SCIENCE FOCUS 科言

Issue 015, 2019

School of Science 理學院
香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Contents

Science Focus Issue 015, 2019

Message from the Editor-in-Chief 主編的話

Dear Readers,

Welcome to the latest issue of *Science Focus*. This time, we bring you articles on scientific discoveries that span many decades. Going beyond the textbook, we introduce a lesser-known hero who played a big part in the discovery of the DNA structure. Have you ever thought of ways jellyfish and tree bark played in biomedical research and medicine? What about the link between a comic character and tissue regeneration? For those of you who are into sports, we delve into the physical principles behind ice-skating.

Have you checked out our Instagram platform? You will find fun graphics and summaries of articles we published in previous issues of *Science Focus*. We hope to post your contributions in the very near future! To share your passion on science, please enter our Instagram competition. Each round of competition will have a theme. All you have to do is send us an original digital photo, together with a caption that explains a related scientific story. For further details, please refer to the next page – *What's Happening in Hong Kong*.

Now get your phones or fancy cameras out, and start snapping away!

Yours faithfully,
Prof. Ho Yi Mak
Editor-in-Chief

親愛的讀者：

歡迎閱讀最新一期《科言》！今期作者們會為您帶來橫跨數十年的科學發現。我們首先會向您介紹一位您未必聽過、課本上也未曾提及過，但在發現 DNA 結構上舉足輕重的英雄。此外，您有想過，在生物醫學和藥物研究方面，水母和樹皮能扮演著甚麼角色？組織再生和漫畫角色之間又可以有著甚麼關係？如果您是運動愛好者，我們亦會與您探討溜冰背後的物理原理。

您有看過我們的 Instagram 嗎？在那裡您會找到一些有趣圖片和之前數期《科言》文章的撮要。我們更希望在以後看到您們的佳作！快參加我們在 Instagram 舉辦的比賽，向大家分享您對科學的熱誠吧！ 每回合比賽將會有不同的主題。請把您拍攝的數碼相片，連同一個介紹相關科學故事的說明傳送給我們，詳情請參閱右頁的〈香港科技活動〉。

快拿出您的手機或專業相機拍照吧！

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WHAT'S HAPPENING IN HONG KONG ?

香港科技活動

Let Your Love for Science Flourish!

The cold winter has passed, and it's time for you to go out and have some fun in the following selected events with your family and friends in this spring!

盡情展現你對科學的喜愛！

寒冷的冬天已經過去，是時候趁著這個和暖的春天與家人朋友到處走走，一起參加以下精選活動吧！

HK SciFest 2019

The annual HK SciFest is back again! The theme this year is STEM (Science, Technology, Engineering and Mathematics) and a wide range of over 140 scientific activities will take place at the Hong Kong Science Museum and their partners over two weeks. Check out the Fun Science Carnival with your family and friends during the holidays. If you are a great fan of sci-fi movies, you can participate in the movie review program, Sci-Fi-Sci, to explore the science behind sci-fi movies! You will surely enjoy the SciFest while enhancing your understanding of science through these interesting activities!

Date: 12 April 2019 - 28 April 2019

Website: *hk.science.museum/scifest2019/*

香港科學節 2019

一年一度的香港科學節即將舉行！今年大會主題是「STEM」(科學、技術、工程和數學)。香港科學館及其合作伙伴會籌辦超過 140 項不同類型的科學活動供大眾參與。在假日不妨與家人或朋友到「玩轉科學嘉年華」逛逛；如果您是科幻電影的忠實粉絲，那您就不能錯過電影觀賞活動 ——「科幻有理」，與主持人一起發掘科幻電影中的科學。我們保證您能透過這些有趣活動加深對科學的認識，盡興而歸！

日期：2019年4月12日至
2019年4月28日

網址：*hk.science.museum/scifest2019/*

Science Focus Instagram Photo Competition

Science Focus is launching a brand new Instagram Photo Competition. We encourage local secondary school students to submit photos, with a caption in 100-200 words, to share interesting scientific stories. There will be multiple rounds in a year with different themes. Through this competition, we hope to spark curiosity, and spread scientific knowledge to a wide audience.

If you enjoy taking photos and love science very much, don't miss the chance to tell us the most interesting stories with your photos! You may win an instant camera or a HK$100 coffee card.

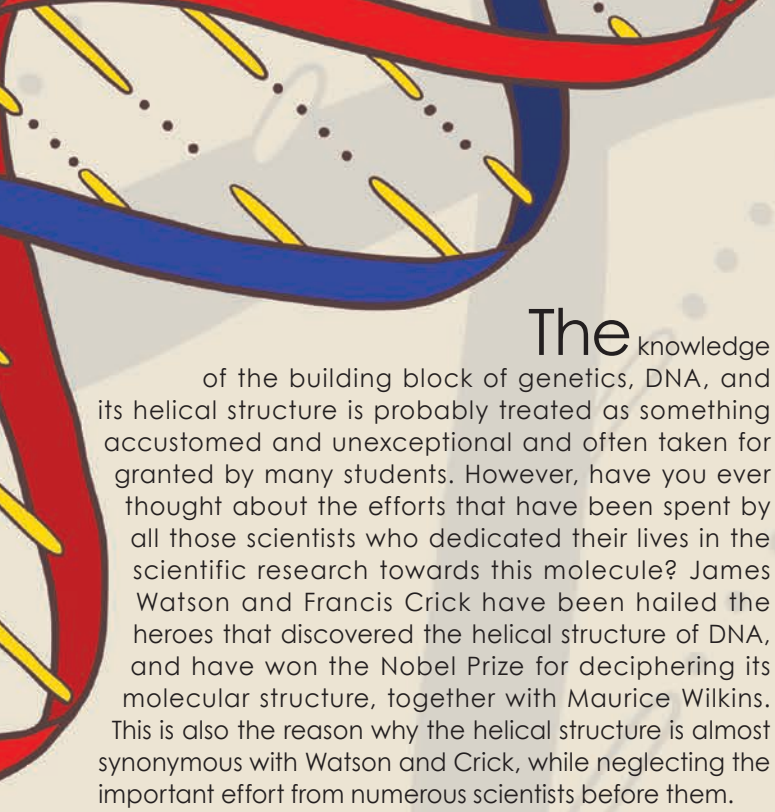
Visit our website to learn more about the competition: *http://sciencefocus.ust.hk/instagram-photo-competition*

《科言》Instagram 攝影比賽

《科言》現正舉辦全新的 Instagram 攝影比賽，我們歡迎各位香港中學生提交您的相片，連同一段 100-200 字的英文說明，分享一個與科學相關的有趣小故事。比賽會在一年間分為幾個回合，並各有不同主題。透過這個比賽，我們希望引發大家的對科學的好奇心，以及鼓勵大家分享科學知識。

喜歡攝影及熱愛科學的您又怎能錯過呢？把握這個機會與我們分享您的相片和最有趣的故事吧！您還有機會贏得即影即有相機乙部或 HK$100 咖啡卡乙張。

有關比賽詳情，請參閱我們網頁：
http://sciencefocus.ust.hk/zh-hk/instagram-photo-competition/



DNA 結構的無名英雄
The Hidden Figure of DNA Structure: ROSALIND FRANKLIN

By Clara Tung 董卓衡

The knowledge of the building block of genetics, DNA, and its helical structure is probably treated as something accustomed and unexceptional and often taken for granted by many students. However, have you ever thought about the efforts that have been spent by all those scientists who dedicated their lives in the scientific research towards this molecule? James Watson and Francis Crick have been hailed the heroes that discovered the helical structure of DNA, and have won the Nobel Prize for deciphering its molecular structure, together with Maurice Wilkins. This is also the reason why the helical structure is almost synonymous with Watson and Crick, while neglecting the important effort from numerous scientists before them.

