of drowning. In this way, it seems that efforts are being made to improve the recording of information regarding deaths by drowning. For example, studies have been published in which there has been significant reduction in cases categorised as "*other drownings and unspecified submersions*".[109]

Prevention is considered the best measure to reduce mortality and morbidity associated with drowning, with a far greater impact than treatment.[1,5,10,24,25,106] WHO has established a total of six interventions at community level for the prevention of drowning:

1. Provide safe places away from water for pre-school children: The 0-4-year-old children are the age group at greatest risk of drowning.[5,110] In a study carried out in Australia that registered

cases of fatal drownings among 0-17 years old children in portable pools, 20% of the cases were less than 5 years old.[111] In other research, also carried out in Australia with drowning cases among 0-14 years old, 65.6% had an age between 0-4 years.[112] Furthermore, out of everyone under 18 hospitalized due to drowning in Quebec (Canada) between 1989 and 2015, around 70% were less than 5 years old.[113] At these ages, the most significant risk factors do not relate directly to the victim, but to the adult charged with supervising the child[5,114] with distractions of the parents or carers representing one of the most common causes of accidents.[115] During the years 2002-2004, in an analysis of the children's mortality at home within 16 European countries, the most vulnerable age was shown to be children under 5, and drowning was the main cause of death in this age range.[116]

There have even been studies which found that 80% of drownings among under-fives were due to a lack of supervision.[117] Consequently, it is essential to reinforce the message that a child's swimming ability does not preclude their need for supervision.[118] As for professionals who are employed with children in an aquatic environment, it is imperative that they are trained with an emphasis on remaining alert throughout all periods of supervision,[5] especially since this is considered one of the most effective measures for the prevention of the drowning at these younger ages.[115,119] In Bangladesh, programs designed to increase the supervision of 1-5 years old children in aquatic environments, amongst other community education measures, contributed to a reduction in deaths by drowning.[120]

2. Install barriers controlling access to water: According to the WHO, 75% of the deaths of children drowned in swimming pools could have been avoided by establishing physical barriers that restrict access,[5] considering the evidence level of this measure to be

"*effective*" principally in low- and middle-income countries.[121] Nevertheless, the installation of barriers must always be accompanied by supervision, since frequently the barrier acts simply as a time-delay device[122] that discourages but does not completely prevent access to the aquatic environment.[123]

3. Teach school-age children swimming and water safety skills: It might be supposed that the ability to swim should be directly related to a reduction in the risk of drowning.[106] Nevertheless, teaching swimming skills alone might increase the risk due to the additional exposure to water and also to an excess of confidence that could encourage swimming in dangerous places.[124] Studies have already been published in which a positive association between an advanced swimming level and the probability of suffering a fatal-drowning has been made.[125] In addition, it is necessary to bear in mind the environment in which the swimming skills are acquired, since learning in a controlled environment such as a swimming pool would not necessarily involve an equal skill level compared with swimming in open waters.[126] Therefore, it seems reasonable to recommend, not only learning to swim, but also water safety and rescue skills. The inclusion of this content in the school syllabus would allow this knowledge to reach the widest population.[108] Although findings have recently been published that address different interventions and the connected acquisition of knowledge and skills related to drowning and the aquatic medium,[127–131] there is little scientific literature that links these interventions to a reduction in the morbid-mortality of drowning. However, results following the implementation of the program PRECISE (Prevention of Child Injury Through Social-Intervention and Education) in Bangladesh, demonstrated that there was indeed a reduction in the mortality for drowning. The teaching of

swimming and basic rescue skills to the 4-12 year-old population was one of several initiatives at community level.[120]

4. Build resilience and manage flood risks and other hazards: Flooding affects more people worldwide than any other type of natural disaster,[132] and drowning is the main cause of death during floods.[133,134] WHO has developed a mix of structural (engineered) and non-structural approaches:[5] 1) assess flood risk; 2) select the most suitable flood risk management methods; 3) develop and implement a flood risk management plan; 4) ensure drowning prevention is integrated with existing disaster risk reduction programs; 5) monitor and evaluate.
5. Train bystanders in safe rescue and resuscitation: To train the population in skills related to swimming and lifesaving might help to reduce the number of deaths by drowning among victims as well as rescuers.[135–137] There are frequently cases in which bystanders (those with no professional duty to assist) lose their lives while attempting to rescue a drowned victim, and these are often linked to a dangerous combination of over-confidence, a lack of training in rescue skills and finally a failure to correctly evaluate all the factors at the scene. In Australia between 2002-2007 and 2006-2015, the figures for deaths among bystanders attempting a rescue were 27[135] and 51[138] respectively; in 2009 the same figure for Turkey was 31 people[136] and in 2013 for China it was more than 50.[137] These findings contrast those of a Dutch study that states that between 1999 and 2004, 503 bystanders performed 343 successful rescues.[139] As the authors point out, a key factor in this high success rate might be that 90% of Dutch children learn to swim. Of the 692 fatal drownings registered by the United Sates Lifesaving Association in the years 2014-2018, 593 (85.7%) took place in aquatic areas with no lifeguard service,[140] this statistic helps

justify this recommendation as well as that which appears as recommendation 3.

In addition to the training of the general population, the training of professionals destined to monitor the safety of aquatic spaces, the lifeguards, must also be of adequate quality.[108] The WHO recommends that at least half of the hours of any such programme should be made up of practical training.[5] The training of the general population in basic rescue skills should extend to CPR training.

6. Set and enforce safe boating, shipping and ferry regulations: The safety of water-borne transport depends fundamentally on educational initiatives and institutional regulation.[5] The use of flotation devices such as life jackets is one of the topics that must be included within education, as they represent the only objects whose relation with prevention of the drowning has been studied.[106] The connection has already been found between their use and a reduction in the likelihood of drowning during a nautical accident.[141,142] The WHO, in order to enforce safe boating, shipping and ferry regulations, has established the following steps for large and small vessels (Table 5).[5]

Table 6. Steps for setting and enforcing safe boating, shipping and ferry regulations.[5] [Original from the author]

<table>
<tr><th>Large vessels</th><th>Small vessels*</th></tr>
<tr><td colspan="2">Assess the situation</td></tr>
<tr><td colspan="2">Train operators to competent and professional standards.</td></tr>
<tr><td colspan="2">Improve detection and dissemination of information about the weather.</td></tr>
<tr><td colspan="2">Ensure vessels are fit for purpose.</td></tr>
<tr><td>Adopt technologies and incentives that promote adherence to regulations for proper loading of vessels.</td><td>Limit alcohol and illicit drug use among small boat operators.</td></tr>
<tr><td rowspan="2"></td><td>Promote regulations for proper loading of vessels.</td></tr>
<tr><td>Regulate and enforce mandatory wearing of lifejackets in high-income countries and encourage and support expansion of their use in low- and middle-income countries.</td></tr>
</table>

*Small vessels: those from 5-8 meters in length.
WHO: World Health Organization.

7.1.2. Pathophysiology: The Autonomic Conflict

In accordance with the definition of drowning as a respiratory impairment resulting from immersion/submersion in a liquid, it is understood that cardiac activity develops from a normal sinus rhythm to a ventricular tachycardia, to extreme bradycardia, to pulseless electrical activity and, finally, to asystole. It seems logical to suppose that a CA in a drowned patient is of respiratory origin. In fact, most of the publications that have studied the cardiac rhythms of drowned patients found asystole in more than 80% of the cases,[143–147] with an increased percentage if patients with pulseless electric activity are included[144–148] and remaining cases with non-shockable rhythms at less than 10%.[143,147–151]

In any case, one must not forget that a ventricular fibrillation (VF) / pulseless ventricular tachycardia (VT) (shockable rhythms) ultimately develop into asystole if the electrical activity of the heart is not re-initiated.[152] Consequently, there are three distinct phases during CA: electric (0-4 min), circulatory (4-10 min) and metabolic (>10 min).[153] In the first of the phases, the use of AED to re-establish cardiac electrical activity is of great significance. As more time passes between the collapse and the first defibrillation, there is a greater risk that VF/VT develops into asystole, diminishing the likelihood of survival and worsening the outcome.[154]

The *autonomic conflict* explains the mechanism by which the number of drownings with CA of cardiac origin might be larger than expected. The effect of submersion in cold water can induce a high incidence of cardiac arrhythmias as a result of the stimulation of both regions of the nervous system (sympathetic and parasympathetic).[155] It is understood that vagal and sympathetic stimulations of the heart act in a reciprocal manner, being activated separated or sequentially. Nevertheless, throughout the drowning process, different factors can trigger the simultaneous stimulation of both the sympathetic and parasympathetic nervous systems, thus creating a cardiac conflict.

