The Zurich group was never in the main stream but nevertheless was successful in stimulating others to think over current concepts and define new ones (open bell bounce diving techniques, Workman M-values, Lambertsen counterdiffusion principle).

The tables are the official dive tables of numerous sports diving associations, the CMAS affiliated diving federations in Germany, Switzerland, Austria, Ireland and Portugal, the British Subaqua Association (BSA) in England and are officially endorsed by NAUI International. The altitude adapted tables for tunnel workers are still often requested. Dive computer development benefits more and more from the "untrue", but very handy, algorithm that continues to be safe in spite of the opinions of many experts.

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A BRIEF HISTORY OF DIVING AND DECOMPRESSION ILLNESS

Chris Acott

Key Words

Decompression illness, history, occupational diving.

Abstract

The significant events in the history of diving and decompression illness (decompression sickness and cerebral arterial gas embolism) are listed in chronological order.

The early history of diving

4,500-3,200 BC

Archaeological evidence shows that breathhold divers harvested sponges, food, mother of pearl and coral.[1,2]

1,194-1,184 BC

Breathhold divers were used in the Trojan wars to sabotage ships. Counter measures were introduced.[1]

900 BC An Assyrian bas-relief that showed a swimmer using an air filled balloon was part of King Assur-Nasir-Pal's palace at Nineveh. This balloon was probably not an air reserve but an early buoyancy device. This bas-relief is displayed now at the British museum.[3]

460 BC Herodotus described a Greek diver, Scyllis, also called Syllias or Scyllos, salvaging treasure for the Persian king, Xexres. He was so successful that Xexres held him captive to continue diving. Scyllis escaped by swimming 9 miles to shore during a storm (probably not underwater as it was reported!). He sabotaged the salvage fleet by cutting its moorings.[4]

332 BC Alexander the Great used divers for underwater demolition during the Siege of Tyre. He was supposed to have dived in a diving bell named "Colimphax". This event was recorded in a French manuscript in 1,250 AD.[1-5]

384-322 BC Aristotle described the use of the snorkel. He also described tympanic membrane perforation in divers and the use of the diving bell by Alexander the Great.[3,5] Reed snorkels have been used throughout history even recently during World War 1 by Allied troops in observation positions and the Germans in World War 2 by the Germans during their retreat from the Battle for Kuban.[4] The snorkel was used by both the American Indians and the Australian Aborigines for hunting.[1]

215-212BC Greek divers were used at the siege of Syracuse to construct defensive underwater obstacles.[2,3,6]

168 BC "Commercial diving" was operational in all Mediterranean harbours.[2]

77 AD Pliny's book "Historia Naturalis" mentioned military divers breathing through snorkels attached to surface floats.[3]

Renaissance diving equipment

1450 Mariano (also known as Taccola) described a diving device similar to a horse's nose bag.[3]

1500s Leonardo Da Vinci sketched a variety of diving rigs but did not develop any for practical use.[3,7,8]

Hooded snorkel designs were described by Vegetius (1511), Vallo (1524), Lorena (1535), Lorini (1597) and Fludd (1617).[3,9]

The Age of Enlightenment

1616 Franz Kessler designed a diving bell. The diver sat on an internal framework and looked through a series of small eye ports. There was no means of adjusting the bell's buoyancy. The bell was slightly negatively buoyant so the diver walked on the seabed.[3,5]

1620 Cornelius Drebbel, a Dutch inventor, developed a diving bell which was probably the first submarine. It relied on a one atmosphere air supply and caustic potash was used as an absorbent for carbon dioxide. Twelve oars powered it and it was operational to 4.5 m (15 ft).[4,7]

1627 Robert Boyle (1627-1691) was born in Lismore, Ireland.[10]

1632 Blaise Pascal (1632-1662) was born in Clermont-Ferrand, France.[10,11]

1635 Robert Hooke (1635-1703) was born on the Isle of Wight, England.[10]

1640 Von Treileben and Peckell used a diving bell to salvage 42 cannon from the Swedish ship "Vasa" which sank on its maiden voyage. The bell's air supply was atmospheric. The divers worked at 40 m (132 ft). There were no recorded cases of decompression sickness.[4]

1649 This was probably the date of publication of Pascal's Principle.[10,11]

1650 Von Guericke developed the first effective air pump.[1,3]

1656 Edmond Halley (1656-1742) was born in Shoreditch, England.[10]

1662 Boyle's Law was published.[12]

Henshaw, an English clergyman, used compressed air to treat various medical conditions. The chamber was an air-tight room, which he named "Domicilium". It was pressurised by a large pair of bellows.[7,13]