There is a hidden heroine of DNA double helix model who deserves more recognition and respect from the public. Her name rarely appeared in high school textbooks – Rosalind Franklin. Franklin had a short yet legendary scientific research life. Her all-rounded scientific background with strong physics and chemistry knowledge and skills had helped her a lot in the process of unravelling the secrets of the DNA structure. However, several sources suggested that Watson and Crick have taken away Franklin's efforts without her knowledge and permission [1-3]. Let's figure out the real story of this "mother of double helix".

Born in an educated and socially conscious Jewish family in 1920, Rosalind Elsie Franklin was determined to be a scientist since she was 15. Her father strongly discouraged her interest as this was an uncommon and difficult career for women at that time. However, she excelled in her academic studies, specifically in science, at St. Paul's Girls' School, one of the few institutions at the time that taught physics and chemistry to girls. Later, she won a scholarship to study chemistry at the University of Cambridge in 1938, and received her Ph.D. in 1945. She then moved to the State Chemical Laboratory in Paris and studied the latest X-ray diffraction technology at that time. This technique was of paramount significance, which contributed towards the discovery of the DNA structure with the well-known X-ray image of DNA, Photo 51. It took Franklin hours and tons of hard work to obtain this image and the calculations in analyzing it [1].

有關遺傳學的重要組成部分 — 脫氧核糖核酸 (DNA)，以及其雙螺旋結構的知識大概已經被很多學生視為理所當然和平平無奇的東西。但你有沒有想過這些科學知識其實是一眾科學家日以繼夜地致力於科學研究的辛勞成果？James Watson 和 Francis Crick[1] 一直被譽為發現 DNA 雙螺旋結構的英雄，並與 Maurice Wilkins 一起因破譯 DNA 的分子結構而獲得了諾貝爾獎的殊榮，這就是為什麼當人們提及雙螺旋結構就會自然聯想到 Watson 和 Crick 的原因。眾多先於他們，而又對 DNA 結構提供了重要科學證據的科學家亦因而被遺忘。

DNA 雙螺旋模型的發現有著一位重要的無名英雄 — Rosalind Franklin，她的名字很少在高中的課本上出現，但她絕對值得獲取更廣泛的認同和尊重。Franklin 擁有一段短暫但傳奇的科學研究生涯。她全面的科學背景、物理和化學方面的深入知識和技能都幫助她其後解開了 DNA 結構的秘密。然而，種種跡象皆顯示 Watson 和 Crick 在沒有她的知情和許可的情況下，把她辛苦取得的數據和研究成果奪去 [1-3]。讓我們一起弄清楚有關這位「雙螺旋之母」的真實故事吧！

Rosalind Elsie Franklin 在 1920 年出生於一個受過良好教育且具有社會意識的猶太家庭，她早於十五歲時已立志成為一名科學家，但她遭到父親強烈勸阻，因為這對當時的女性來說是一個不尋常和困難的職業。然而，她仍在聖保羅女子學校 (St. Paul's Girls'

Franklin had gone through a lot of difficulties that were not only confined to science but also due to the conflict between her and her senior colleague, Maurice Wilkins. Suspiciously, Wilkins showed Photo 51 to Watson and Crick without Franklin's knowledge. Together with other Franklin's unpublished data obtained from Max Perutz, Crick's PhD thesis advisor, without Franklin's knowledge, Watson and Crick came up with the similar conclusion as Franklin. This led to the concurrent publication of their articles in the journal *Nature*, where Franklin's article was placed last, giving a misconception that her experiments were just a verification of Watson and Crick's discovery. According to Watson's book, *The Double Helix*, published in 1968, Watson admitted that their model was greatly inspired by Franklin's unpublished data. Without Franklin's key data, they might have proposed a wrong structure with bases pointing outwards [1]. However, not only didn't they acknowledge Franklin's contribution clearly and adequately in their journal articles published in 1953, but they also didn't acknowledge Franklin's contributions in the 1962 Nobel Prize ceremony [1].

> "We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M. H. F. Wilkins, Dr. R. E. Franklin and their co-workers at King's College, London." — The acknowledgment which is considered as an understatement extracted from Watson and Crick's 1953 *Nature* paper [4].

If the Nobel Prize could be awarded posthumously, Franklin would probably be recognized with the same level of honor as Watson and Crick. It is time to spread the hidden story of an intelligent brave woman who provided crucial clues for the double helix model. It is time to honor Rosalind Elsie Franklin, the unsung mother of the double helix.

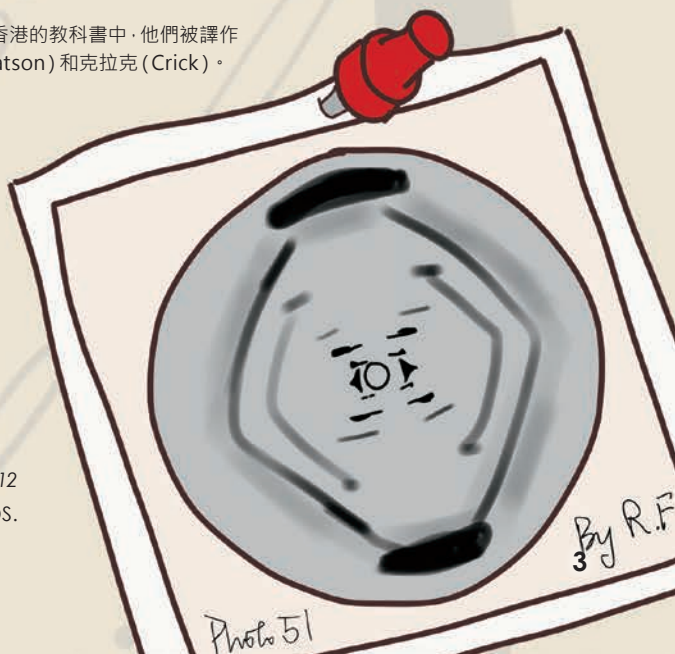
School) 中有著出色的學業成績，特別是在科學方面，而聖保羅女子學校是當時少數向女孩教授物理和化學的學校之一。後來，她獲取了一筆獎學金，使她可以在 1938 年到劍橋大學修讀化學，更於 1945 年取得博士學位。其後，她移居到巴黎，並有機會於國家化學實驗室學習當時最先進的 X 射線繞射技術 (X-ray diffraction technology)。這項技術對其後取得的著名 X 射線影像 —「第 51 號照片」至關重要，而正正就是因為這張照片，令科學家得以發現 DNA 的結構。Franklin 花費了不少心力和時間才能獲得這個圖像以及相關的計算結果 [1]。