Only immersion in cold water triggers the so-called *Cold Shock*; a series of cardiorespiratory responses caused by the stimulation of cutaneous receptors and the sudden drop their temperature.[156] The minimal temperature change required to provoke *cold shock* has not been established,[157] but these responses can be triggered in immersions of ≈25ºC,[156] and are maximized in temperatures of <15ºC.[158] Typical signs of *cold shock* are hyperventilation, hypocapnia, tachycardia, peripheral vasoconstriction and hypertension,[156,159] and these respiratory (mainly) and cardiovascular responses are thought to represent the highest threat in the initial moments of immersion in cold water.[160] In the first 20-30 s post-immersion, a significant increase of respiratory frequency is produced along with a negative correlation with the tidal volume. To be able to have a better perspective of the intensity of *cold shock* at the respiratory level, participants of a study took part in an immersion at 10ºC having hyperventilated just before. The target was to verify if hyperventilation, mitigating the respiratory reflex, was capable of reducing the reactions to *cold shock*. Nevertheless, as in other immersions where prior hyperventilation did not take place, a significant increase of the respiratory frequency was observed, suggesting that the effects and chemical factors involved in hyperventilation are not sufficient to hold back the respiratory responses triggered by immersion in cold water.[159,160]

Research that studied the capacity to sustain respiration during immersions in cold water found that said capacity falls dramatically from an average of about 60 s in air to 5-20 s in water at 10ºC[158] depending on the clothing of the person.[161] This reduction in ability to maintain respiration is one of the biggest risks that increases the likelihood of aspirating water and drowning.[156] Due to the rapid appearance of these respiratory responses, hyperventilation following immersion in cold water cannot be considered a result of the stimulation of central chemoreceptors, but in fact of the superficial sub-epidermal receptors.[159] Furthermore, hyperventilation as a result of immersion in cold water reduces the cerebral blood flow[162] with the consequent hypoxia, respiratory alkalosis that can cause tetany and a reduction of the capacity to maintain respiration.[158] A dramatic drop in the cerebral irrigation is associated with such pre-syncope symptoms like morning sickness or lightheadedness.[163] Therefore, these symptoms have to be added to those related to *cold shock*, increasing the risk of suffering disorientation, blurred vision and even loss of consciousness, which all in turn increase the difficulty of maintaining oneself afloat.

Cardiovascular responses to immersion in cold water include tachycardia, an increase in both systolic volume and blood pressure, which increases the possibilities of cerebrovascular accident.[158] The dangers associated with these cardiac responses might be underestimated. The incidence of arrhythmias in young and healthy subjects during immersion in cold water is relatively low (1-2%), but it increases greatly during the submersion (80-82 %).[156,158] At this point, the aforementioned *autonomic conflict* comes into play.

The responses described are triggered by immersion, with airways above water line. Nevertheless, in cases of submersion, the responses caused by the *cold shock* (sympathetic region) are compounded by those caused by the diving reflex and breath holding (region parasympathetic). The diving reflex -which is an endogenous defense mechanism to preserve life in situations of hypoxia-[156] prompted by submersion and the cooling of the oronasal region, sets off the parasympathetic stimulation and induces bradycardia.[155] This nervous conflict will generate arrhythmias within 10 s of the cessation of breath holding, which might become fatal. After cessation of breath holding, arrhythmias have also been observed in subjects while they are immersed in cold water, which suggests that breath holding might be, in itself, a arrhythmogenic trigger.[155]

In order to extend analysis and understanding of the *autonomic conflict*, investigations have been carried out on isolated hearts *in vitro*. In one investigation, rat hearts were administered a dose of 75 nM adrenaline + 313 nM noradrenaline: Adr-NA, which is equivalent to indexes of situations of moderate stress (sympathetic stimulation). In turn, acetyl-choline was administered (ACh: 5 μM – to simulate parasympathetic stimulation such as maintaining respiration). The authors observed a wide range of arrhythmias such as: block atrioventricular block, tachycardia, bradycardia, bigeminy and *Torsade de Pointes*.[155] The latter arrhythmia is associated with Long QT Syndrome (LQTS),[164] an inherited primary arrhythmogenic syndrome which represents a risk factor for VF. The found arrhythmias were similar to those registered during immersion in cold water.

The *autonomic conflict* might be accentuated by different predisposing factors such as LQTS.[108,155,156,158] In another study also carried out with rat hearts, two protocols were compared after perfusing the hearts with clofilium tosylate in order to cause substantive QT prolongation without AV-block. In one of them, vagal nerve stimulation (VNS) was compared with a combination of VNS and sustained noradrenaline perfusion. With the clofilium perfusion, researchers observed a reduction of the HR and extension of the QT interval without the appearance of arrhythmias. Following the VNS, early afterdepolarisations (EAD) were noted, in up to 73% of the hearts and ventricular tachycardia took place in 55%. These arrhythmias were significantly reduced with the sustained noradrenaline perfusion. In the second protocol, instead of sustained noradrenaline, bolus noradrenaline was applied to the heart. This increased the number of cases with EAD and with ventricular tachycardia, even leading to VF in one case.[165]

The repercussions of the *autonomic conflict* might be underestimated due to the inability to measure cardiac rhythm *post mortem*. For example, in deaths during the triathlon competitions, in which the majority take place in the swimming phase, the *autonomic conflict* has been described as a potential cause. Sympathetic region is seen to be stimulated by factors such as immersion, stress of competition and exercise, and parasympathetic region as result of facial wetting, water entry in the nasopharynx and breath holding.[166] In a study that described the case of a 32 year-old helicopter rescue swimmer with no personal history of cardiac disease, *autonomic conflict* was associated to the atrium fibrillation with normal QRS complex and QTc of 399 ms observed after an underwater training exercise.[167]

Considering the points discussed so far, one might suppose that during some drownings the *autonomic conflict* might have produced arrhythmias, and that these were the primary cause of the death, and fatal-drowning a consequence these. Most of the published research has reported non-shockable rhythms in drowned victims, and hence it has been supposed that the origin of PCR was respiratory. Nevertheless, a deeper analysis of some of the variables described in such investigations, and after the *autonomic conflict* has been evidenced, gives rise to a suggestion that some of these drownings were preceded by arrhythmias associated with *autonomic conflict* that might have resulted to asystole or pulseless electrical activity, caused in each case, by the delay in treatment:

1. Submersion time: Those studies that have recorded or estimated the submersion time generally suggested ranges above 10 min.[143,144,146,168] The time taken during the victim´s rescue should be added to this time.

2. Presence of witnesses: Many studies have showed that less than 30% of drownings were witnessed.[143,145,148–151,169,170]

3. Bystander CPR: The indexes for bystander CPR are notably low, ≤40 % in many investigations.[145,146,148–151]

4. Times for EMS response: These ranged between 5-28 min[145,148,150,169,170] and rose as high as 85 min in some study.[149]

7.1.3. Treatment controversy(?): Compression:ventilation CPR vs. Compression-only CPR

Although the *autonomic conflict* has been established as a genuine trigger of arrhythmias,[155,165] the protocols for acting when dealing with drowned victims should bear in mind that, in the first moment, drowning is a principally a respiratory impairment. As a result, resuscitation methods for drowned victims should bear in mind both risks. From the perspective of the *autonomic conflict*, it is best to recommend the use of the AED in drowned victims, even more so when said AED is the ultimate source of the advice to deliver (or not) the shock.

Taking into account the definition of drowning, the BLS protocol when dealing with drowned victims establishes the delivery of 5 rescue breaths before beginning with compressions.[39] Also it recommends ventilating in the water during aquatic rescue in cases where the environmental conditions permit it, flotation material is available, and the rescuer is trained in said technique.[10,39,108,171]

Recently, a study has been published which concluded that CO-CPR might be as effective as CV-CPR for drowned victims.[147] Following its publication, another publication supported it, commenting on its results and encouraging researchers to be open to any ideas that might change clinical practice.[172] Accepting the clear premise that CO-CPR will always be more effective compared with not doing anything, and accepting that researchers must be willing to change treatments where scientific evidence demands, it is also necessary to analyze the reason why certain results might occur. In the study by Fukuda *et al*,[147] determining factors in drowning such submersion time or water temperature were not recorded. Also, the average age of the recorded cases was above 70, which contrasts enormously with other publications about fatal drownings,[173] many of which focus on children as the main population at risk,[174–176] in which average ages far below 70 years were reported,[177,178] or with a percentage of drowned victims >65 years below 40%.[179] With age, the cardiovascular risk increases and alongside this there is a predominance of coronary heart disease, which is one of the predisposing factors of the *autonomic conflict*.[155] Bearing this in mind, also that ≈90% of drownings were not witnessed, and that in 50% of cases EMS response times were superior to 9 minutes, it can be supposed that many cases might have occurred in which, although the origin of the PCR was cardiac (*autonomic conflict*), the cardiac rhythm was not shockable. This would also explain the low indexes of favorable neurologic outcome in both groups (CO-CPR & CV-CPR). In a recent publication, 5-15-yeard-old drowned victims assisted with bystander CV-CPR were associated with better neurological outcome and survival than those treated with CO-CPR.[180]

In another study published in the same year, non-traumatic OHCA was taken as sample. It appeared that if more than 50% of the breaks in CPR set aside to perform rescue breaths, and those were effective, helped to increase rate of return of spontaneous circulation and survival with more likelihood of favorable neurological outcome.[181] Therefore, perhaps it is to early to draw the conclusion that application of CO-CPR to drowned patients should be favored rather than focusing attention on the management of the airway and the reduction of no-flow time in the CPR.

