Champagne's Magical Bubbles

Champagne's life starts in the vineyards around Epernay, where the soil is chalky and the climate is cool. In the *Méthode Champenoise,* the grapes are first fermented to make white wine, while a second fermentation of the white wine in a sealed bottle creates the carbonation. With its sparkling crispness, champagne is the perfect apéritif and accompaniment for various different dishes.

The physics of bubbles

The partial pressure of CO_2 over the wine (P_{CO2}) is proportional to the concentration of CO_2 dissolved in the wine (c): $C = k_H P_{CO2}$, where k_H (Henry's law constant) expresses the solubility of the gas in liquid in grammes/litres/bar. During the second fermentation, the 24 g/litre sugar that is typically set for a bottle of white wine will be converted into 1.2 vol% alcohol and 9 g of CO_2. An ideal gas fills 24 l/mol at 12°C; and with its molecular weight of 24 g/mol, the 9 g of CO_2 in 0.75 litre of champagne will correspond to 4.8 litres of CO_2 in gaseous state (1). At 8-10°C, the partial pressure of CO_2 in the 25-ml air pocket between wine and cork will be 5-6 bar. For comparison, the pressure in a lorry tyre is 6-9bar. The partial pressure of CO_2 creates pressure of approximately 15 kilos against the underside of the just over 10 g cork stopper. The serving temperature, which plays a role for the partial pressure (Fig 1), determines the speed at which the cork is ejected: 39 km/h at 6°C (4 bar), 47 km/h at 12°C (6 bar) and 54 km/h at 18°C (8 bar) (2).

Take care of your eyes

Sometimes the cork is ejected in the same split second as the bottleneck's steel wire is loosened (photo), which comes as a surprise to both host and guests. Even a lightning-fast blinking reflex (1/10 second) is no match for a missile that is propelled at 14 m/s and hits the cornea at an atmospheric pressure of 100 (3). Archer et al. describe severe ocular lesions in nine patients referred to Moorfields Eye Hospital after being hit by a champagne cork. Seven lesions concerned the left eye, which was ascribed to the typical position of a champagne bottle opened with the right hand. Statistics for 43 cork lesions showed that 26% of the eye lesions led to residual eyesight of ≤ 6/60 (4). So it is better to follow the guidelines of Helmig et al. for opening a bottle of champagne: "The temperature of around 8-10°C must be complied with. A white serviette must be held above the cork and the bottleneck, while the steel wire is loosened, and the cork must be gently pushed away with your fingers, while the bottle is pointing away from your face in a direction approximately 60° towards the ceiling. It must not go 'bang', but give a deep, moist 'sigh'." (5).

From the physics of bubbles to the chemistry of bubbles

The tingling sensation in the mouth after a sip of champagne has been attributed to myriads of CO_2 bubbles' impact on the mucous membrane's mechanoreceptors, when they explode on the tongue (6). Focus switched from the physics of bubbles to the chemistry of bubbles when a pressure-chamber trial found no difference in the tingling sensation on ingestion of sparkling water at atmospheric pressure compared to ingestion at an atmospheric pressure of 2, which prevents the formation of the sparkling CO_2 bubbles (7). At atmospheric pressure, 90 $cm^3$of CO_2 per 100 ml water can be dissolved, which has a pH of 5.65 after the reaction: $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$. At an atmospheric pressure of 2.5, 250 $cm^3$of CO_2 per 100 ml water can be dissolved, which gives a pH of 3.72 in a bottle of Apollinaris sparkling water. Carsten et al. trained 20 students to assess the tingling sensation on having their tongues dipped in Apollinaris for 15 seconds. On repeating the experiment with half of the tongue being treated with a 2% acetazolamide solution, the average score for the tingling on the tongue was clearly reduced on the treated half of the tongue (8). What could the reason be?