Franklin 經歷了許多困難，她面對的困難不只局限於科學上，還有與其上級同事 Maurice Wilkins 之間的矛盾。可疑的是，Wilkins 在沒有通知 Franklin 的情況下向 Watson 和 Crick 展示了「第 51 號照片」。除此之外，Watson 和 Crick 同樣亦在 Franklin 不知情的情況下從 Crick 的博士論文指導老師 Max Perutz 中，取得 Franklin 其他未公開的數據，從而得出與 Franklin 相類似的結論。這導致他們的文章同時間刊登於《自然》(*Nature*) 雜誌，但基於 Franklin 的文章被編排在 Watson 和 Crick 之後，容易使人誤解為她的實驗結果只是為了驗證 Watson 和 Crick 的發現。在 Watson 於 1968 年出版的《雙螺旋》(*The Double Helix*) 一書中，Watson 承認他們當時提出的模型其實深受 Franklin 未發表的數據所啟發：如果沒有 Franklin 決定性的數據，他們便有可能提出一個鹼基指向外面的錯誤結構 [1]。不過，他們不僅沒有在 1953 年發表的期刊文章中清楚明確和充足地指出和承認 Franklin 的貢獻，也沒有在 1962 年諾貝爾獎頒獎典禮上感謝 Franklin 的貢獻 [1]。

> 「我們亦受到了 M. H. F. Wilkins 博士，R. E. Franklin 博士和倫敦國王學院研究人員的一些未公開發表的實驗結果和想法所啟發。」— 這一段取自 Watson 和 Crick 在 1953 年發佈於《自然》雜誌論文上的引文，普遍被認為是對於 Franklin 的貢獻過於輕描淡寫 [4]。

如果諾貝爾獎可以在得獎人死後追頒，那麼 Franklin 大概會得到與 Watson 和 Crick 齊名的認可和榮耀。該是時候把這位聰明又勇敢的女科學家的隱藏故事傳揚開去，是時候表彰為雙螺旋模型提供了重要線索的「雙螺旋的無名母親」— Rosalind Elsie Franklin。

[1] 編按：在香港的教科書中，他們被譯作華生 (Watson) 和克拉克 (Crick)。



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[1] Elkin, L. O. (2003). Rosalind Franklin and the double helix. *Physics Today, 56*(3), 42-48.

[2] Smith, K. N. (2018, April 16). Rosalind Franklin Died 60 Years Ago Today Without The Nobel Prize She Deserved. Retrieved from *https://www.forbes.com/sites/kionasmith/2018/04/16/rosalind-franklin-died-60-years-ago-today-without-the-nobel-prize-she-deserved/#61f35c879e77*

[3] Rosalind Franklin: A Crucial Contribution. (n.d.). Retrieved from *https://www.nature.com/scitable/topicpage/rosalind-franklin-a-crucial-contribution-6538012*

[4] Watson, J. D., & Crick, F. H. C. (1953). MOLECULAR STRUCTURE OF NUCLEIC ACIDS. *Nature, 422*(6934), 737-741.

If you want to study the crucial proteins related to cancer, aging, or Alzheimer's disease, or if you want to understand the neural developments in the brain…would you think of a jellyfish?

Most of you would say "No way! What do jellyfishes have to do with us?"

In a way you are right, jellyfishes are extremely different from humans, and won't be affected by many of our diseases.

But they do have a unique feature – they give off a bioluminescent[1] glow. This has intrigued scientists for decades – what exactly are the substances within these jellyfishes that create this effect?

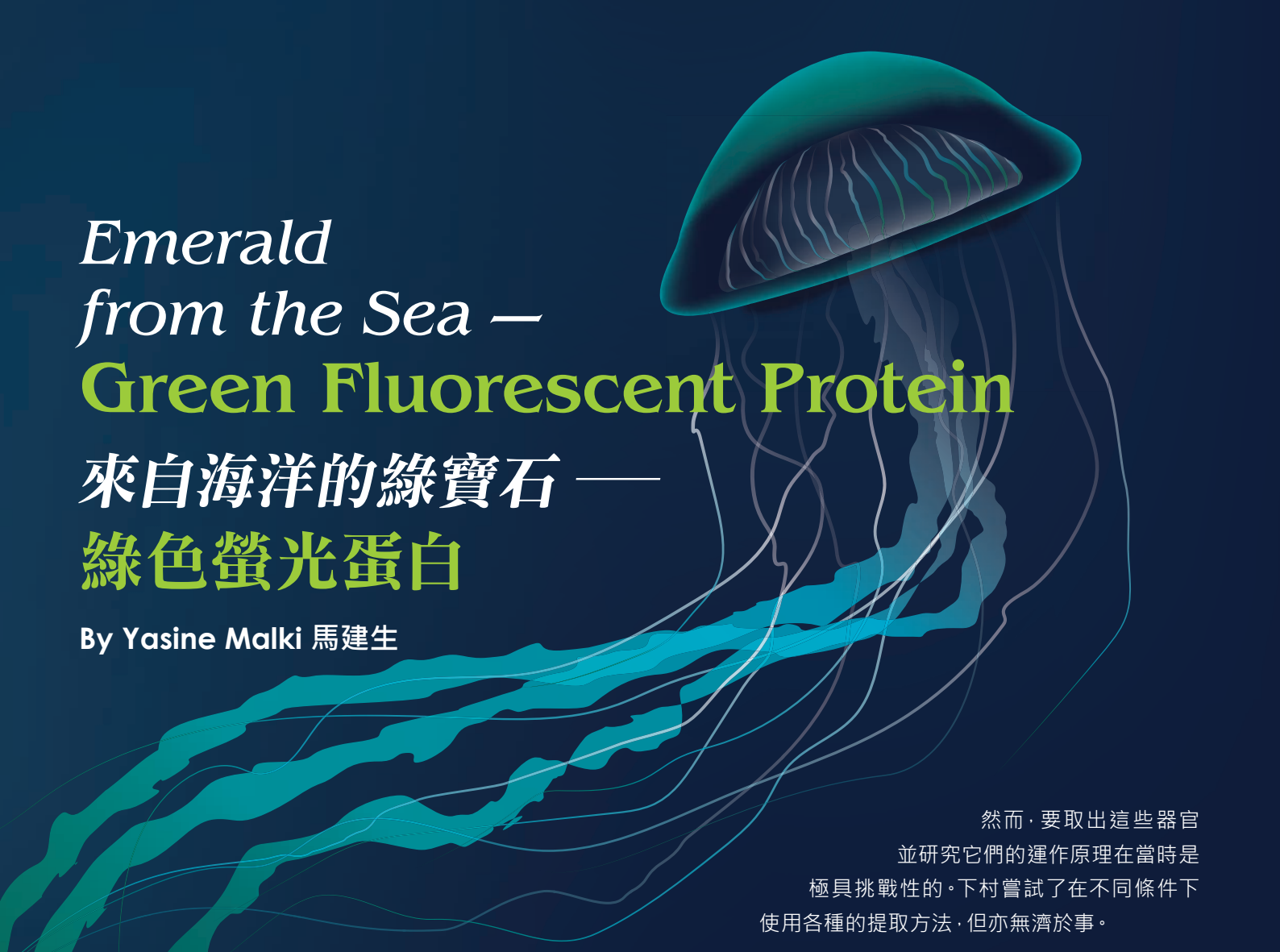
This is the story of a marine biologist and organic chemist, Osamu Shimomura. He has spent 19 summers with his colleagues, collecting millions of crystal jellyfishes, *Aequorea victoria*, from Friday Harbor in Washington [1]. These jellyfishes had rings of organs within their "umbrella" that generate green bioluminescence. However, isolating these organs and studying how they worked proved to be challenging. Shimomura attempted multiple extraction methods and conditions, but many were to no avail.