7.1.4. Treatment: Non-invasive ventilation and end-expiratory positive pressure

Few studies have been published that clarify which methods of managing the airway would be ideal in the case of a drowned victim. Simulation studies have shown results favorable to mouth-to-mouth ventilation with regards to the reduction of no-flow time.[182]

Nevertheless, pocket-masks or bag-valve-masks add a barrier mechanism, in addition to providing the greater ability to combat hypoxia, by connecting to an external oxygen supply. Therefore, it seems reasonable to improve airway management by means of pocket-masks and/or bag-valve-masks. In the case of the latter, it is not recommended when only one rescuer manages the airway,[183] and its use having always to be evaluated in accordance with the skills and experience of the rescuer.[184]

As for the use of supraglottic devices, rescuers' effectiveness has also been demonstrated in their correct handling in simulated conditions.[185] Nevertheless, they might not be perfectly adapted for drowned victims due to the reduction of pulmonary compliance and the increase in airway resistance,[186] for which reasons many cases studies advise against their use for this patient profile.[187]

The application of non-invasive ventilation (NIV) in drowned patients as opposed to mechanical ventilation (MV) is also a topic that has alerted the interest of researchers in both hospital and pre-hospital settings. In patients with an acute respiratory failure secondary to drowning, differences have not been observed in survival rate when comparing two cohorts of patients treated with NIV and MV (patients in CPR are excluded from the study). Also, neurological recovery was more rapid in the NIV group, with higher Glasgow Coma Scale at ICU admission.[188] The application of NIV allows earlier oxygenation in addition to earlier complementary use of positive end-expiratory positive pressure (PEEP), which is especially useful to maintain the recruitment of alveolar units that were previously collapsed.[189,190] Consequently, within NIV the use of PEEP should be considered in the ventilation of patients who do not reach saturations of 93-95% with high FiO_2.[191] In hospital setting, it seems that individualized PEEP selection based on the best static compliance in patients with acute respiratory distress syndrome was associated with lower numbers of multiple organ failure,[189] although more studies are required in order to establish optimum levels for PEEP.

It seems then that NIV is a genuine option for the ventilation treatment of drowned patients, also avoiding possible complications associated with MV, such as iatrogenic injury via ventilator-induced lung injury as well as hyperoxia.[192]

7.2. TREATMENT: CARDIOPULMONARY RESUSCITATION FROM PHYSICAL EXERCISE

Thus far, the discussion has focused on those aspects of drowning where there are significant gaps or a certain controversy exists. At this point, CPR, one of the main treatments for drowned victims in PCR, will be tackled. This will be addressed from the perspective of physical exercise, as an activity that generates fatigue in the rescuer and that, consequently, leads to a reduction in the quality of resuscitation and therefore the outcome of the patient.

7.2.1. Cardiopulmonary resuscitation: fatigue, training and quality

Two articles justify the inclusion of this section in the present thesis. Neuromuscular fatigue as a result of performing CPR was studied, in addition the improvements in the CPR quality when delivered by rescuers who had previously undergone a strength-training program.

Fatigue generated by CPR in the rescuer has been studied extensively from different perspectives: comparing fatigue from both CV-CPR and CO-CPR protocols;[42,46–49] during different time intervals;[48,49,193] comparing manual and mechanical CPR;[66,194,195] comparing different types of guidelines;[50] using adult models[42,46–49,193–195] as well as pediatric.[196,197] Nevertheless, in most of the studies, fatigue has been described in CPR terms. In other words, fatigue has been defined as a reduction in the quality of CPR over time.

We have studied fatigue at the neuromuscular level by means of the use of TMG to describe the effects of said fatigue at an internal level (rescuer) and not externally (quality of CPR). Until now, there is just one study which has evaluated the acute muscular fatigue (AMF) of the rescuer using TMG.[198] We found that after each CPR period, CO-CPR showed a significantly lower value for Dm (greater stiffness) and Vc (slower muscle fiber conduction) in triceps brachii and hence, greater signs of AMF than CV-CPR. Previous studies already showed high levels of activation of the triceps bachii during CPR,[89,91–93] being the musculature with most significant activation in some cases[89,91,92] with ranges over 30% of MVC and significant drops in its activation.[89,91] In our study, differences in the variables measured by TMG over time were not observed in triceps brachii, a result that might be explained by the fact that in both protocols the participants were asked to perform cycles of 2-min of CPR with 2-min of rest between them. Likewise, other authors have studied internal variables of the rescuer as the force applied as a way to compare CV-CPR and CO-CPR protocols. Said variable drops in both protocols, but in CO-CPR the reduction occurs earlier and is more marked than in CV-CPR.[89,91]

Taking into account our results, it is plausible that 2-min cycles of CO-CPR might induce too much neuromuscular fatigue, compromising CPR quality. A previous study concluded that fatigue of the spinal and lumbar musculature measured by EMG occurred after 2-min. In this case, participants had to reach an 80% of chest compression quality without feedback, and those who failed to do so were excluded.[199] In our study, AMF had no influence on CPR quality, perhaps because participants were guided by visual feedback.

While none of the variables from the TMG experiment changed throughout the CPR cycles in the triceps brachii, there were significant Tc differences in rectus abdominis. In a further analysis, Tc in the fifth period was higher than in the other periods. The implication of rectus abdominis in CPR has already been reported and it has been categorized as a moderate-high intensity.[90] Based on the findings of our study, whatever CPR protocol is applied, a 2-min resting period appears to be insufficient to recover the minimum mechanical properties of rectus abdominis after 4 consecutive 2-min periods of simulated CPR. This is a significant result since in cases of OHCA, the rescuer might have to perform CPR for a considerable time. A study carried out in Melbourne (Australia) analyzed more than one million EMS responses, recording a median of 10.6 min (IQR: 8.1±14.0) between call receipt and the arrival of the EMS.[200] This delay might be longer depending on different factors related to the patient or the EMS, which would increase the time performing CPR and thereby decrease the mechanical properties of the muscles assessed in our study. As has already been mentioned in a previous paragraph, in studies that provide information regarding delay time for EMS responses in cases of drowning, they range between 5-28 min[145,148,150,169,170] reaching even 85 min on occasion.[149]

The use of feedback devices for teaching-learning[27,28,60,84,201,202] and for performing CPR in real situations[203–205] is strongly recommended. Our study showed the effectiveness of using feedback devices when participants were in adequate physical condition, with compression quality over 90% in all periods in both protocols. Moreover, those participants who had previous CPR feedback training reached better CPR quality in both compressions and ventilations. However, the use of feedback devices might not be sufficient to deliver high quality compressions in cases where rescuers lack physical strength. In fact, seven participants were excluded because they were not able to reach high CPR quality despite feedback in the pre-test.[198] For this reason, strength training programs have also been designed, which have been seen to produce positive results in terms of maintaining CPR quality over time (third PhD article).[206]

After the analysis of muscular activation in CPR by means of EMG, a 12-seasons (3 seasons x 4 weeks) program of physical exercise has been designed.[206] Our results showed that in the control group, and equally experimental group (before training period), the quality of the CPR dropped drastically after the first two minutes of CPR. Although studies have been published in which different groups were capable of maintaining high CPR quality for more than two minutes,[49,193,198] both ERC and AHA are more conservative in their recommendations and they establish two minutes as a cutting point at which the rescuer should be relieved.[27,28] Obviously, these recommendations are based also on evidence that showed negative results in the quality of the CPR after two minutes.[50]

After the training period, a clear improvement was observed in the quality of the CPR in the group undergoing training compared to the control group. Our results support other investigations in which muscular strength was linked with the quality of resuscitation.[70,71,77] In the study of Hansen *et al*,[77] associations were found between the maximal upper extremity muscle and the quality of compressions after five minutes of CPR, but not in the initial minutes. In our study, we observed that during the first minute of CPR the quality was similar between the control group and the experimental group, but differences were already recorded from the second minute (included), with higher CPR quality in the trained group.

Our work, focused on physical strength, is the first study that has evaluated the effect of a training program on the quality of CPR, specifically of the chest compressions. Other studies have showed the positive association between anthropometric variables (height, weight, BMI) and variables related to compressions.[68,70,92,198] In this sense, values of height, weight or BMI associated with a lower quality of compressions (i.e. BMI <25 kg · m^{-2})[68] might be compensated with increases of muscular strength.[207,208] In addition to strength, cardiorespiratory fitness also is a variable associated with better quality of CPR,[70,76,77] with physically active rescuers achieving better results than sedentary ones.[76,84] These results should be born in mind amongst those groups with a duty to assist, since regular exercise, in addition to improving their health levels, would also contribute to the delivery of better CPR. Bearing in mind that the quality of CPR is related to the survival and the outcome of a person in CA, the physical fitness of the rescuer might be an indirect factor.

Regarding ventilations, in the analysis of both AMF and the effects of strength training they have proved to be of low,[198,206] as suggested by previous studies.[193,194,209] Mainly for the delivery of high quality ventilations, the use of the so-called Rolling-refreshers might be especially important; regular short training sessions to avoid the deterioration of skills.[210] In fact, studies have already been published that conclude that Rolling-refreshers are more effective when repeated monthly rather than more often (3, 6, 12 months).[211] Bearing in mind that CPR is a physical activity, CPR maneuvers themselves might be included in strength training programs. In CRH units, studies have assessed the effectiveness of including CPR within training programs aiming to improve skills related to BLS. The studies published until now showed positive results, not only in the quality of CPR (CO-CPR) but also in other aspects of BLS like the BLS sequence and the use of AED, both short-term[212–214] and mid-term.[215] It would be necessary to evaluate if CPR itself also leads to improvements in indexes of strength. The combination of strength training and CPR might maximize the effects of a said training and of the Rolling-refreshers.

8. LIMITATIONS AND STRENGTHS

8.1. LIMITATIONS

The studies included in this doctoral thesis are not free of limitations. First of all, although the review of drowning research is aimed to tackle the most relevant aspects making use of keywords and MeSH terms, it is not a systematical review nor a quantitative analysis of the studies (meta-analysis). In addition, no section has been devoted to the quality of recommendations as are included in guidelines of different international organizations like the *European Resuscitation Council*, *American Heart Association* or *European Society of Cardiology*.

With regard to the other two studies, both have been carried out in simulated conditions in which the victim was a mannequin. Consequently, psychological factors such as the sensation of danger or the fear of hurting the victim -indicated in the scientific literature as factors that discourage witnesses from providing first aid- do not influence the actions of the participants, even though they might certainly affect any actions in real conditions.