1670 Boyle demonstrated that a reduction in ambient pressure could lead to bubble formation in living tissue, however, this was not appreciated for nearly 200 years; "*.. The little Bubbles ..... by choking up some passages, vitiating the figure of others, disturbe or hinder the due circulation of blood*". His description of the viper when it was placed in a vacuum was the first recorded description of decompression sickness.[14,15]

1677 The Cadaques bell was used to salvage treasure from 2 wrecks in the port of Cadaques, Spain. The bell measured 3.9 (13 ft) by 2.7 m (9 ft) across. Two divers were used.[3,5]

1680 Borelli, an Italian mathematician, developed a rebreathing diving set. The exhaled gas was passed through some copper tubing cooled by sea water to purify it. The brass helmet was 0.6 m (2 ft) in diameter and had a glass window. The air supply was atmospheric. A piston device was used for buoyancy control. The diver was illustrated with claw like fins which suggested that he was a swimmer rather than a bottom walker. This apparatus was probably never used or tested.[3,8,16]

1681-87 Sir William Phipp used a bell and a team of divers for treasure salvage from a wrecked Spanish galleon in the Caribbean. Little is known about the bell.[3,6]

1689 Dr Denis Papin suggested that force pumps or bellows could be used to keep a constant pressure within a diving bell to maintain a constant supply of fresh air to prolong the divers' underwater endurance. This idea was first used by Englishman, John Smeaton in 1789. Papin's design was not constructed.[4]

1690 Edmund Halley developed a diving bell. In 1716 this design was improved by the use of 2 weighted air-filled 36 gallon barrels to replenish the bell's air supply.[3-7]

1715 Becker designed a helmet with 3 snorkels. Apparently he stayed submerged in the Thames for an hour, the depth is unknown.[4]

1715 Lethbridge designed a "diving machine" There are no drawings of this only an artist's impression sketched from later descriptions, which shows it as a barrel with a window at the head end and the diver's arms penetrating the barrel.[3,17]

1733 Joseph Priestley (1733-1804) was born in England.[10,11]

1742 C Scheele (1742-1786) was born in Sweden.[10]

1743 A Lavoisier (1743-1794) was born in France.[10]

1746 Jacques Charles (1746-1827) was born in France.[10]

1749 Pierre-Simon Laplace (1749-1827) was born in Beaumount-en-Auge, France.[10,11]

1766 John Dalton (1766-1844) was born in Eaglesfield, England.[10,11]

1769 Giovani Battista Morgagni described the post mortem findings of 2 cases in which air was seen in the cerebral circulation. He surmised that death was due to this.[18,19]

1772 Nitrogen was recognised by a Scottish botanist, Daniel Rutherford.[10]

1772 Freminet, a French scientist, designed a diving rig similar to Borelli's. The copper helmet was connected to an air reservoir bag. Exhaled gas was passed to and fro from the reservoir through copper tubing cooled by sea water. A set of bellows mixed the air supply in the reservoir. This apparatus allowed a diver to stay submerged probably for about 10 minutes. Although the system of air purification was invalid, the concept of extending the diver's bottom time and mobility was becoming a reality.[3,7,8]

1772 Oxygen was discovered independently by Scheele in 1772 and Joseph Priestly in 1774. They were ignorant of the each other's work. Priestly called it "dephlogisticated air". [10,20,21]

1755 William Henry (1775-1836) was born in England.[10]

1781 Lavoisier named "dephlogisticated air" oxygen (meaning acid producer).[10]

1782 The ROYAL GEORGE (a 3 deck battleship commanded by Rear Admiral Kempenfeldt) capsized on August 29 in Spithead. There were 1,000 people on board at the time, including women and children. Only 200 were rescued, Admiral Kempenfeldt and a large number of the crew drowned. It was rumoured at the time that the Royal Navy did not want the ship salvaged because it would reveal that the ROYAL GEORGE should not have been in service at the time. It was thought that the hull split open causing her to sink.[4,9,22]

Between 1782 and 1783 William Tracey used a diving bell in several unsuccessful salvage attempts. Cables were attached around the hull in an endeavour to refloat her. Tracey became bankrupt because of these salvage attempts and was imprisoned. He was later bailed out and pensioned off. [3,22]

1783 Forfait designed a diving rig which gave the diver the appearance of a submarine sandwich man. Two boards were hinged at the diver's waist and had 2 springs attached at the diver's shoulders. A rope was attached to the diver's right foot. By foot movement the diver could move these boards and either allow air in or out thus altering buoyancy. The helmet used a candle as a light source. This apparatus was not used.[3]