In one summer afternoon in 1961, Shimomura tested if a change in pH would affect the bioluminescent glow. Some pH levels triggered only a faint glow but not the intense glow he was looking for. Towards the end of the day, he tossed the remains of his unsuccessful experiment into a nearby sink, and that was when he saw the inside of the sink being lit up with "bright blue flashes" [2]. After noticing that this sink contained seawater drained from his fish tanks, this meant that something within the seawater had allowed for the remnants to emit light.

His research then made tremendous progress – after testing every component of seawater, he identified that calcium was a crucial factor for the bioluminescence. From there, he narrowed down the luminescent substance gradually to a single protein which he called aequorin [2] – the protein that emits blue light.

But this didn't account for why the jellyfish would glow green. That's when Shimomura hypothesized that there is another protein that coexists with aequorin, and is responsible for absorbing the higher-energy blue light, and using it to emit lower-energy green light. Further experiments proved his theory was correct. He narrowed down the source of the green glow, and subsequently discovered a fairly small but important protein – the green fluorescent protein (GFP) [3].

Another breakthrough came in 1987, when American microbiologist, Douglas Prasher, studied in detail the DNA and protein sequence of GFP. He proposed that GFP could be used to tag[2] proteins, by taking advantage of the genetics and protein production in a cell [4]. This would be a more practical way to study proteins, as most proteins are colorless and too small to be seen with microscopy techniques directly. If GFP could be linked to a target protein, followed by excitation with high-energy light, the target protein could be tracked within a cell by detecting the green fluorescence signal.



Emerald from the Sea — Green Fluorescent Protein

來自海洋的綠寶石 — 綠色螢光蛋白

By Yasine Malki 馬建生

如果你想研究與癌症、衰老或腦退化症相關的重要蛋白質，又或者如果你想了解大腦神經的發育 ..... 你會想到水母嗎？

大多數人會說：「沒可能吧！這跟水母又有什麼關係呢？」

在某種程度上這是正確的，水母與人類極為不同，而且不會受我們大部份的疾病影響。

可是它們確實擁有一個獨特的特徵 — 它們能發出生物光[1]。科學家對此沉醉了幾十年：到底是水母體內的甚麼物質使其發光呢？

這是一個關於海洋生物學及有機化學家 — 下村脩（Osamu Shimomura）的故事。他與同事花了十九個夏天在華盛頓的星期五港，收集了數以百萬隻水晶水母 — 維多利亞多管發光水母（*Aequorea victoria*）[1]。這些水母的「傘」內有一些環狀器官，能夠產生綠色的生物光。

然而，要取出這些器官並研究它們的運作原理在當時是極具挑戰性的。下村嘗試了在不同條件下使用各種的提取方法，但亦無濟於事。

1961 年的一個夏日午後，下村測試了酸鹼度對水晶水母生物光的影響。可是酸鹼值的變化僅引發微弱的光暈，但那不是他想尋找的強烈光芒。正當他收拾實驗用品準備下班前，他把實驗失敗後的殘餘物倒進水槽裡，然後看到水槽裡出現了「明亮的藍色閃光」[2]。他意識到水槽裡含有從他魚缸中排出的海水，這意味著海水中的某種物質能使殘餘物發光。

他的研究因而取得了重大的進展：在測試海水裡的每一種成分後，他發現鈣是令水晶水母發出生物光的關鍵因素。從那裡開始，他逐步發現發光物質為單一蛋白質，他稱之為「aequorin」（譯作水母發光蛋白或水母素）[2] — 發出藍光的蛋白質。

但是，這還沒有解釋為什麼水母會發綠光。那時下村假設還有另一種蛋白質與水母發光蛋白共存，負責吸收較高能量的藍光，並把它轉化為較低能量的綠光。進一步的實驗證明他的理論是正確的。他篩選了很多物質，發現綠光來自一種相當小但重要的蛋白質 — 綠色螢光蛋白（green fluorescent protein，簡稱 GFP）[3]。

For protein synthesis, the DNA sequence of a gene has to be transcribed into messenger RNA (mRNA), which is then translated into a polypeptide. Prasher imagined that it would be possible to use tools in molecular biology to insert the GFP gene right near the gene of interest. The cell would then produce a single molecule of fusion protein – the target protein is fused to the GFP – which ideally retains the original functions of both proteins.

Prasher's idea was made into reality by a professor in Columbia University, Martin Chalfie, and his wife Tulle Hazelrigg. Chalfie and his team were the first to incorporate GFP into other organisms. He first managed to express GFP in bacteria *Escherichia coli*, which produced a beautiful green pattern when grown on an agar plate. He then succeeded to light up a small number of neurons in the transparent nematode *Caenorhabditis elegans*, by expressing GFP in them. Hazelrigg employed her husband's techniques, and successfully studied numerous critical proteins in fruit fly development [5].

In the following years, biochemists Roger Tsien and other scientists made alterations, by introducing mutations to the original GFP. This results in many new versions of GFP, including some with greater brightness of green light emitted, and those that fluoresce different colors – like yellow fluorescent protein (YFP), enhanced cyan fluorescent protein (ECFP) [6]. Wait, did you notice that the colors near the red end of the spectrum are missing? Scientists discovered a red fluorescent protein, mRFP1, from mushroom anemone *Discosoma* after the discovery of GFP [7]. Tsien and other researchers then used the same technique to engineer the red fluorescent proteins so that variations of different colors, like cherry (mCherry) and orange (mOrange), are available [6]. This complete rainbow of fluorescent proteins allows scientists to label multiple target proteins simultaneously.

The potential applications of fluorescent proteins are enormous! It has now become regular practice to study the function and activity of countless proteins, especially those implicated for certain diseases. The true importance and potential of GFP were finally recognized in 2008 - Shimomura, Chalfie and Tsien were awarded the Nobel Prize in Chemistry [8].