Although TMG has been reported as a quick and non-invasive method to describe muscular properties, more research is needed to characterize and fully understand the amount of data that it is able to register. In addition, in this study, CPR quality might have been over-estimated compared with real situations since feedback is not always available to help the rescuer. In this regard, the use of feedback might have under-estimated the effect of AMF on CPR quality because the participants had the possibility of adjusting his/her performance in function of the mannequin feedback.

Finally, with regard to the study of the effect of strength training on CPR quality, although the results do have a real practical implication, the implementation of the described training program in the hospital services, for example, is more difficult and costly because of the need for specific equipment.

8.2. STRENGTHS

In spite of the existing limitations in the narrative review regarding drowning, it is one of few existing scientific publications (the only one in Spanish) that tackles the main aspects of this cause of death. In this way, a large part of the most significant information published regarding epidemiology, prevention, pathophysiology and the treatment of drowned victims has been integrated into a single work.

In the other two investigations, accurate and reliable materials for the study of the described variables were used. Regarding muscular fatigue, the TMG, which has already been used in recent years for different kinds of research into the muscle contractile properties. Also, those variables considered most reliable have been utilized. As for the measurement of CPR quality, very sensitive mannequins that report quality in real-time of different variables related to compressions and ventilations. Moving on the strength training, all the sessions have been supervised by a Sport Science professional, giving consistency to the results.

9. PRACTICAL IMPLICATIONS

The review carried out into drowning has revealed a series of questions that must be considered both by the scientific community and by institutional organisms:

- ✓ Regarding epidemiology and prevention, it is necessary that systems of records are improved and are unified between different private and public, local, national and international organisms. Only in this way will it be possible to assess the real burden of this cause of death and to have a complete understanding of its epidemiology in order to aid prevention. Also, more research describing the effects on drowning statistics of preventive strategies is required, whether these be short-, medium- or long-term schemes.
- ✓ More randomized and non-randomized controlled trials are needed to increase and improve current information about the pathophysiology and treatment of drowning patients. In-water and on-going boat CPR, the *autonomic conflict*, oxygenation, use of AED, bystander CPR, airway management, ventilation strategies, ECMO and discharge indicators are some of the topics on which the scientific literature could focus its efforts.

Based on the reviewed published literature, it is certainly possible to establish different recommendations, as well as design protocols for prevention, rescue and treatment whilst addressing the following points:

- ✓ An aquatic rescue should be carried out by a person trained in lifesaving. Untrained rescuers should try to offer the drowning victim some kind of flotation support, since it is possible that they would not have the physical fitness necessary for the execution of a full rescue, nor the precise aquatic skills or the aptitude to fully evaluate their capacities and the characteristics of the environment.

- ✓ In-water resuscitation should be carried out only by trained personnel, with flotation materials and in stable conditions.
- ✓ The recommended protocol for the resuscitation of the drowned patient is CV-CPR. Only bysanders without training in ventilations should consider CO-CPR, as opposed to the alternative of not doing anything.
- ✓ In the resuscitation of a drowned victim oxygen should be administered to high concentration.
- ✓ Controversy exists surrounding the use of supraglottic devices due to the characteristics of the airway of the drowned patient.
- ✓ NIV should be considered when dealing with MV in pre-hospital setting.
- ✓ AED should be used when available.

Studies carried out into fatigue and training showed that CPR generates muscular fatigue and that strength training can slow down the effects of fatigue on CPR quality. In training courses for SVB and AED a section should be included which reflects the results described in our studies. Also, different emergency services should evaluate the possibility of incorporating both strength training as well as CPR sessions into the working day, since the proposed training program can be undertaken at an intensity which would not compromise the work timetable.

Different investigations have found links between the quality of chest compressions and anthropometric variables like weight, height and BMI. Some significant rates of strength achieved by means of a strength training program might overcome rescuer difficulties in reaching minimal compression depth due to factors such as relatively low weight or height.

10. CONCLUSIONS

The conclusions have been determined based on the following hypotheses:

H.0- Sufficient scientific evidence exists to make firm recommendations for the prevention and treatment of drowning.

C.0- With regard to the review of the current literature, although it is the case that more research is necessary to allow more definitive recommendations, the existing evidence is sufficient for the creation of specific guidelines regarding drowning, which can be updated in the future following the completion of more randomized and non-randomized controlled trials.

At present, the following measures are considered effective; the installation of barriers to restrict access to water; school education of lifesaving and aquatic skills; lifesaving and resuscitation training for the general population; and establishing safety regulations for navigation. The key factor in drowning outcome is the submersion time, whilst it may also be influenced by the temperature of the water, the presence of witnesses and the EMS response times. As an event caused by a respiratory impairment, the supply of oxygen and CV-CPR are necessary protocols. The number of drownings with a primary cardiac origin as a result of the *autonomic conflict* might be underestimated, and consequently AED should be used whenever available. Acute pulmonary injury and hypoxia constitute the predominant framework and the objective of the therapeutic response.

H.1- Compression-only cardiopulmonary resuscitation leads to more acute muscle fatigue than compression-ventilation.

C.1- In the analysis of acute muscle fatigue by means of tensiomyography, lower values were found for radial displacement and contraction velocity in the triceps brachii during compression-only resuscitation. This suggests higher rates of muscular stiffness and slower muscle fiber conduction respectively, which implies higher muscle fatigue rates.

Furthermore, increased contraction time has been found in the rectus abdominis during the fifth resuscitation cycle, which suggests reduced efficiency of the excitation-contraction coupling. In other words, a fifth cycle of 2-min resuscitation might present too much fatigue to maintain quality resuscitation.

In view of the obtained results, compression-only resuscitation causes more muscle fatigue in the rescuer than compression-ventilation resuscitation.

H.2- A strength training program helps rescuers to maintain optimum cardiopulmonary resuscitation quality over longer time.

C.2- The group of participants that underwent the strength-training program for 4 weeks was capable of maintaining a quality close to 70% throughout 10 minutes of CPR. This represented an increase of more 20% in the quality of the compressions in the test carried out after 4 weeks of training compared with the previous test. Therefore, a strength-training program helped to improve resuscitation quality and to maintain it over time.

In view of the obtained results, higher resuscitation quality is reached after following a strength-training program.

11. FUTURE RELATED OR DERIVED RESEARCH

The Utstein-Style was created to facilitate and to structure research in terms of the consideration of OHCA. Likewise, when dealing with the morbid-mortality associated with drowning, the Utstein-Style Recommended Guidelines for Uniform Reporting of Data From Drowning-Related Resuscitation have also been created. Therefore, in the same way that different international recommendations exist for the consideration of CA, and bearing in mind the scientific evidence published in different fields that include drowning (epidemiology, prevention, pathophysiology and treatment), specific international guidelines should also be created with recommendations on this issue.

In addition to a recommendations document in the sphere of drowning, more randomized and non-randomized trials are necessary, which could serve as justification for future updates of these recommendations. Some of the topics that should be studied in more depth are the in-water and on-going boat CPR, *autonomic conflict*, oxygenation, use of AED, bystander CPR, airway management, ventilation strategies, ECMO and discharge indicators.

Regarding fatigue and training, a line of investigation has been opened concerning strength training and CPR. In our study, the participants carried out training with sports facilities equipment, which implies a limitation for the implementation of the training program within health services or among employees with a duty to assist. A strength training program with alternative equipment or based on calisthenics could be designed and evaluated, as this would be simpler to roll out.

Bearing in mind that Rolling-refreshers have been confirmed as an effective way to prevent CPR quality decline due to lapses in training, and that correct CPR is a physical activity of moderate intensity, training programs that integrate CPR itself with strength exercise should be considered. In this way, the principal of transference would be maximized, meaning, in this case, the influence of strength training on CPR. In addition, it would help correct the tendency to carry out ventilations with insufflated air volume above recommended levels.

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APPENDIX

Drowning epidemiology, prevention, pathophysiology, resuscitation, and hospital treatment. (Translated to English).

Drowning: epidemiology, prevention, pathophysiology, resuscitation of the drowned victim and hospital treatment

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This narrative review discusses the evidence relevant to key aspects of drowning, which is defined by the World Health Organization as the process of respiratory difficulty caused by submersion/immersion in liquid. The length of time the victim is submerged is a key factor in survival and neurologic damage. Although respiratory distress and hypoxia are the main events, other complications affecting various systems and organs may develop. Drowning is one of the main causes of accidental death worldwide, yet deaths from drowning are underestimated and morbidity is unknown. Prevention is essential for reducing both mortality and morbidity, but if prevention fails, the speed of access to and the quality of prehospital and hospital care will determine the prognosis. It is therefore essential to understand the factors and mechanisms involved in these emergencies.

Keywords: Risk factors. Mortality. Respiratory distress syndrome, adult. Cardiac arrest. Case management. Cardiopulmonary resuscitation. Prognosis. Survival.

"Every hour, every day, more than 40 people lose their lives by drowning". This is the beginning of the World Drowning Report in 2014 from the World Health Organization (WHO), which indicates that drowning is among the top ten causes of death in children and young people in almost every region of the world[1].

Drowning is a leading cause of death that was associated with lower rates of funding and publications than the estimation based on mortality[2], resulting in a marked discrepancy between the relevance of the problem and the limited amount of information available yet. Fortunately, the number of publications and initiatives aimed at increasing the knowledge about this important cause of death and how to prevent it is recently increasing, and now the so-called Drowning Survival Chain has even been created[3]. This literature review aims to bring together in one document the main factors that should be considered in the study of drowning according to the current evidence: epidemiology, prevention, pathophysiology and treatment of drowned victim.