1784 Laplace's Law was published. [10]

1787 Charles' Law was formulated but not published.[10]

1788 In 1788 John Smeaton probably designed the first modern diving bell. It was used during the repair of the foundations of the Hexham bridge but it was not intended to be submerged. A force pump on the roof provided workers with a continuous supply of fresh air. In 1790 he modified this design to enable it to be submerged. This was used to construct the breakwater at Ramsgate Harbour.[3]

Augustus Siebe (1788-1872) was born in Saxony.[22]

1789 Lavoisier and Sequin were the first to describe the pulmonary effects of a prolonged exposure to normobaric oxygen and so discouraged its use.[10,22]

1790 Nitrogen was named by French chemist, Jean-Antoine-Claude Chaptal.[10]

1794 Lavoisier was beheaded.[10]

1796 Beddes and Watt wrote the first book on the medical applications of oxygen.[7]

1797 Klingert, a German, designed two diving rigs. One was a modified version of Forfait's design with the helmet attached to a surface float by a pipe. He used it in a shallow dive in the Oder river. It was not suitable for deep diving. His second design enabled the diver to control his buoyancy. It consisted of a large cylindrical air-reservoir which had a platform attached to it. The diver stood on this platform and was connected to the reservoir by a pipe. A rope connected the air-reservoir's top to the surface. Ballast was in the bottom of the air-reservoir attached to a pulley system operated by the diver. By either raising or lowering the ballast the diver could alter his buoyancy. Although impressive for its time the diver air supply was atmospheric and the apparatus difficult to handle and transport.[3,4,9]

1801 Dalton's Gas Laws were published.[11]

1802 Forder designed a snorkelled helmet attached to a set of surface bellows.[3]

Fullarton (1805) and Drieberg (1808) also designed snorkelled helmeted diving rigs which had limited success.[3]

1803 Henry's law was published.[10]

1821 F Magendie described gas embolism during surgery.[18]

1825 William James's compressed air diving rig (pressurised to 30 atmospheres absolute or ATA) had its air reservoir attached to the diver's waist. The diver regulated his air supply with a hand operated valve. The exhaust air escaped through a valve on the crown of diver's helmet. This was probably the first self-contained diving dress.[4,8,23]

1826 Von Derschau described the use of compressed air to raise water.[3]

1828 D'Augerville, a French dentist, designed a self contained compressed air back mounted diving rig with a reservoir air bag on the diver's chest. A hand held valve regulated the air flow to the reservoir bag from the air reservoir. The mask was made of copper and lined with dental cement to provide a good seal. The diver's buoyancy was controlled by the air content of the reservoir bag and ballast weights which could be jettisoned. D'Augerville used this rig in a salvage attempt of the wreck *Bellona*. It was used in depths between 9-20 m.[23]

1829 Bichat demonstrated that venous gas embolism could be tolerated but was dependent on the dose of air and site of injection. Small amounts of air, however, if injected into the cerebral circulation were fatal.[18]

Charles Dean used his open helmet diving dress for salvage work on the *Carn Brae Castle*, the first recorded use of suited divers in salvage work.[22]

1830 Cochrane patented the concept of the caisson (the use of compressed air to raise water).[3]

1832 Charles Condert, an American machinist, dived to 6m (20 ft) using a compressed air diving rig. It was a similar design to that of William James. A horse shoe shaped air reservoir, made from 6 inch (150 mm) copper tubing, was suspended around the diver's waist by shoulder straps. Air was supplied to the helmet by a hand controlled valve, the exhaust air escaping from a hole in the helmet's crown. Condert made several dives in the East River, New York, using this rig but he drowned in 1832 when his air hose broke and he was unable to ditch his weight belt.[8,16,23]

1833 Paul Bert was born in Auxere, France.[10]

1834 Junod, a Frenchman, constructed a hyperbaric chamber and used hyperbaric air (2-4 ATA) to treat pulmonary disease.[7]

1834-6 Between 1834 and 1836 the Deane brothers (John and Charles) made several successful salvage dives on the ROYAL GEORGE using the their diving rig. They were able to salvage 30 cannon, however, the ROYAL GEORGE still remained a hazard to shipping.[3,4,9,22]

1836 William Henry committed suicide.[10]

1837 Pravaz, a Frenchman, used hyperbaric air to treat a variety of illnesses. Between 1837-77 various hyperbaric air chambers were constructed in Europe to treat a variety of medical conditions.[7]

1839 In August 1839 Colonel Palsey, of the Royal Engineers, was employed to destroy the wreck of the ROYAL GEORGE. His divers used both the Deane diving rig and the newer Siebe "closed rig" (which made the diver more mobile and had a better air supply). Gunpowder kegs were placed around the wreck and electricity used to explode them. Palsey recommended that the Royal Navy use the Siebe rig which became the so called "classical diving rig".[3,4,9,22]