And who would have thought that jellyfishes' exquisite glow would light the way in biological research?

Emerald from the Sea — Green Fluorescent Protein

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另一個重大突破出現在 1987 年，當時美國微生物學家 Douglas Prasher 詳細研究了 GFP 的 DNA 和蛋白質序列。他提出可以透過一些遺傳學上的技術，以及利用細胞合成蛋白質的機制，使 GFP 可以用於標籤[2]蛋白質 [4]。這將是對研究蛋白質十分實用的方法，因為大多數蛋白質都是無色的，並且因太小而不能用顯微技術直接觀察。如果 GFP 可以與目標蛋白連接，然後在有高能量的光把其激發的情況下，則可以透過檢測綠色螢光信號在細胞內追踪目標蛋白。

對於蛋白質合成，基因的 DNA 序列必須被轉錄成信使 RNA（mRNA），然後轉譯成多肽。Prasher 想像出可以利用分子生物學工具將 GFP 基因插入目標基因旁邊，然後細胞便會產生一個單一的融合蛋白 —— 目標蛋白與 GFP 融合。在理想情況下，產生的融合蛋白會保留兩種蛋白質原來的功能。

哥倫比亞大學教授 Martin Chalfie 和他的妻子 Tulle Hazelrigg 實現了 Prasher 的想法。Chalfie 和他的團隊最先成功應用 GFP 在其他生物上。他最初在大腸桿菌中表達 GFP，令其在瓊脂平板上生長時產生出美麗的綠色圖案。然後，他透過在秀麗隱桿線蟲（*Caenorhabditis elegans*）中表達 GFP，成功把其少量的神經元「點亮」。Hazelrigg 採用了她丈夫的技術，成功研究了果蠅發育中的許多的關鍵蛋白 [5]。

在接下來的幾年裡，生物化學家錢永健和其他科學家通過向原始 GFP 引入突變，把其「改造」。這創造了許多新版本的 GFP，當中有些能發出更高亮度的綠光，以及有些能發出不同顏色的螢光：黃色螢光蛋白（yellow fluorescent protein; YFP）、增強藍綠色螢光蛋白（enhanced cyan fluorescent protein; ECFP）[6] 等。但是，您是否注意到光譜中近紅色的顏色丟失了？在發現 GFP 後，科學家亦發現了一種來自蘑菇珊瑚 *Discosoma* 的紅色螢光蛋白 mRFP1 [7]。然後，錢教授和其他研究人員使用相同的技術來「改造」紅色螢光蛋白，以得到更多不同顏色的螢光蛋白，如櫻桃紅（mCherry）和橙色（mOrange）[6]。色彩齊備的螢光蛋白使科學家能夠同時標記多種目標蛋白。

螢光蛋白的應用範圍可大了！現在已被慣常地用於研究無數蛋白質的功能和活性，特別是那些與疾病相關的蛋白質。GFP 的真正重要性和潛力最終在 2008 年得到認可：Martin Chalfie、下村脩和錢永健被授予該年度的諾貝爾化學獎 [8]。

誰會想到水母的精緻光芒會照亮生物研究的道路？

來自海洋的綠寶石 —— 綠色螢光蛋白

[1] Bioluminescence: Emission of light by a living organism
生物光：生物體的發光現象

[2] Tag: To add a label to a molecule so it can be detected and traced
標籤：為分子添加記號，以便檢測和追踪

Taxol
— The Pathway to Cancer Treatment?
紫杉醇 — 從自然而來的癌症良藥?

By Yasine Malki 馬建生

Cancer is often regarded as a grim and dreadful state of human health in our modern society – with millions of new diagnoses annually; statistics estimated that more than one in three people will develop cancer at some stages of their lives [1]. Cancer is a group of diseases that commences when certain cells start mixing up signals and instructions, causing the cells to grow and divide abnormally, with the potential of spreading throughout the body causing numerous complications. Although a lot remained unknown regarding its mechanism, scientists work extremely hard to save the lives of as many patients as possible! And of course, they would always be hoping to discover a substance to "cure" cancer....

In the early 1960s, the American National Cancer Institute (NCI) initiated a wide anti-cancer screening, where they analyzed thousands of plant species for their ability to stop tumor[1] growth. One source that displayed promising activity against cancer was the stem and bark of Pacific yew trees, *Taxus brevifolia*. Drs. Monroe Wall and Mansukh Wani's team at the Natural Products Laboratory spent years concentrating and purifying the active anti-cancer component, with repeated careful organic solvents partitioning. Eventually, in 1967, they managed to collect a pure form of the active ingredient[2] – a very complex, non-polar molecule, which they named paclitaxel, later known by its tradename Taxol [2].

The NCI carried out further testing to study the anti-cancer activity of Taxol during the next 10 years. It was found to be a very potent substance, showing significant activity against lung, ovarian and mammary cancers, at various stages of progression when tested in mice [3]. Furthermore, Dr. Susan Horwitz of Yeshiva University revealed that Taxol works by targeting rapidly dividing cells, getting inside of them and attaching to a tubular scaffold structure called microtubules, preventing the cells from dividing [4].

It seems to be going so well! Taxol stops the division of cancer cells, which could counter the rising cases of cancer, however...

In 1983, further experiments with Taxol were halted quickly due to a shortage of supplies. In fact, Taxol is found only in small amounts in nature, and along with many difficulties in harvesting and extraction – only 0.5 g of Taxol was isolated from 12 kg of Pacific yew tree samples (equivalent to 0.004 % yield), requiring the removal of six 100-year old trees to treat one patient [5]. On top of that, these trees are amongst the slowest growing trees in the world and were already on the brink of extinction. Complete chemical synthesis was not commercially viable – Taxol has a very complex structure, requiring 35 to 51 steps for its total synthesis, resulting in a low yield (0.4 %) and very high costs [6, 7]. This pressured scientists to find more efficient ways to obtain Taxol.

在現今社會，癌症一向被認為是對人類健康來說一場可怕，而又令人絕望的橫禍。可是，每年卻有數以百萬計的人被確診；統計指出約每三個人中，便有多於一個人會在其生命的後半部分罹患癌症 [1]。癌症泛指一組疾病，起初由某些細胞把信號和指令搞亂，令其不正常地生長和分裂，最後更有可能擴散至全身並引起不同的併發症。雖然我們對癌症發病機制的認識尚未全面，科學家依然盡其所能把最多的病人拯救。其中一個關鍵是對新藥的研發。

在上世紀六十年代初，美國國家癌症研究所展開了一個大型抗癌藥物篩檢計劃，他們測試了數以千計植物對於防止腫瘤[1]增生的能力。其中，一個樣本展示了為對抗癌症帶來希望的效用：那是太平洋紫杉 (*Taxus brevifolia*) 的樹幹和樹皮。Monroe Wall 博士和 Mansukh Wani 博士在自然製品研究所的研究團隊花了很長的時間，小心翼翼地用不同的有機溶劑反覆進行分配 (partitioning)，嘗試濃縮和提取樣本中抗癌的活性成分[2]。終於，他們成功在 1967 年提取出當中的活性成分 —— 一個結構非常複雜、非極性的分子，他們稱之為 paclitaxel (紫杉醇)，後來以商標 Taxol (汰癌勝) 作銷售名稱而為人認識 [2] [編按：紫杉醇在中文較為常用]。