Epidemiology

Drowning is one of the leading causes of unintentional death in the world. Every year around 372,000 deaths are recorded, of which 90% occur in developing countries according to WHO statistics based on the codes of the International Classification of Diseases (ICD)[1].

The change from the ninth to the tenth version of the ICD, and its subsequent revisions and the inclusion of a fourth character in the registration codes on the location of the event meant a substantial increase in the accuracy of the registration of deaths by drowning.

Even so, in a study that analyzed 52 countries, only 23 were using ICD-10 with the fourth character[4]. In another one in which 69 countries were analyzed, many of the drowning deaths were registered with codes that referred to unspecified situations or places, doubting the quality of the information reported in 1 of 7 countries[5]. WHO itself recognizes that drowning mortality is underestimated and can be 50% more than that recorded in developed countries and multiplied by five in developing countries[1].

In Spain, the National Statistics Institute (INE) has reported a total of 5,848 deaths due to "accidental drowning, submersion and suffocation" between 2016 and 2017, of which 1,175 were specifically related to submersion (Table 1). However, the number of deaths and the ICD classification system may be insufficient to know exactly the epidemiology due to insufficient information in medical reports, insufficient training of the forensic service or from lack of resources[5]. In addition, Spain is one of the countries with the worst quality of registration with respect to the fourth character of the ICD-10[4] for reasons such as the complexity of the procedures by which the information circulates, starting from the event to its final registration, from the time between autopsy and the final results[6]. According to the INE data, more than 25% of recorded deaths occurred "in an unspecified place", which is added to the events categorized as "other drowning and unspecified submersions", resulting in a lack of relevant information in almost half of the cases. Other epidemiological reports on drowning in Spain have considered only the news from the press[7] or have not taken into account all drowning events[8]. However, some research has tried to deepen the description of the profile of the drowned victim just like the multicenter study of 21 hospital emergency services in Spain has done ,who identified children under 6 years as risk subgroup within the minors[9]. However, this type of study is not usual.

Table 1. Number of deaths in Spain in 2016 and 2017 related to drowning and submersion

	2016			2017		
	F	M	Total	F	M	Total
V90-V94 Water transport accidents	0	10	10	3	21	24
V90 Accident to watercraft causing drowning and submersion	0	7	7	3	16	19
V92 Water-transport-related drowning and submersion without accident to watercraft	0	3	3	0	5	5
W65-74 Accidental drowning and submersion	95	344	439	88	387	475
W65 While in bath-tub	2	1	3	0	1	1
W67 While in swimming-pool	11	8	19	10	21	31
W68 Fall into swimming-pool	0	4	4	5	10	15
W69 While in natural water	32	110	142	33	134	167
W70 Fall into natural water	0	31	31	4	45	49
W73 Other specified drowning and submersion	0	12	12	4	23	27
W74 Unspecified drowning and submersion	50	178	228	32	153	185
X71- Intentional self-harm by drowning and submersion	43	73	116	44	62	106
X92- Assault by drowning and submersion	0	0	0	0	1	1
Y21- Drowning and submersion, undetermined intent	1	1	2	1	1	2
Total	139	428	567	136	472	608

M: Males; F: Females.

Based on international literature, three variables seem to influence the number of deaths from drowning: age, sex and location of the event. In this sense, men are twice as likely to drown as women, more than half of the victims are under 25 years of age and mortality in low-income countries is 3 times higher than that of high-income countries[1]. However, since the drowning is such a complex event, its epidemiology is different in each country. So, the suicide was the cause of 36% of drowning between 1988 and 2012 in Ireland[10]; between 2008 and 2012 in Canada, no flotation material was carried in 65.6% of the drownings related to navigation accidents[11]; alcohol consumption was present in more than 70% of unintentional drowning between 1970 and 2000 in Finland[12]; and people over 65 accounted for 17.3%

of drowning in Australia between 2002 and 2012[13]. Epilepsy has even been shown to multiply the risk of drowning up to ten times[14]. This heterogeneity in epidemiological factors highlights the need for adequate registration systems that would allow a greater accuracy. However, a study that recorded drowning in swimming pools in France showed that up to nine different services were responsible for recording the information, which makes it difficult to evaluate the number and the causes of drowning[15].

The unification of the registration and the collaboration tools of different local, national and international levels would greatly contribute to greater precision on the epidemiological knowledge of drowning. In an attempt to improve the quality of the registry, the recommendations for recording the resuscitation data caused by drowning (Utstein style) contemplate in their latest update the inclusion of cases of patients treated only by first interveners and those in which it has not been necessary a hospital admission[16].

Figure 1. Preventive measures proposed by the World Health Organization[i]

Drowning Prevention

Most drowning deaths could be avoided with preventive measures[1], which are considered a key factor in fighting this problem (Figure 1). The lack of education on prevention and the aquatic safety is one of the greatest risks, so training in basic swimming techniques, the safety in the aquatic environment and rescue at school age have been identified as the priority measures[17]. But the unique teaching of swimming techniques could also increase the risk of

[i] Reprinted from World Health Organization, *Global report on drowning*, 3-6, Copyright (2014)[1].

drowning due to increased exposure to water and an excess of confidence that would lead to swimming in dangerous places[18]. The inclusion of these contents in the school curriculum would facilitate reaching a large part of the population, but also requires an increase in the budget allocated to education and to the modification of these established structures. Some examples are in Switzerland, where after ten years of negotiations with the Ministry of Education its implementation was achieved in most of the German-speaking cantons[19], or Bangladesh, where about 100,000 children aged 1 to 12 years were trained with a positive economic balance comparing the cost of the training program and the cost derived from mortality and morbidity[20]. This was possible thanks to the PRECISE (Prevention of Child Injury through Social-Intervention and Education) program, whose most important actions were the increase in supervision of children aged 1-5, the swimming instruction and the basic rescue techniques in the population of 4-12 years and the implementation of community education programs[20].

At the same time, training the public in techniques of mastering the aquatic environment and the first aid could help reduce deaths from drowning of both the victims and the potential rescuers[17,21-23]. Are not uncommon cases of people who died trying to rescue a victim, where an excess of confidence, lack of information to assess all the factors of the scene and the lack of knowledge in rescuing techniques are a dangerous combination. Between 2002 and 2007, 27 people died in Australia trying to rescue victims who were drowning[21]; in 2009 in Turkey 31 people[22], and in 2013 in China more than 50[23]. These data contrast with those of a Dutch study that documents that between 1999 and 2004, 503 people without any obligation to assist a drowning person successfully rescued 343 victims[24]. As the authors point out, the fact that in the Netherlands more than 90% of children learn to swim early could be a key factor explaining this success.

In addition to the education of the public, the adequate training of the group responsible for ensuring the safety in water environments, like the lifeguards, accompanied also by research that pursues the best evidence-based training, is truly essential. In Spain, lifeguard training has begun to be regulated recently, although not everywhere. This means that, while in some communities such as Galicia and Catalunya, the contents and duration of the training are established and controlled, in other regions these aspects depend exclusively on the criteria of the training entity.

Another measure considered of great importance, especially at an early age, is the installation of barriers that limit access to aquatic areas. It is estimated that 75% of the deaths of young children in swimming pools could be avoided with a fence surrounding the pool[17]. This measure should be complemented by the supervision of children by their parents[25]. In a study conducted in Spain, one in 5 drowned children were unguarded and in 2 out of 3 cases was admitted negligence in supervision[9].

The consumption of alcohol or other drugs is another major risk factor1, since it increases the number of reckless behaviors and reduces the ability to swim and stay afloat due to its effects on psychomotor and cognitive functions. Moreover, this consumption could trigger potentially fatal mechanisms in this situation, such as arrhythmias26. Alcohol and the absence of floatation materials are factors particularly associated with drowning deaths in boat accidents27. Therefore, the policies and the legislation are necessary to establish and apply these regulations in order to ensure security in this context17.

Progress in the prevention of drowning requires some political will and also technical assistance. In this way, a national water safety plan, together with the integration of these contents in the school curriculum, would be a great contribution in the fight against drowning. In Spain, prevention campaigns are born from initiatives of entities that are closely related to the water environment or the lifeguards, and they should have more government support and also provide them with greater funding and increase these numbers.

Pathophysiology of drowning

At the World Drowning Congress (Amsterdam, Netherlands, 2002), drowning was defined as “the process of experiencing respiratory impairment from submersion/immersion in liquid”[28]. If the person is rescued, the drowning process is interrupted and the person survives, and it is called non-fatal drowning; if he dies at any time during the process, then we would define it as a fatal- drowning[29].

The pathophysiology of drowning is related to two concepts: immersion (upper airways above the surface of the water) and submersion (upper airways below the surface of the water). Both events also differ in physiological responses that they trigger[30]. Immersion triggers a series of cardiorespiratory responses linked to changes in central and peripheral temperatures, which depend on the temperature of the water. Submersion is related to another series of cardiorespiratory and nervous system responses, in addition to those derived from hypoxia due to eventual water aspiration, which largely marks the pathophysiology. In its simplest version, drowning is a respiratory impairment derived from immersion/submersion in a liquid that causes the rhythm of a healthy heart to gradually slow-down until it stops due to tissue hypoxia. However, the complexity of the pathophysiology of drowning, how the organism responds during immersion and submersion and the most appropriate resuscitation mechanisms make up a field that still requires further study.