1841 Triger, a Frenchman, constructed a caisson (caisse is a box in French). Triger is credited with the invention of the caisson although the concept of using compressed air to raise water was an idea of Von Derschau's in 1826 and patented by Cochrane in 1830. Triger's caisson consisted of 4 iron cylinders about 1 m in diameter and 5 to 6 m long. It was sunk to a depth of 20 m (66 ft). It was used to excavate a coal mine at Chalonnes and to penetrate quicksand under the Loire River.[7,14,24-26]

In his first report Triger (1845) noted ear pain during compression. He also noted at 3 ATA:

that candles burned brightly;
that it was impossible to whistle;
that voices had a nasal accent;
and that respiratory rates were decreased and less effort was required to perform tasks.

He recorded the first 2 cases of decompression sickness in 2 miners. One complained of a "very sharp pain" in his left arm, the other a pain in his knees and left shoulder. These miners had been working at 2.4 ATA for 4.25 hours. Alcohol was massaged over the affected areas and both men returned to work the next day. Apparently the pain had disappeared.[24,25]

In subsequent reports, Triger noted that ear pain was relieved by swallowing (he knew about the Eustachian Tube) and that a dog and bird had been kept alive in the caisson for many days.[24]

In 1852 he was awarded the Prix de Mechanique for the invention of the Caisson.[24]

1846 Blavier reported that some caisson workers (Douchy mines, France) complained of a post decompression "heavy head" and limb pains. These pains were relieved by local massage.[26]

1847 Pol and Wattelle (both Frenchmen) noted "several untoward symptoms" (unconsciousness, convulsions and death) after decompression in caisson workers at Lourdes. They noted that symptomatic relief was gained with recompression in one worker. Although this is thought to be the first reported case describing the effectiveness of recompression for treatment, (".... *a sure and prompt means of relief would be to recompress immediately, then decompress very carefully*") there is no evidence that they used recompression routinely in their affected workers.[24,26,27]

They also observed that there was a relationship between symptoms, depth and duration of exposure and the rapidity of decompression and that fit 18 year olds were less susceptible to decompression sickness than older workers.

They concluded that workers should be between the ages of 18-26. These data were published in 1854.[24,26-28]

1850-51 Hughes, an Englishman, described similar observations to Triger's (except for decompression sickness) during the construction of the Medway bridge.[26]

1855 Littleton reported 25 cases of decompression sickness in caisson workers during the construction of the Tamar bridge. Limb pains, paralysis and unconsciousness were noted a few minutes after decompression. He thought that decompression sickness was due to "...extrication of air occasioning pressure on the brain....". He recommended a gradual application and reduction of pressure.[26]

1857 Hoppe-Seyler repeated Boyle's experiments. He thought that sudden death seen following decompression was due to the sudden release of intravascular gas.[1]

1860 John Scott Haldane (1860-1936) was born in Edinburgh, Scotland.[10]

1861 Bucquoy published an account of the hazards of compressed air work. He was probably the first to do so. He advised a slow decompression.[29]

1863 Foley recommended recompression as the "true specific" treatment for decompression sickness. [27]

1864 Roger, a French physician, described the collapse of an 8 year old girl following irrigation of her empyema cavity. He thought that this was caused by "pleural reflexes". In 1875 Raynard and colleagues tried to verify this experimentally but were unable to do so. Collapse following empyema irrigation was called "pleural eclampsia" by Bessnier (1874) and "pleural epilepsy" by Legnoux and Leprice (1875).[18]

1865 Rouquayrol and Denayrouze developed their demand valve and diving rig. A pressure regulator was connected to a compressed air reservoir carried on the diver's back. This was a major advance in diving technology as it increased the diver's mobility. Rouquayrol and Denayrouze's diving rig was referred to in Jules Verne's Book "20,000 Leagues under the Sea" (written in 1869, published in 1875). Later Rouquayrol designed a flexible diving dress with a metal three-bolted helmet.[3,9,16]

1866 Leonard Hill (1866-1952) was born.[4]

1868 Helium (from the Greek word for sun) was discovered surrounding the sun by two English astronomers, Lockyer and Frankland.[10]

Gal described a case of paraplegia in a Greek sponge diver. The diver made a spontaneous recovery over 2 weeks. This case report was not published until 1872 and may have been the first description of neurological decompression sickness in a diver.[30,31]

1870 Bauer published a report of 25 paralysed caisson workers. Four died but the majority recovered within 1 - 4 weeks.[28,32]

Between 1870 and 1910 all the salient features of decompression sickness were established. Early explanations included:

- reflex spinal cord damage caused by either by exhaustion or cold;
- frictional tissue electricity caused by compression;
- or decompression induced organ congestion and vascular stasis.[24, 25, 27, 30, 32]

1871 The St Louis Eades bridge project employed 352 compressed air workers. Thirty of these workers were seriously injured, 12 died. Dr Alphonse Jaminet was the physician in charge. He developed decompression sickness following an exposure of 2.75 hours at 29 m with a decompression of 3.5 minutes. His symptoms were: dizziness, limb pain, paralysis of one arm and both legs and an inability to speak. He elevated his legs and drank rum and made a spontaneous recovery within a week. His personal description of these events were the first such recorded.[13,24]

1872 Friedburg noted:

the similarity between severe decompression sickness and surgically induced gas embolism;
the association between decompression sickness and inadequate decompression.

He thought that a rapid decompression released intravascular gas and so suggested:

a slow compression and decompression (at least 15 minutes each);
that shifts be limited to 4 hours;
that 44.1 psig (4 ATA) should not be exceeded;
and only healthy individuals be used.

He also recommended recompression for severe cases.[26]

1872 Gal published data which showed that paralysed patients either recovered spontaneously (over 5 days - 3 weeks) or died from septicaemia (complications of bed sores or cystitis).[31]

1873 The Brooklyn bridge project employed 600 workers. The caissons were to a depth of 78.5 feet (23.8 m. These caissons were steam heated because it was thought that decompression sickness was due to extreme cold. Andrew Smith, an ENT surgeon, was the physician in charge. He described 110 cases of decompression sickness which he considered serious enough to warrant his attention (there were 119 cases in total). Fourteen of these died. He was the first to use the term "caisson disease". He did not use recompression because he believed it to be a ".... *heroic mode*.." of treatment. The chief engineer, Roebling, developed neurological decompression sickness (mainly spinal cord symptoms). He directed the project from his sick bed. He was not treated but made a slow spontaneous recovery.[13,24,26,33,34]

During this project the colloquial term "the bends" was used. "Doing the bend" was used to describe the posture of the caisson workers who suffered from decompression sickness. These workers walked with a stoop resembling a posture known as the "Grecian bend" affected by fashionable women. "Doing the bend" was later changed to being bent or the bends.[13,24]

Some of the caisson workers wore bimetallic or "galvanic" bands either to prevent or relieve the symptoms of decompression sickness.[13,24]

1875 Raynard and co-workers tried to verify that pleural reflexes were responsible for pleural "eclampsia" or "epilepsy".[18]

1877 L von Bremen developed a speaking tube which improved communication between the diver and his surface attendant. This tube was connected to the diver's helmet.[4]

1878 Paul Bert published "La Pression Barometrique". He described the acute toxic central nervous system effects of oxygen (acute oxygen toxicity or the "Paul Bert effect").[13,24,29,35]

He recommended recompression and the use of normobaric oxygen for treatment.

He not only demonstrated that nitrogen bubbles caused decompression sickness but also recognised the existence of "silent bubbles" following decompression. He described the association between obesity and an increased susceptibility to decompression sickness (he experimented on his pet dog. It had survived many decompressions from 7-8 ATA while thin, however it died when subjected to the same pressure exposures while obese).[13,14,24,35]

1880 Fleuss designed an oxygen rebreathing set. The absorbent was rope soaked in caustic potash. It was first used for diving, by Lambert, during the flooding of the Severn tunnel. Fleuss was the surface attendant.[3,9]

1880-1910 Additional safety devices were added to diving helmets. These included:

a valve which regulated the amount of air in the helmet;
a "chin button" which enabled the diver to release air from the helmet giving him some control over his buoyancy;
a non-return valve which prevented air escaping up a damaged hose air hose or if there was an air pump failure;
and a hand operated 'spitcock' for helmet defogging.[4]

1881 Woodward reported that the majority of "pain only" and some cases of neurological decompression sickness resolved spontaneously.[30,31]

1884 Nowak published a summary on the medical aspects of compressed air work.[26]

1889 E W Moir installed a medical lock during the construction of the Hudson river tunnel. He used recompression for treatment. When Moir became the superintendent the incidence of decompression sickness was high with a death rate of 25% from decompression sickness. Following the installation of the medical lock only 2 deaths occurred in the subsequent 120 cases. Moir did not publish these data until 1896 and they are probably the earliest reference to the routine use of recompression for treatment. Moir's recompression regime was to recompress to 1/2 -2/3rds the working pressure followed by a stay at this pressure for 25-30 minutes and a decompression of 1 psi per minute. Haldane used some of Moir's clinical data for his experiments.[2,13,24]