在其後十年，國家癌症研究所對紫杉醇的抗癌能力作進一步評估。紫杉醇被發現擁有強大的效用；在老鼠測試中，紫杉醇對不同階段的肺癌、卵巢癌和乳腺癌均起顯著的作用 [3]。此外，葉史瓦大學 (Yeshiva University) 的 Susan Horwitz 博士發現紫杉醇發揮作用的方式是透過進入細胞，並附在被稱為微管 (microtubule) 的細胞管狀支撐結構上，阻止細胞分裂，因此對快速分裂中的癌細胞尤其有效 [4]。

一切都似乎十分順利，紫杉醇能阻止癌細胞的分裂，阻止癌症的惡化，可是……

在 1983 年，紫杉醇的研究因其供應量不足而被迫停止。事實上，我們只能在自然界中找到少量的紫杉醇，而且提取過程十分困難 — 12 公斤的太平洋紫杉樹只能提供 0.5 克的紫杉醇 (產量相等於 0.004 %)，治療一個病人需要伐掉六棵百年老樹 [5]。更甚的是，太平洋紫杉是世界上長得最慢的樹之一，而且瀕臨絕種的邊緣。完全由化學方式來合成紫杉醇在商業上並不可行，因為紫杉醇的結構極之複雜，全合成 (total synthesis) 需要 35 至 51 步，這會令產量變得極低 (0.4 %) 以及成本變得極高 [6, 7]，因而迫使科學家尋找更有效的方法取得紫杉醇。

紫杉醇合成的主要突破出現在八十年代後期，當時一間名為 Polysciences Inc. 的公司提出了一個可持續、大型生產紫杉醇的方法。當中涉及提取紫杉醇在自然界中的前驅物 (precursor)[3] — 10-脫乙酰基巴卡亭 III (10-deacetylbaccatin III)。10-脫乙酰基巴卡亭 III 可以從一種較容易培植，而且數量較多的歐洲紫杉 (*Taxus baccata*) 中提取，過程不需要把樹砍掉 [3]。10-脫乙酰基巴卡亭 III 可以較容易地被轉化成紫杉醇，因為合成的過程不需要由零開始。總的來說，相比起直接從太平洋紫杉中提取紫杉醇，這種被稱為半合成的方法可以把紫杉醇的提取產量提升 50 倍，而且是個可再生和更環保的方法 [8]。

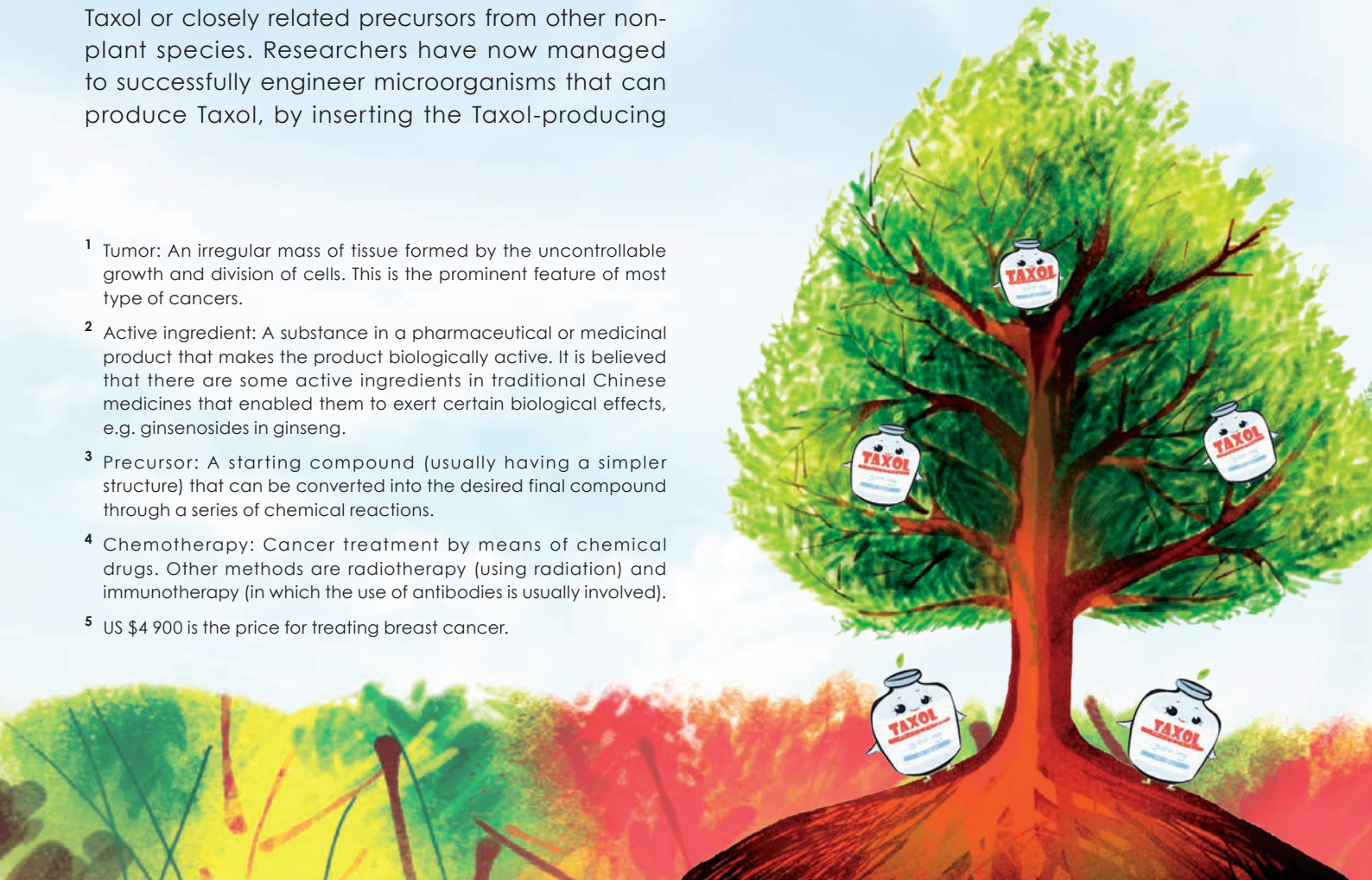
生物科技上的發展甚至讓科學家可以嘗試從其他非植物物種中製造紫杉醇、或與其相關的前驅物。科學家現在可以透過基因工程，把一些參與合成紫杉醇的基因，從包括太平洋紫杉在內的紅豆杉 (*Taxus*) 屬移至一些微生物，例如大腸桿菌 (*Escherichia coli*) [6] 和一些真菌 [9, 10]，令其生產出紫杉醇。

Taxol — The Pathway to Cancer Treatment?
紫杉醇 — 從自然而來的癌症良藥？

A major breakthrough in Taxol synthesis was made in the late 1980s, when Polysciences Inc. proposed a method of sustainable, large-scale production. This involved the isolation of a natural precursor[3] to Taxol, called 10-deacetylbaccatin III, from the more easily cultivated and abundant European yew tree, *Taxus baccata*, and without needing to kill the trees [3]. 10-Deacetylbaccatin III could then be converted to Taxol in a relatively easy manner, without synthesizing from scratch. Overall, this approach, known as semisynthesis, had a 50-fold increase in purification yield, and is far more renewable and environmentally friendly compared to extracting Taxol directly from the Pacific yew [8].