When a person is not able to keep the airways out of the water, the water that enters the oral cavity can be expelled or ingested[29]. Although the next conscious response is to hold the breath, over time, the respiratory muscles are stimulated by hypercapnia (increase in the concentration of CO_2) and hypoxemia (decrease of O_2) until involuntary breathing occurs[30]. After this breathing, the water enters into the lungs by the airway, and then two involuntary defense mechanisms are triggered: cough and laryngospasm. The latter has been described as a reason for the finding of drowned victims with macroscopically dry lungs, although it was widely criticized when its failure was confirmed as the hypoxia increases. Further research found how the macroscopically dry lungs were not at the microscopic level. In fact, in a 2004 study, more than 98% of the drowning analyzed showed signs of water aspiration, thus advocating the removal of the term dry-drowning[31].

During the laryngospasm, large amounts of water have entered the digestive tract[31]. Although the known data on the incidence and the clinical relevance of water swallowing are limited, it has been reported that ingested water favors vomiting[30], with the consequent risk of bronchoaspiration.

At the end of the laryngospasm, water is introduced into the respiratory tract. Basically, the water that enters the lungs triggers an inflammatory response that leads to alveolar effusion and reduction of distensibility, generating atelectasis. In addition, in a subacute way, the aspirated water damages locally the alveolo-capillary membrane, particularly the type II alveolar cells, with the consequent arrest in the production of surfactant and contributing in this way to atelectasis. The reduction of the gas exchange zone makes it difficult for oxygen to reach the capillaries during ventilation, by keeping in this way the tissue hypoxia. As a consequence, there is a marked increase in ventilation-perfusion mismatch and the right-to-left cardiac shunt is favored. If the person is not rescued, water aspiration continues and hypoxia will lead to loss of consciousness.

Regarding the differences between fresh and salt water aspiration, there are studies that support that the damage caused by the salt water aspiration is significantly greater than by fresh water[32]. Salt water, due to its greater osmolarity compared to plasma, attracts liquid from the pulmonary circulation to the alveolus, inducing pulmonary edema, hypovolemia and hemoconcentration[30,33]. On the other hand, fresh water, being hypotonic, quickly passes from the alveoli to the circulation, diluting the pulmonary surfactant and contributing to hypervolemia, hemolysis and electrolyte alterations[34]. In both cases, in addition to increasing ventilation-perfusion discordance, homeostasis of the internal environment is altered due to plasma variations of the electrolytes, and the severity of complications will depend on the volume of water aspirated. The mechanism of lung damage produced is a complex process that requires further experimental and *post-mortem* research[33].

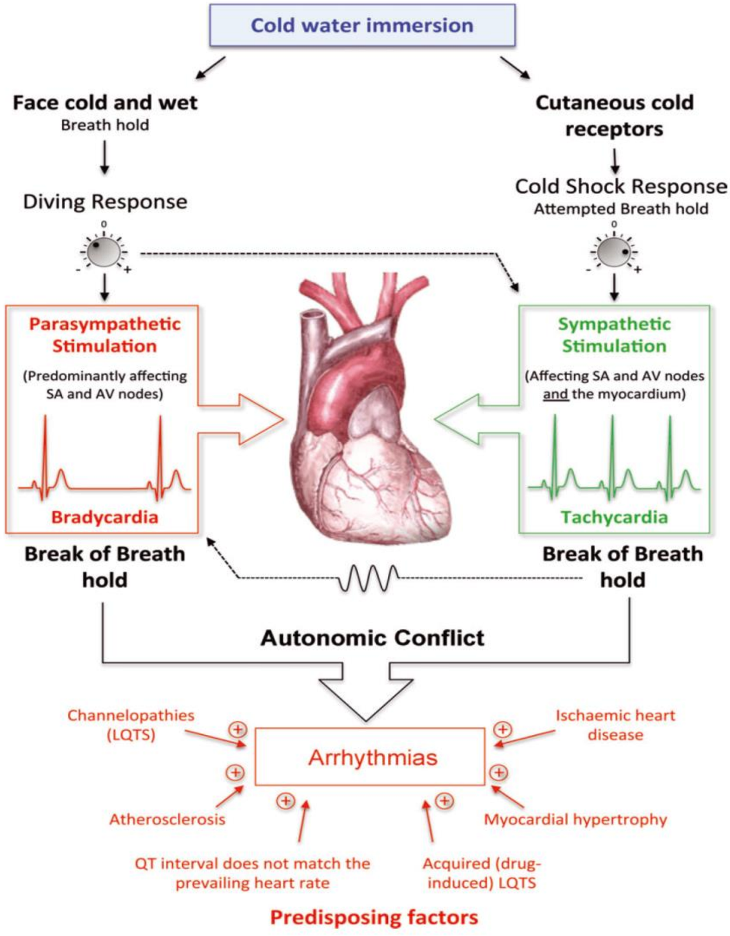

Figure 2. Autonomic conflict proposed by Shattock MJ and Tipton MJ[ii]

[ii] Reprinted from *The Journal of Physiology*, 590(14), Michael J. Shattock et al, *'Autonomic conflict': a different way to die during cold water immersion?* 3219-30, Copyright (2012), with permission from John Wiley and Sons. License number: 4744231407218[36]

As for the cardiac electrical activity throughout the drowning process, the appearance of ventricular tachycardia is being described, followed by extreme bradycardia, the electrical activity without pulse and, finally the asystole[35]. However, in practice, the process may vary depending on the circumstances of the incident and the characteristics of the victim, when the exact pathophysiological mechanisms are still largely unknown. A study published in 2012 addresses the so-called "*autonomic conflict*" as an explanation for possible arrhythmias during immersion/submersion in cold water[36]. This conflict derives from the simultaneous stimulation of the parasympathetic and sympathetic divisions of the autonomic nervous system (Figure 2). The contact with cold water stimulates the sympathetic system and induces tachycardia, hyperventilation, peripheral vasoconstriction and increases the blood pressure. Moreover, the diving reflex -endogenous defense mechanism in order to preserve life in hypoxia situations[30]- caused by immersion/submersion and the cooling of the oronasal region, triggers the parasympathetic stimulation and induces bradycardia[36]. This nervous conflict will generate arrhythmias within 10 seconds after reflex breathing, which could be fatal. After cessation of maintaining the breathing, arrhythmias have also been observed in subjects while diving in cold water, suggesting that reflex breathing could itself be an arrhythmogenic trigger. The impact of the "autonomic conflict" may be underestimated due to the inability to analyze the heart rhythm and to detect possible *post mortem* fatal arrhythmias in a drowned victim[36]. The factors that cause, mitigate and enhance the "autonomic conflict", and those that in particular favor the occurrence of fatal arrhythmias are aspects that need further study[37]. Figure 2 reflects some predisposing factors, highlighting cardiac diseases with an important arrhythmic base which is sensitive to physical activity in water, such as the established channelopathies (SQTL1)[38] or ischemic heart disease.

Regarding the neurophysiology of drowning, much of the information assumed comes from experimental models of cardiac arrest (CA) despite the fact that the mechanism of hypoxia in CA is different. While in CA by ventricular fibrillation the cerebral circulation is interrupted immediately, cerebral hypoxia is progressive in drowning[39]. The duration of hypoxia and water temperature are external determinant factors as far as brain damage and survival: a longer duration of cerebral hypoxia aggravates neurological damage, while cold water acts as a protective factor, since it cools down the brain, reducing in this way its metabolism and oxygen demand[37]. Considering the victim's body temperature as a reference to their core temperature and trying to establish a relationship with the prognosis has its limitations. The entry of cold water through the airway cools the heart, the circulating blood and the carotid, producing a selective cerebral cooling[37,40] due to the increase in cardiac output directed to the brain because of the peripheral vasoconstriction and cerebral vasodilation derived from hypercapnia[40]. This mechanism will persist until the respiratory and cardiac movements cease (approximately 70 second post-submersion)[37,40]. Cerebral metabolism is reduced by approximately 5-6% for every centigrade of lost temperature[29,41], having been reduced by 50% at 22ºC and 75% at 18ºC[41].

Resuscitation of the drowned victim

The European Resuscitation Council establishes an algorithm according to the particularities of drowning (Figure 3)[41]. The drowned victim dies primarily from oxygen deficit, so the priority in drowning is oxygenation and ventilation. For this reason, cardiopulmonary resuscitation (CPR) should begin with ventilation, ensuring adequate oxygenation, and not compression[41], with good airway management being a key aspect.

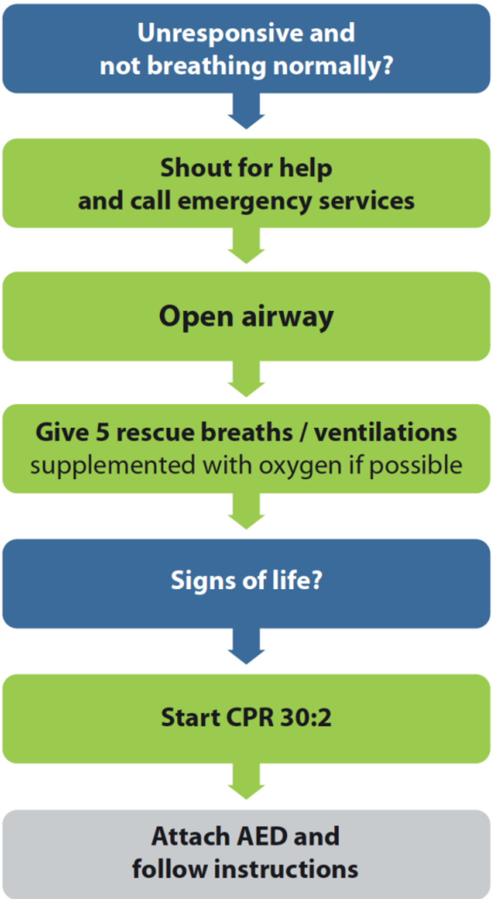

Figure 3. Resuscitation algorithm for the drowned victim proposed by the European Resuscitation Council[41] [Reprinted from Elsevier see Footnote 7]

Two situations can be distinguished: resuscitation in the aquatic environment and the resuscitation in mainland. Given that it is possible for the drowned victim to respond only with ventilation, it is recommended that to a drowned victim in the aquatic environment, the ventilation should begin before extraction to the mainland if it is attempted in sufficient safety conditions and by a highly trained rescuer[29,41,42]. It has already been documented the real possibility of ventilating effectively in the aquatic environment, which, on the other hand, increases the rescue time[43]. Therefore, it is recommended to extract the victim as quickly as possible in case of showing no signs of life after ventilation in the water[29]. The use of semi-rigid inflatable boats would contribute to reduce the intervention times, as well as providing the possibility of ventilations and compression on board[44].