1892 John Burdon Sanderson Haldane (1892-1964) was born.[10,12]

1894 Buchanan and Gordon, two Australians, patented a deep diving suit. This was manufactured by Siebe Gorman. Another Australian, Hamilton, designed a diving suit, however, this was not used.[3]

1895 Ramsay discovered helium on Earth.[10]

Snell used recompression during the construction of the Blackwall Tunnel (he had had a medical lock installed). He was the first to describe the association between an increased risk of decompression sickness and an elevation in the atmospheric carbon dioxide tension due to inadequate caisson ventilation [36]

1897 Zuntz discussed the factors that controlled bubble size and resolution but overlooked the role of fat in the pathogenesis of decompression sickness. He used oxygen and recompression for treatment, however, this mode of treatment was unpopular due to the fear of acute oxygen toxicity.[30,37,38]

1900 L Hill demonstrated experimentally, in a frog, that decompression caused bubbles and that these cleared on recompression.[40]

Heller, Mager and von Schrotter recommended a linear decompression of 1 atmosphere per 20 minutes.[14,40]

1902 Construction restarted on the Hudson River tunnels.[26]

Albert Behnke (1902-1992) was born in Chicago, USA.[41]

1904 Greek and Swedish divers were diving to 58 m using air but the rate of decompression sickness was high.[3]

1905 The British Admiralty appointed Haldane to develop safe decompression procedures. The Royal Navy had a 100 ft (30 m) limit on air diving.[14]

1906 Von Schrotter suggested the use of oxygen with recompression but again the fear of acute oxygen toxicity thwarted its use.[28, 42]

Hill and Greenwood recommended a uniform decompression of 20 minutes per atmosphere, similar to Heller and von Schrotter. They also experimented on themselves. To discover the saturation of the body's 'fast' tissues (the kidneys were used as an example) they measured their urinary nitrogen content. They disregarded the effects of carbon dioxide on decompression sickness. These data were subsequently used by Haldane.[39]

1908 JS Haldane, Boycott and Damant published "The Prevention of Compressed Air Illness". They recommended staged decompression. These tables were accepted by the RN and were used for dives to 34 fathoms (204 ft or 61.2 m).[39]

1909 The German company, Dräger, developed their rebreather.[9]

Keays described 3,692 cases of decompression sickness. He established recompression as the treatment of choice. He showed that there was a persistence of symptoms in 14% of Caisson workers who were not recompressed compared with 0.5% in who were. However he admitted that recompression often failed in "serious" cases. These data were published again in 1912.[43, 44]

Blick described 200 cases of decompression sickness in the Australian pearl divers. He showed that in the majority of 'pain only' cases the symptoms resolved spontaneously. There were some cases of spontaneous improvement in neurological cases. The pearl divers often died because of the complications of paraplegia (septicaemia from urinary stasis and infection), hence, they carried metal urinary catheters with them while diving to treat the paraplegic bladder. At post mortem Blick described "*..teasing of the spinal cord..*" in divers who had died from spinal cord decompression sickness.[45]

1910 Jacques Cousteau (1919-1997) was born in France.[10,68]

Jacobs reported the medical problems associated with caisson work during the construction of the Hudson River tunnels. Between 1902 and 1910 there were 1575 cases of decompression sickness in 8400 workers. Three died.[26]

1911 Bassoe described chronic joint pain and stiffness in 11 out of 161 compressed air workers in Illinois, USA. The radiological description was reported as "arthritis deformans".[46]

Knowles reported 115 cases of decompression sickness in 100 caisson workers during the construction of the Boulac Bridge across the Nile. There were 4 deaths due to decompression sickness. These were the first repetitive cases of decompression sickness to be published.[26]

1911-1912 Borstein and Plate described 3 cases of joint disease in 500 compressed air workers employed in the construction of the Elbe Tunnel in Hamburg. One had a single hip lesion, another bilateral hip lesions and the third a lesion in his right shoulder. All had suffered from decompression sickness. The maximum pressure they had worked in was 3.4 ATA.[46]

1912 Kenneth Donald (1912-1994) was born.[47]

Hill emphasised the increased risk of permanent disability or death in compressed air workers.[48]

Ryan published a treatment regime which had limited acceptance. He advocated a return to 2/3rds the original pressure followed by a slow decompression.[59]

M Brandes described the post mortem finding of bismuth paste in a patient's cerebral arterial and venous circulation following its use in the irrigation of an empyema cavity.[18]

1913 L Brauer suggested that the symptoms and signs of "pleural shock" or "pleural eclampsia" could be explained by cerebral gas embolism. He was probably the first to use the term "arterial gas embolism". [18]