Further advancements in biotechnology enabled scientists to make attempts to produce Taxol or closely related precursors from other non-plant species. Researchers have now managed to successfully engineer microorganisms that can produce Taxol, by inserting the Taxol-producing genes from the genus *Taxus* into microorganisms such as the bacterium *Escherichia coli* [6] and various fungi [9, 10].

With the help of scientists from multiple disciplines, Taxol has gone from being extremely scarce, and possibly endangering Pacific yew trees; to now being produced efficiently by fermentation and semisynthesis, and is being prescribed worldwide for chemotherapy[4] to treat breast, ovarian and lung cancers, at a price of around US$ 4 900 per patient[5] [11]. These approaches in the Taxol story may be extended to other herbal drug molecules, providing opportunities to make treatments more readily available and affordable.



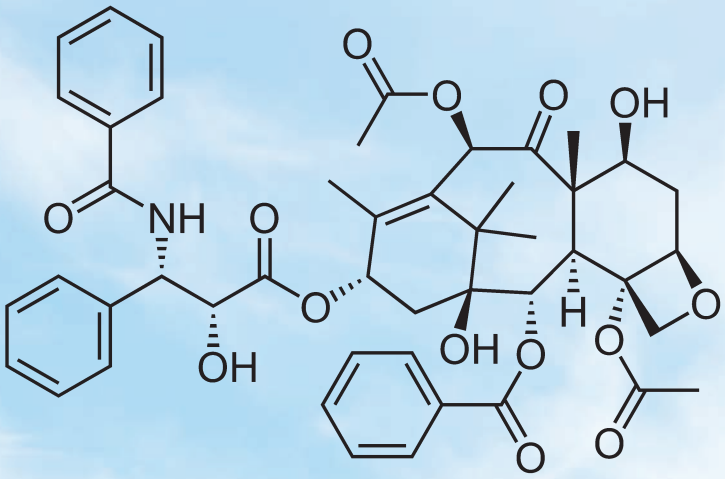
[1] Tumor: An irregular mass of tissue formed by the uncontrollable growth and division of cells. This is the prominent feature of most type of cancers.

[2] Active ingredient: A substance in a pharmaceutical or medicinal product that makes the product biologically active. It is believed that there are some active ingredients in traditional Chinese medicines that enabled them to exert certain biological effects, e.g. ginsenosides in ginseng.

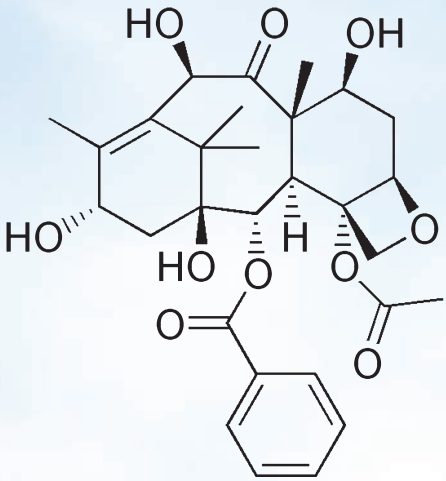
[3] Precursor: A starting compound (usually having a simpler structure) that can be converted into the desired final compound through a series of chemical reactions.

[4] Chemotherapy: Cancer treatment by means of chemical drugs. Other methods are radiotherapy (using radiation) and immunotherapy (in which the use of antibodies is usually involved).

[5] US $4 900 is the price for treating breast cancer.



Taxol
紫杉醇



10-Deacetylbaccatin III
10-脫乙酰基巴卡亭 III

在不同領域科學家的合作之下，紫杉醇由最初極為稀有，其提取甚至可能令太平洋杉樹瀕臨絕種，到今天可以透過發酵和半合成有效地生產，在定價僅為每患者 4900 美元[4]的價錢下被全球廣泛地用作治療乳癌、卵巢癌和肺癌的化療[5]藥物 [11]。紫杉醇的故事相信可以作為其他科學家的借鑑，把當中的方法嘗試利用於生產其他從植物而來的藥物分子上，令更多藥物變得垂手可得和實惠相宜，使這個傳奇得以延續。

[1] 腫瘤：因細胞不受控制地生長和分裂而形成、形狀不規則的一團組織。這也是大部分癌症的明顯特徵。

[2] 活性成分：一些存在於藥物或藥用產品內，令其在生理上帶來藥效的物質。科學家相信很多中藥藥材均含不同的活性成分，令其可在身體內發揮相應的效用，例如人參含有人參皂苷 (ginsenosides)。

[3] 前驅物：在一連串化學作用中起始的化合物。它通常具有較簡單的結構，在化學作用後會被轉化成最終的目標產物。

[4] 4 900 美元為用作治療乳癌時的價錢。

[5] 化療：指利用化學藥物治療癌症，是現時癌症的治療方法之一，其他方法包括放射治療 (俗稱「電療」，即使用放射線) 和免疫療法 (很多時涉及使用抗體)。

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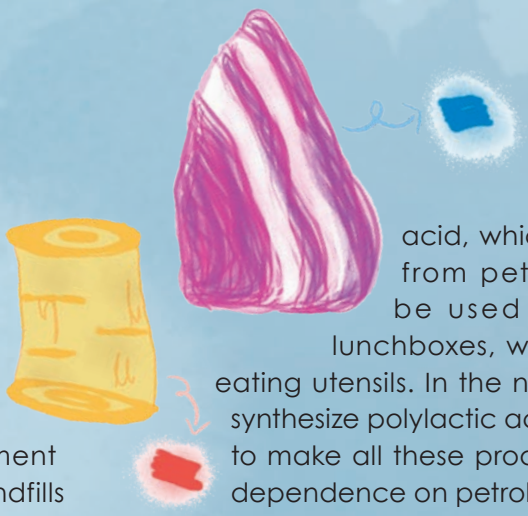
Food waste generally refers to uneaten, discarded food. It seems that no matter how hard we try to make full use of food and avoid generating food waste with our personal effort, municipal food waste is still unavoidable. According to the latest data from the Environmental Protection Department in 2017 [1], the solid waste disposed in the landfills in Hong Kong weighs up to 10 733 tonnes daily, of which nearly 34% is food waste, weighing up to 3 662 tonnes. With the amount of food waste on the rise, there is an urgent need for novel solutions to alleviate this problem.