Once on the ground, there are different techniques to open the airway, oxygenate and ventilate a drowned victim in a CA situation. In manikin simulation studies, mouth-to-mouth respiration has been shown to be more effective and faster than other methods of non-invasive ventilation[45]. However, pocket-mask and bag-valve-mask are barrier mechanisms and, in addition, might combat the hypoxia to a greater extent by connecting to an external oxygen provider. Therefore, the use of the bag-valve-mask seems reasonable when two lifeguards can be in charge of the airway, but its use is considered inappropriate by a single rescuer[45,46]. As for supraglottic devices, they may not be entirely appropriate for drowned victims due to decreased pulmonary distensibility and increased airway resistance, which is why some case studies advise against their use in this kind of patient[47]. Basically, there is no consensus on the most appropriate ventilatory method for a drowned victim, although there is evidence of the safety and effectiveness of ventilation without intubation in the prehospital setting[48]. As for oxygen administration, is recommended 100% and as soon as possible[42].

Although oxygenation and ventilation are the priority in drowning, the overall quality of CPR should be high. Studies carried out with lifeguards have shown that the quality of compressions drops significantly after performing a water rescue, falling below 70% after the first minute of CPR[49]. It is recommended that another rescuer other than the one who executes the rescue should initiate CPR to guarantee its quality, and that is relieved after the first minute. Under simulated conditions and after an aquatic rescue, the use of automatic compression mechanisms has proven useful for increasing the quality of compressions, especially when the lifeguard is found with extremely fatigued[50], although its impact on survival has not been confirmed.

Regarding the defibrillator, numerous studies reported a majority of non-shockable heart rhythms in samples of drowned people[35,51-55], while ventricular fibrillation and pulseless ventricular tachycardia accounted for less than 10%. Therefore, it is recommended to prioritize the start of CPR in the case of a single rescuer[41]. If there are several of them, one should start CPR while another should dry the victim's chest and use the defibrillator.

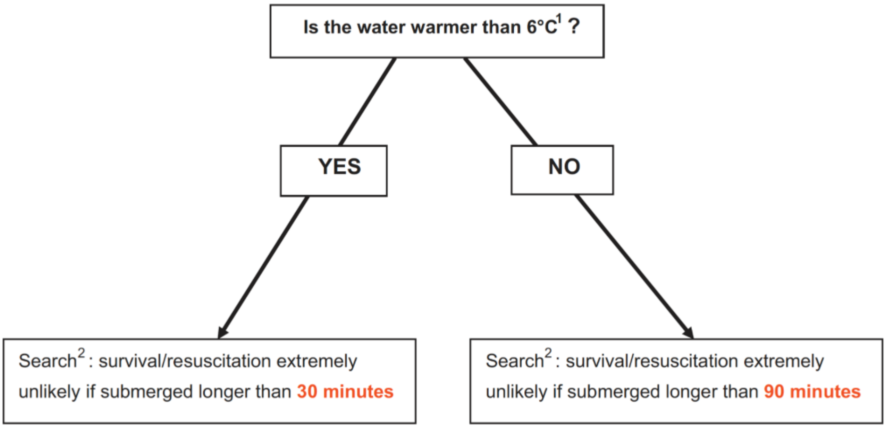

Figure 4. Scheme for decision-making based on the water temperature proposed by Tipton MJ and Golden FS[iii]

[1]Water temperature outdoors in and around the UK averages about 10 ◦C over the year but varies between about 0 and 25 ◦C, depending on location and the type of the water. UK coastal water can, on occasion, fall below 6 ◦C and mountain streams and pools can be below 6 ◦C for the majority of the year. [2]Search. Factors to consider when making a risk assessment: the perennial problem facing members of the Emergency Services when confronted with the rescue of a submerged victim is whether the risk to the rescuer outweighs the probability of a successful outcome

Due to the effect of submersion is very likely the presence of hypothermia. In a study in which 43 cases of drowning were analyzed, it was concluded that prolonged submersions in water >6℃ have a negative effect on survival and on neurological damage. Considering this temperature as a prognosis threshold, the authors established a decision scheme when rescuing a submerged victim based on the time of submersion (Figure 4)[56]. However, establishing a decision scheme solely based on water temperature and submersion time has its limitations, since environmental factors, related

[iii] Reprinted from *Resuscitation*, 82(7), Michael J. Tipton et al, *A proposed decision-making guide for the search, rescue and resuscitation of submersion (head under) victims based on expert opinion*, 819-24, Copyright (2011), with permission from Elsevier. License number: 4751010844600[56]

to the victim or to the treatment itself, can influence the outcome[57]. In another study with pediatric victims, the outcome of drowning in winter (0-8℃ water temperature) was better, but the duration of the longest CPR that achieved a good recovery of neurological activity was only 25 minutes. So, a decision scheme was proposed for children in PCR derived from drowning and related to the recovery or not of pulse after 30 minutes of advanced life support (Figure 5)[51].

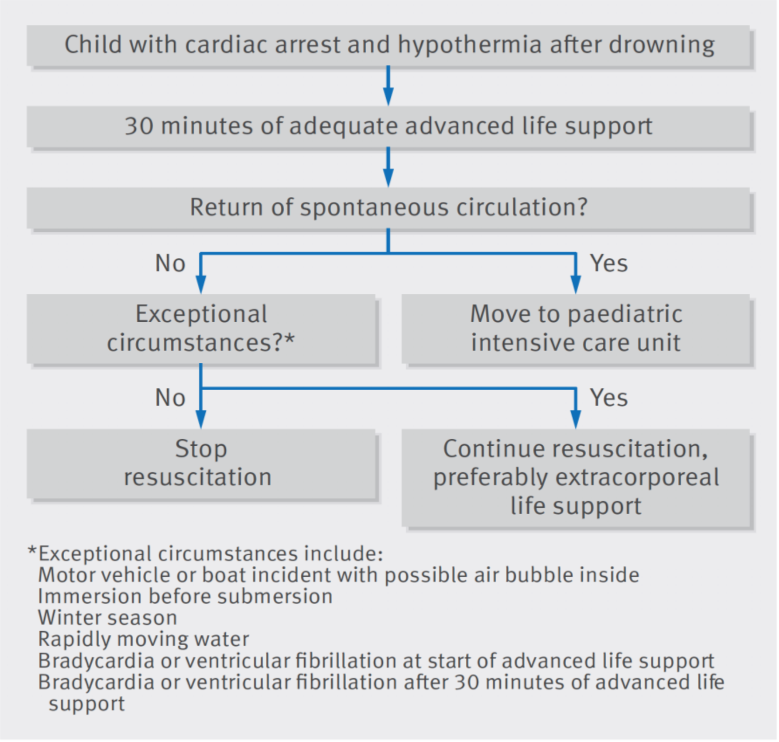

Figure 5. Proposed decision tree for pediatric CPR after 30 min of advanced life support[iv]

The knowledge of the patient's temperature in the prehospital setting requires the use of thermometers capable of recording low temperatures. Tympanic reading should be avoided due to the presence of water in the

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[iv] Reprinted from *The BMJ*, 350, J. K. Kieboom et al, *Outcome after resuscitation beyond 30 minutes in drowned children with cardiac arrest and hypothermia: Dutch nationwide retrospective cohort study*, 3219-30, Copyright (2015) with permission from BMJ Publishing Group Ltd. License number: 4744250556303[51]

acoustic cavities[41]. The hypothermic patient in PCR should receive CPR continuously. The use of automatic compression mechanisms is recommended in case of severe hypothermia (<28°C) due to thoracic stiffness. CPR should not stop unless there is clear evidence that its application would be useless (putrefaction, massive traumatic injuries, etc.)[41]. Although different publications consider the possibility of stopping CPR in hypothermic patients with prolonged asphyxiation, the difficulty in determining the submersion time, the origin of the CA and time asphyxiation complicates establishing a protocol decision to stop CPR. Therefore, it is recommended to follow the premise that "No one is dead until warm and dead".

Outcome

Since drowning is a multifactorial event and subject to multiple elements, it is difficult to establish definitively those independent variables that are key in the forecast. As previously noted, different studies have considered water temperature[51,56] and submersion time[9,51,52,56] as key exogenous factors in survival and neurological damage. However, in the case of water temperature, a recent study has found no association between this variable and the prognosis[58].