1915 The United States Navy (USN) Diving Tables were first published. These were a version of the original Haldane tables modified by French and Stillson. Maximum depth was 300 ft (90 m). They were used, in 1916, to salvage the submarine *F4* which sank to a depth of 306 ft (92 m).[51]

1917 Levy advocated a recompression regime of a return to the original pressure followed by a slow decompression. It had limited acceptance.[49]

Dräger developed a nitrox rebreather. [3,9]

1918 A Tokyo engineer, Watanabe Riichi, patented his self-contained diving apparatus. This was marketed under the name of "Ohgushi's Peerless Respirator". The diver controlled his own air supply with 2 levers in his helmet which he manipulated with his teeth. His air supply was either surface supplied or from two cylinders, containing 1,000 litres when pressurised to 150 atmospheres. The surface supplied version of the Ohgushi regulator was illustrated and described in a 1945 Russian Navy diving manual and was apparently still in use at this time.[23]

1919 Elihu Thompson suggested the use of helium to the US Department of Mines. He thought that the use of heliox would decrease breathing resistance and double diving depths. Nitrogen narcosis was unknown at this time.[14]

The RN and US Department of Mines began experimenting with heliox. They used air decompression schedules which gave a high incidence of decompression sickness. As a result heliox was abandoned.[14]

1921 **Dr O Cunningham used hyperbaric air to treat a variety of illnesses, including diabetes.**[7]

1922 K Schlaepfer suggested the Trendelenberg position for any collapse following irrigation of an empyema cavity.[51]

1924 The USN first published the first standard recompression procedure.[27]

1926 A French Naval officer, Yves Le Prieur, patented the Frenez-Le-Prieur self contained diving apparatus. It consisted of a back mounted Michelin air cylinder connected to a Frenez mouthpiece. The diver wore Frenez goggles and a nose clip. This apparatus was superseded in 1934 by the Le Prieur apparatus which used the same cylinder but mounted on the diver's chest. A hand controlled regulator fed a continuous stream of air to a full face mask.[8,23]

1927 Haldane proposed that bubble resolution could take over 24 hours.[52]

1928 Rukstinat and Le Count advised that any post mortem examination should be conducted under water if the cause of death was suspected to be a gas embolism. [53]

Cunningham's hyperbaric "Sphere" was constructed. It was 5 stories high and 64 feet in diameter. Each floor had 12 bedrooms. Cunningham published only one article on the use of hyperbaric air despite repeated requests from the American Medical Association. He was censured by the American Medical Association. His chamber was demolished in 1937 for scrap metal.[7,13]

1929 Van Allen's data on the head down posture and gas embolism was published. He also noted that gas was not trapped in the cerebral circulation. [18]

Joseph Peress designed his watertight joint to be used in his one atmosphere diving suit.[54]

The Davis decompression chamber was designed.[3,4,39]

1930 Peress trialled his one atmosphere diving suit, "Tritonia", in a tank at Byfleet, England. It was later trialled in Loch Ness, the diver was James Jarret, Peress's assistant.[17,54]

The RN Second Deep Diving Unit was formed. Successive chairmen were Captain FA Buckly RN, Captain (later Admiral Sir Francis) Pridham, Captain Robertson RN, Leonard Hill (later Sir) and Robert Davis (later Sir). Experimental work was delayed by World War Two but resumed again in 1946. The RN began experimenting with oxygen decompression from 60 ft (18 m) in air dives to 325 ft (98 m). The RN used the submersible Davis

Decompression chamber for their oxygen decompression. During the deep dive experiments Damant noted unpredictable behaviour in the divers at depth. Various reasons were proposed for this:

L Hill and A Phillip (1932) psychological causes;
JS Haldane (1935) oxygen toxicity;
Behnke (1935) the result of an increased partial pressure of nitrogen. These oxygen decompression experiments stimulated Behnke to start his oxygen tolerance experiments.[3,39,55]

Courlieu, a Frenchman, developed the rubber foot fin.[8]

In the 1930's the USN Submarine Escape Unit, particularly Behnke, recognised arterial gas embolism as a different disorder from decompression sickness.[24]

1931 Six submariners escaped from the RN Submarine HMS POSEIDON which had sunk in 100 ft (30 m) in the China Sea. Five survived the escape, one died from a head injury received while exiting the submarine. All of the survivors suffered from decompression sickness. Four were found to have dysbaric osteonecrosis 12 years later (1 was lost to follow up). Apparently this was their only exposure to compressed air.[3,56]

1932 The first snorkel was patented. The name snorkel was adapted from the air tube used in German U Boats.[3,8]

1934 Kagiyama's data showed divers could ascend from deeper depths without decompressing if the exposure time was limited.[14]