Champagne blues

The chemical equilibrium between carbonic acid and CO_2 in water is 1.7×10^{-3}, which means that most of the dissolved carbon dioxide exists as CO_2 molecules. This explains the minimal difference in acidity (at 4°C) between champagne with normal CO_2 content (pH 2.91) and without CO_2 (pH 2.96) (9). The carbonic anhydrase enzyme catalyses the reversible reaction $CO_2 + H_2O \leftrightarrow HCO_3^- + H^+$ with a turnover rate of one million CO_2 molecules per second. In 2009, Chandrashekar et al. localised carbonic anhydrase IV (CA IV) in the surface membrane of the taste buds at the very back of the tongue, which pick up the acidic taste (10). When champagne's CO_2 molecules are dissolved in the saliva on the surface of the tongue, CA IV will create myriads of hydrogen ions – a relevant signal for taste buds that capture sour tastes. Azetazolamide blocks the carbonic anhydrase enzyme, which explains the reduced tingling on the blocked half of the tongue, as well as Stephen Kelleher's "champagne blues" (11). Kelleher wanted to celebrate climbing a mountain peak with a can of cold beer, but was disappointed, since at the top of the mountain the beer tasted like dishwater. Once safely back down again, Kelleher found that a carbonated soft drink was also flat, while there was nothing wrong with the taste of whisky with tap water. The culprit was the carbonic anhydrase inhibitor, Diamox, which he had taken as a prophylaxis against altitude sickness. Experiments have shown that CO_2 bubbles can affect the free nerve endings from the trigeminal nerve in oral mucosa. The tingling sensation on your tongue when you drink a glass of champagne is thus a result of multimodal perception: an interaction between sensory modalities such as mouthfeel, CA IV activity and taste buds that capture the sour taste (12).

Rapid intoxication with bubbles

In 1824, Henderson gave the first medical description of champagne intoxication: "The brisk wines of Champagne intoxicate very speedily, probably in consequence of the carbonic acid gas in which they abound, and the volatile state in which their alcohol is held; and the excitement is of a more lively and agreeable character and shorter duration, than that which is caused by any other species of wine, and the subsequent exhaustion less."(13). A hundred years later, the hypothesis of rapid intoxication by bubbles was supported by the results of Edkins et al.'s experiments with cats, which showed more rapid absorption of alcohol from the gastric mucosa in the presence of CO_2 (14). It was not until 2003 that the effect of champagne bubbles on humans was studied. Twelve men and women each emptied three glasses of champagne in the course of 20 minutes; and a week later, they received the same ration, but only after the CO_2 bubbles had been removed using a handheld blender (9). Their BAC level five minutes after the last sip of champagne was higher when there were bubbles in the glass (0.52‰) than without CO_2 (0.40‰) (Fig 2). The area (mg·min/100 ml) below the plasma concentration's time curve was significantly different for up to 20 minutes after ingestion: 203.08 for champagne with CO_2, versus 167.33 for degassed champagne. The result of a Compensatory Tracking Test 20 minutes after ingestion showed increased cerebral alcohol influence after the champagne with bubbles (196.4 msec), versus champagne without bubbles (CTT 46.3 msec).

Champagne's 125-year war

The wine's health-promoting effect as the trump card in the competition for market shares laid the foundation for the 125-year war between Champagne and Burgundy; a war that was fought between doctors and professors with pen and ink as their weapons, and prose and verse as their ammunition. The only blood that was shed was the blood of the grape. The shot which started the war in 1652 was a thesis that extolled the virtues of the wine from Beaune as tastier and more healthy than any other wine. In 1677 came the riposte, *An vinum Remense sit omnium saluberrium*, which highlighted the wine from Rheims as the healthiest. A royal casuistry became explosive ammunition in the next attack from Burgundy. Louis XIV, who had been crowned in Rheims and who on his personal physician’s recommendation had drunk champagne at every meal, now had the gout. In 1693, the King's new personal physician, Guy-Crescent Fagon, blamed the champagne, banned the bubbles and prescribed burgundy as the only wine to be served at the King's table. Three years later, a Burgundian thesis was ready, claiming that champagne irritated the nerves and led to catarrh and gout. The shock at these outrageous accusations provoked a rapid counter-attack from the medical faculty in Rheims: *An vinum Remense Burgundico suavius a salubrius*, which as evidence of the beneficial effect of champagne among other things named the winegrower Pierre Pieton from Hautvillers, who married at the age of 110 and died at the grand old age of 118 (15).