In addition to water temperature and immersion time, there are other aspects that could play a determining role. A better outcome has been recorded for young victims than for adults[53,54]. Another study conducted in 2013 obtained similar results, but the incidents in people under 18 were more frequently witnessed and assisted by volunteers before the arrival of the emergency services than in the group of adults. In addition, the number of CPRs combined with compressions and ventilations was also higher in the case of minors[55]. These variations on initial care may have accentuated the differences in prognosis attributed to age[39,53,55]. In contrast, a recent meta-analysis found no difference in the outcome of drowned victims with respect to age, water temperature, and the presence of bystanders during drowning, associating in this way a better outcome only for the short period of immersion, the short latency until medical attention, and drowning in salt water[59]. It has also been studied the possible impact of the initial heart rhythm on survival. Studies have shown contradictory results in this regard: in favor of the association between survival and initial defibrillation rhythm in some cases[53,55], and neutral results in others[54].

Therefore, although there are many variables that can influence the prognosis of the drowned victim, the time of immersion has a greater consensus.

Hospital treatment

Medical complications from drowning will usually require monitoring and treatment in an intensive care unit (ICU). Acute lung injury is the predominant picture and may require different therapeutic measures to ensure adequate oxygenation. In addition, hypoxia can result in vary degrees of neurological impairment and cause cardiocirculatory, hematological, renal and electrolyte problems, which are usually short-term (Table 2).

Table 2. Main complications from drowning

Pulmonary complications
Acute lung injury/Acute respiratory distress syndrome
Lung infection
Neurological complications
Various levels and duration of neurological impairment
Local level damage
Cardiocirculatory problems
Disseminated intravascular coagulation
Acute renal failure
Electrolyte disorders
Hypothermia

Acute lung injury and the acute respiratory distress syndrome

By definition, drowning is a respiratory impairment from water aspiration[28], which can also lead to complications (Table 3). Respiratory involvement typically manifests itself as dyspnea, tachypnea, coughing, cyanosis and crackle sounds during auscultation, as well as foam at the mouth in the most severe cases of pulmonary edema. Initially, the arterial blood gas shows hypoxemia and metabolic acidosis (lactic acid) and may progress to mixed acidosis. Thorax X-ray on admission may vary from normal to localized consolidation, peripheral or diffuse pulmonary edema[60].

Table 3. Main causes of respiratory complications resulting from drowning

Aspiration of water
Aspiration of bacteria, virus or fungi
Aspiration of chemicals
Obstructive material in the airways
Swimming related pulmonary oedema
Post-laryngospasm pulmonary oedema

The clinical picture bears great similarities to acute lung injury (ALI) or acute respiratory distress syndrome (ARDS), with the main difference that drowning initially affects only the lungs. The ALI/ARDS produced after a drowning event may occur immediately after rescue or within 6-24 hours. When APL/SDRA develops, the adequate oxygenation of the patient should be ensured, with target oxygen saturation above 94% maintaining normocapnia, especially if brain injury is suspected. If there is an adequate level of consciousness, the high-flow oxygen therapy can be used with a mask, or non-invasive mechanical ventilation with continuous positive pressure or bilevel if this is not sufficient. The indications for endotracheal intubation and connection to invasive mechanical ventilation are shown in Table 4. Although there are no specific clinical trials in this subtype of patients, these individuals should be treated as in other cases of ARDS, with positive end-expiratory pressure and protective pulmonary ventilation (tidal volume of 6 ml/kg of ideal body weight and pressure < $30cmH_2O$)[61].

Table 4. Indications for endotracheal intubation

Signs of neurological impairment or inability to protect the airway.
Inability to maintain a PaO_2 > 60mmHg or SpO_2 > 90% despite supplemental high-flow oxygen administration.
$PaCO_2$ > 50 mmHg

$PaCO_2$: carbon dioxide pressure; PaO_2: oxygen pressure; SpO_2: oxygen saturation

The use of oxygenation for extracorporeal membrane oxygenation (ECMO) is presented as a good therapeutic option[39], especially in victims who have not suffered CA. An international multicenter retrospective study documented a survival of 71% in drowned victims without CA, 57% in CA cases with restore of spontaneous circulation and 23% in the case of application of ECMO during resuscitation[62]. The fact that the cohort of patients in whom ECMO was applied during CPR had significantly more hypothermic patients is a limitation to be taken into account when interpreting the results, since it could have implied a longer immersion time and duration of asphyxia and therefore a worse outcome. However, in the absence of detailed pre-hospital data, such an association cannot be concluded. Similarly, the low prevalence of hypothermic patients in the other two cohorts suggests relatively short immersion periods, which may have favored the results. Although positive results have been shown, the use of ECMO in the drowning patient still needs to be further studied.

In addition to all that described, the initial respiratory deterioration may be aggravated by primary infections caused by a wide variety of microorganisms (Table 5) or associated with ventilation.

Table 5. Variety of bacteria in drowned victims

Aerobic gram-positive	Aerobic gram-negative
Streptococcus	*Pseudomonas*
Anaerobic gram-positive	*Haemophilus*
Staphylococcus aureus	*Branhamella*
Clostridium	*Citrobacter*
Peptostreptococcus	*Burkholderia psudomallei*
Propionibacterium	*Francisella philomiragia*
Fungi	*Legionella*
Aspergillus	Anaerobic gram-negative
Pseudoallescheria boydii	*Escherichia coli*
Scedosporium apiospernum	*Aeromonas*
Candida	*Klebsiella*
	Bacteroides
	Enterobacter
	Chromobacterium violaceum

Neurological complications

Neurological damage can range from mild temporary cognitive dysfunction to a permanent vegetative state. In comatose patients it is not possible to guess a neurological outcome until at least after three days, through a combination of clinical assessment (Glasgow Coma Scale), continuous electroencephalogram, neuro-imaging (brain magnetic resonance) and neuro-physiological tests (somatosensory evoked potentials), as well as biochemical markers such as the specific neuronal enolase[39].

Regarding the treatment, the level of evidence of neuroprotective measures is for the moment low or absent, so the recommendations have been established by consensus. These include optimizing oxygenation and maintaining homeostasis, with close monitoring of capnography, blood pressure, blood volume, osmosis and patient temperature. In particular, chills and convulsions, as well as non-convulsive epileptic status, which should be prevented and treated[39].

Cardiocirculatory problems

Hypotension is common immediately after resuscitation as a result of low cardiac output or vasoplegia. In the context of saltwater drowning, hypervolemia due to fluid extravasation into the alveoli may also contribute, although this will depend on the amount of water aspirated[30]. Since most victims are young and healthy, transient hypotension will usually be corrected spontaneously.

Control of diuresis, organic perfusion (lactic acid) and hemodynamic monitoring are essential to guide the fluid management. There is no evidence on the use of specific fluid therapy, diuretics or water restriction. If hemodynamics is not restored by infusion of crystalloids, echocardiography may help decide on the use of inotropic or vasopressor agents[29]. However, there is also no specific evidence on the use of these drugs in this context; the general assumptions for critically ill patients should be followed, carefully monitoring their use in case of hypothermia.

Rhythm disorders, especially supraventricular arrhythmias, are common in drowned victims and usually resolve with the correction of hypoxia and acidosis. In addition, in hypothermic victims, electrocardiographic alterations (lengthening PR, widening QRS, lowering ST or elevation of the J point) may occur, they are generally nonspecific and transitory.

Disseminated intravascular coagulation

Although this is a common complication in the drowning patient, it has not been studied in depth. It is believed to be induced by hypoxia, which promotes the release of activator tissue of plasminogen. This disorder manifests itself with high concentrations of D-dimer and antiplasmin antibodies, low concentration of fibrinogen and extended coagulation times. For monitoring purposes, there is no characteristic thromboelastometry pattern.

Acute renal failure

There may be analytical abnormalities in plasma and urine, and low glomerular filtration rates during the first 72 hours. Its origin is multifactorial, due to acute tubular injury by hypoxia, abrupt osmotic overload in the distal tubule, renal vasoconstriction, rhabdomyolysis, and hypothermia. It is usually reversible and rarely requires renal replacement therapy.

Electrolyte disorders

The variation of electrolytes by aspiration/ingestion of both fresh and salt water has been studied in animal studies. However, its actual clinical importance is limited, as fluid redistribution in the body rapidly restores the electrolyte balance.

Hypothermia

The management of the patient's temperature is a critical issue that can determine the prognosis. Body temperature should be measured as soon as possible, as spontaneous hypothermia at the time of ICU admission is a strong predictor of unfavourable outcome. Overheating of the drowned victim should be progressive, avoiding aggressive measures. With regard to therapeutic hypothermia, the recommendations are based on studies of asphyxia and cardiac CRP, since from the scarce published literature on this procedure in drowning; no specific recommendations can be made. One practical recommendation is to maintain a core temperature of 32-34℃ and allow the body temperature to stabilize after a period of 12-72 hours of intensive care. Reheating should be progressive to a maximum of 0.5℃/h. During all care, both shivering and hyperthermia should be avoided (>37℃).

Conclusions

Drowning is a public health problem in which institutions should take on greater responsibility by allocating resources and funding, and by ensuring greater efficiency in the recording and production of statistics. More accurate reporting will encourage the implementation of effective preventive measures in each situation, as well as studies to evaluate their effectiveness in terms of mortality. Currently, the removal of barriers restricting access to water, the teaching of first aid and aquatic skills at school, training in emergency response and CPR for the entire population, and the establishment of safety standards for navigation are considered to be effective. The key prognostic factor in drowning is the time of immersion. Acute lung injury and hypoxia constitute the predominant and objective picture of therapeutic management. However, more research is needed in order to provide the best treatment for these patients.

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