1935 Behnke and Shaw investigated the use of oxygen (to create a maximum elimination gradient and relieve bubble induced ischaemia) in the treatment of decompression sickness.[42]

James Jarret dived on the *Lusitania* (304 ft, 91 m) in "Tritonia" the one atmosphere diving suit.[17,54]

1937 Behnke and Shaw published their oxygen tables. These tables were not used because the USN Bureau of Medicine and Surgery decided that oxygen breathing in a chamber was not "sailor-proof" (fear of oxygen toxicity and fire).[27]

Behnke and Shaw restated Van Allen's posture recommendation to prevent cerebral embolisation by bubbles.[42]

Behnke introduced the "no-stop" decompression tables.[14]

1939 Yarborough and Behnke showed a 50% recurrence rate with USN recompression procedures. They suggested recompression to 165 ft (50 m) combined with the use of hyperbaric oxygen from 60 ft (18 m). This treatment regime was not adopted.[57]

Momsen and Wheland published the first operational heliox operational decompression schedules. Heliox was used in the salvage of the US submarine *Squalus* which had sunk in 240 fsw (73 m). Behnke supervised the diving. Thirty six men were rescued. None of the divers complained about any decrement in co-ordination and cognitive function, which verified Behnke's theory of nitrogen narcosis.[58]

1942-1945 Donald conducted his oxygen diving experiments.[4,55,59]

1942 JL Fulton was appointed the head of a committee to investigate decompression sickness in aviators. This committee included Behnke.[26]

1943 Emile Gagnan, an engineer, and J Cousteau adapted a gas pressure reducing valve for use underwater. The "aqualung" was born. This valve had been previously evaluated by Gagnan for use in gas powered cars.[1,7,23]

1945 Van der Aue et al. developed the USN's Treatment Tables 1 - 4. Gas embolism was treated on either Tables 3 or 4.[60]

Zetterstrom, a Swedish engineer, died diving while using a hydrogen/oxygen mixture. He had previously demonstrated that the risks of hypoxia and explosion were reduced in hydrox diving if the diver used air to 30 m followed by a 4% nitrox mixture and then a 4% hydrox mixture. He died during ascent from a dive to 160 m using these combinations, apparently the ascent was too rapid due operator error.[1,4]

1946 The RN Deep Diving Unit resumed its activities under Commander Shelford RN, but it was renamed the Admiralty Experimental Diving Unit. It was mainly concerned with heliox diving.[4]

1947 Dr Edgar End began treating compressed air workers with 3 ATA oxygen. His treatment times varied between 30 minutes to one hour or more depending upon the rapidity of relief. Between 1947-67 he successfully treated 250 patients. Unfortunately, his work was not published.[24]

1950 Molumphy modified Momsen and Wheland's heliox tables.[54]

1955 Haymaker et al. published their post mortem data which showed that decompression sickness in divers, caisson workers and aviators was identical.[61]

1957 Des Granges produced the USN Repetitive Air Diving Tables, using tissue half times of 40, 80, 120 and 240 minutes. These tables were based on Dwyer's data.[58]

1957-1963 Dr G Bond conducted the "Genesis studies". These studies were the forerunner of saturation diving.[16,62]

1960 Golding et al. classified decompression sickness into Type 1 and 2. This view was supported historically by the USN classification of decompression sickness into mild (or pain only) and serious.[1,51,63]

The USN used the Des Granges repetitive air tables.[58]

1962 Hans Keller dived successfully to 305 m in the sea using a Hydrox mixture.[1,4]

1962-1978 Various underwater habitats were tried. Sixty five were built in total, 41 of these in Europe. The aquanauts, as they became known, either dived on air or a heliox mixture. Between 700 and 800 aquanauts were used including astronaut Scott Carpenter.[16,62]

1965 Goodman and Workman began their studies on minimal pressure oxygen tables.[27,31]

1967 The USN accepted the Goodman and Workman tables. These were published as Tables 5 and, 6 in the USN Diving Manual.[27]

Waite and Mazzone began to re-evaluate the treatment of cerebral arterial gas embolism in submarine escape trainees.[64]

1968 Waite and Van Gendren modified USN Tables 5 and 6 for the treatment of cerebral arterial air embolism. These tables were called Tables 5A and 6A.[65]

1976 Table 5A was abandoned because it was considered that there was insufficient time at 165 ft (50 m) to evaluate the diver.[66]

1985 The USN published an algorithm for examination of the Central Nervous System in its Diving Manual.[67]

1990 A meeting was held at Alverstoke, UK, to discuss the classification of decompression sickness. A change in terminology was proposed, the term decompression illness was to embrace both the maladies of decompression sickness and cerebral arterial gas embolism.

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