Champagne as a medicament

A dissertation from 1777, *Sur usage du Vin de Champagne Mousseux*, by Jean-Claude Navier, dean of the faculty of medicine in Rheims, ended the battle (16). The dissertation was a diplomatic stroke of genius since, on the one hand, it credited all French wines, including burgundy, with health-promoting properties, but on the other hand emphasised that only champagne, by virtue of its bubbles (*l'air fixe*), could be used as a medicament. Antiseptic qualities made it e.g. the obvious remedy for febrile illnesses, and this advice was maintained by a French doctor, Dr. Maury, in 1974, who prescribed a bottle of dry champagne per day for a fever, ingested as a small glass every hour (17). Another advantage of *l'air fixe* was its ability to dissolve stones in the body – a hypothesis supported by an observation study of 194,095 participants who were followed for eight years: a regular intake of white wine was associated with a 33% (95% KI 15-45%) lower risk of kidney stones (18). Bertin du Rocheret rejected the hypothesis of champagne as the reason for gout with a case history from his list of the deceased in Epernay since 1644: “Jeanne Maillard died on 1 January 1733 at the age of 75 as the only person in the area who had ever had the gout” (19). After 12 years’ observation of 51,529 *Health Professionals* the relative risk of gout per glass of wine per day was 1.04 (95% KI 0.88-1.22) (20).

Golden moderation

Alcohol is an addictive substance that is the cause of around 60 different diseases and conditions (21). The integration of alcoholic beverages in a healthy lifestyle requires regular, moderate ingestion in connection with healthy meals. There is a J-shaped link between alcohol and mortality, with the low point of the curve at around one unit per day. The quantity of alcohol connected with the same mortality as full abstinence is 20-25 g/day for women, and 40 g/day for men (22).
Moderate consumption of alcohol is associated with a reduced risk of:

- Total mortality: 18%
- Fatal and non-fatal ischemic heart disease: 25-50%
- Stroke: 20%
- Peripheral arteriosclerosis: 26%
- Metabolic syndrome: ♂ 16% ♀ 25%
- Type 2 diabetes: 30%
- Dementia: 25-40%

Moderate consumption of alcohol is associated with an increased risk of:

- Cancer in the oral cavity and pharynx: 21%
- Oesophageal cancer (planocellular carcinoma): 17%
- Breast cancer: 4%

Memory cure

In a laboratory experiment with neurons from rat brains, Vauzour et al. found a protective effect from an extract of champagne's plant phenols against peroxynitrite-induced damage to the neurons (23). On comparison with an isocaloric fluid with the same alcohol dose, Corona et al. found a significant improvement in older rats' spatial memory after the addition of champagne (1.78 ml/kg body weight) to food for six weeks. The rat was released into the maze where it found a hidden tasty snack. Five minutes later, the exercise was repeated to see whether the rat could remember where it had found its first titbit and might be able to find the next. Without champagne the rats' success rate was 50%; and with champagne it increased to 70%. Biopsies from the hippocampus showed a 200% increase in the volume of proteins with significance for the short-term memory, which the researchers attributed to champagne's content of tyrosol and other plant phenols (24). In an interview with the *Daily Mail*, professor Spencer encourages people over 40 to drink two to three glasses of champagne per week (25). "The development of dementia probably starts in the 40s and continues gradually up to the 80s, so the earlier people ingest the beneficial substances in champagne, the better it will be for them."

FACT BOX

- In 0.75 litres of champagne, 9 g of CO_2 is dissolved, which takes up 4.8 l as gas.
- At 8-10°C the partial pressure of CO_2 in champagne is 5-6 bar.
- The cork can hit the cornea at 14 metres/second and an atmospheric pressure of 100.
- Taste buds with the carbonic anhydrase IV enzyme capture the tingling taste of CO_2.
- Champagne gives a faster and higher BAC than wine without bubbles.
- Alcohol in moderation is associated with a reduced risk of total mortality, ischemic heart disease, stroke, type 2 diabetes and dementia, and an increased risk of breast cancer and cancer of the oral cavity, pharynx and oesophagus.
- Champagne improved older rats' spatial memory by 40%.

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