There are many recent discoveries on new uses of food waste, including textiles manufacturing and dyeing. This also provides innovations to green fashion, which is no longer limited to organic cotton or organic silk. Dr. Carol Lin, an assistant professor from the School of Energy and Environment of the City University of Hong Kong, leads her team in the research on synthesizing textile by extraction and conversion of useful materials in food waste [2].

Firstly, the team collects food waste from fast food shops, supermarkets and bakeries. They then apply fungal hydrolysis[1] to the collected food waste, through which the food is broken down into glucose, free amino nitrogen, vitamins and minerals. This step also transforms solid food waste into liquid which will give a brownish yellow color after precipitation.

Next, the team makes use of bacterial fermentation[2] to produce lactic acid from food molecules, and further generate polylactic acid (PLA) through polymerization[3]. With the technique of melt spinning, lactic acid fiber can be obtained. With additional steps, the brownish yellow thread can be transformed into white, fine thread. The team succeeded in turning 100 grams of food waste into 10 grams of lactic acid fiber within a week.

This discovery is exciting for several reasons. First of all, this process can reduce the solid waste being sent to the landfills. Besides, this method has a low production cost as food waste is readily available. At the same time, the equipment involved is neither complicated nor expensive, so it can provide environmentally friendly, economical raw materials to the textile industry. On the other hand, polylactic acid, which currently comes from petroleum, can also be used to manufacture lunchboxes, wrapping bags and eating utensils. In the near future, we can synthesize polylactic acid from food waste to make all these products, reducing our dependence on petroleum.



Apart from manufacturing thread, food waste can be used to produce dyes as well. The campaign of using food waste in cloth dyeing was started by a food designer, Eric Cheung, a graduate from the Open University of Hong Kong. Eric and a group of teenagers have been picking the leftover vegetables from piles of waste, recycling vegetables discarded by the greengrocers and coffee grounds from cafes. With the food waste as dyes, the teenagers have produced colorful fabrics using a traditional tie-dye technique. In fact, the vegetables that they collect from the greengrocers are the ones with only minor flaws or cracks on the surface. Eric thinks that it would be a waste if they are sent to the landfills and therefore decided to receive them. Eric's group would then extract the pigments from the food waste by a series of steps, including sterilizing, air-drying and squeezing the food. The color of the fabric can be adjusted by altering different parameters of the dyeing process, including duration and pH. For instance, the purple cabbage turns into blue upon addition of baking soda; but turns into dark pink upon addition of vinegar. Therefore, food waste can indeed be used to create a rich color palette.

Power generation is no longer the only way to fully utilize food waste. In the future, you may find models wearing "food waste" down the catwalk. If scientists succeed in scaling up the production of textile from food waste, it should partially relieve the pressure on landfills. This would also bring good news to the textile industry and environmentalists.

[1] Hydrolysis: The chemical breakdown of some more complicated, larger molecules to simpler, smaller molecules. Water is required in the reaction.

[2] Fermentation: The catabolic reaction that breaks down larger molecules into smaller molecules by microorganisms.

[3] Polymerization: The process of connecting many monomers to form larger polymers which consist of the monomers as repeating units.

Putting On Food Waste

把廚餘穿在身上

By Melody Ma 馬嘉怡

廚餘，泛指未經食用而被丟棄的食物。然而，不論我們如何在日常生活「惜食」或盡用食材，都市廚餘還是避無可避。根據環保署 2017 年的最新數據 [1]，香港每天所棄置在堆填區的固體廢物高達 10 733 公噸，當中近三成半 (34%) 都是廚餘，達 3 662 公噸，佔各種固體廢物中最高比例。廚餘數量越來越多，我們需要儘快找出一些創新的方法，解決廚餘過盛的問題。

近年，有不少活用廚餘製衣或染布的新發現，為廚餘提供堆填區以外的新出路，也令環保時尚不再局限於有機棉或有機絲。香港城市大學能源及環境學院助理教授連思琪博士率領她的研究團隊，利用新技術使廚餘不再只是廢料，而是透過重新提煉及轉化變成製衣材料 [2]。

連博士的團隊首先從快餐店、超市及麵包店收集廚餘。其後，團隊利用真菌把收集得來的廚餘進行水解[1]，把食物分解成葡萄糖、游離氨基氮、維他命及礦物質。這個步驟會將固體廚餘變成液態，這些液體會於沉澱後變成啡黃色。

接著，團隊用細菌把這些分解出來的食物分子進行發酵[2]，形成乳酸，並透過聚合作用[3]形成聚乳酸 (PLA)。最後，團隊運用一種名為熔融紡絲技術的方法，將聚乳酸紡織成乳酸纖維。這些纖維是一條條像紡紗一樣幼、呈啡黃色的線，經過加工後會變為雪白的紗線。連博士的研究團隊成功在一星期內，將 100 克廚餘轉化為 10 克聚乳酸纖維。

這項研究相信能為社會各方帶來不少好處。首先這個過程可大大減少送往堆填區的固體垃圾。同時，這種用廚餘製成紗線這種做法成本不高，因為廚餘本身垂手可得，而使用的器材既不複雜也不算昂貴，因此能經濟地為紡織界提供環保的原料。再者，聚乳酸亦被應用於製造餐盒、包裝袋和餐具；現時聚乳酸一般來源於石油，但未來我們可以利用廚餘合成聚乳酸，減少我們對石油的依賴。

除了用廚餘製成紗線，廚餘更可用作染料，這種做法由一位從香港公開大學畢業的食物設計師張駿霖發起。一群包括他在內的年輕人嘗試把剩菜從垃圾堆撿出來，又從菜商和咖啡店回收棄置的蔬菜和咖啡渣，把這些廚餘用作染料，利用傳統的紮染技術把布料染出色彩。當中所回收的瓜果蔬菜其實只是長得不完美或有一些裂痕，直接送往堆填區只會造成浪費，所以張駿霖決定接收它們，為其帶來價值。他成立的染坊會收集這些廚餘，然後進行一系列的步驟，包括消毒、風乾及壓榨等，提煉出食物的色素。浸染的顏色可以透過控制浸染的時間、染料的酸鹼度等方法調節。比如說，紫椰菜加上了梳打粉會變成藍色，但是加上醋卻會變成深粉紅色。因此，廚餘幾乎可變出所有顏色的染料，非常有趣。

發電已經不再是唯一可以完全利用廚餘的方法，在不久的將來，你可以會看見時裝模特兒穿著一身「廚餘」在天橋上大放異彩。如果科學家能找到方法把廚餘大規模地用於製衣，這應該可以有助舒緩堆填區的部分壓力，同時亦為紡織業和環保人士帶來喜訊。

[1] 水解：即把較複雜及較大的分子分解成較簡單及較小分子，水解過程需要耗用水。

[2] 發酵：利用微生物把更大的分子代謝為較小的分子

[3] 聚合作用：即把多個單體分子連結成一個由其重複而組成的較大分子

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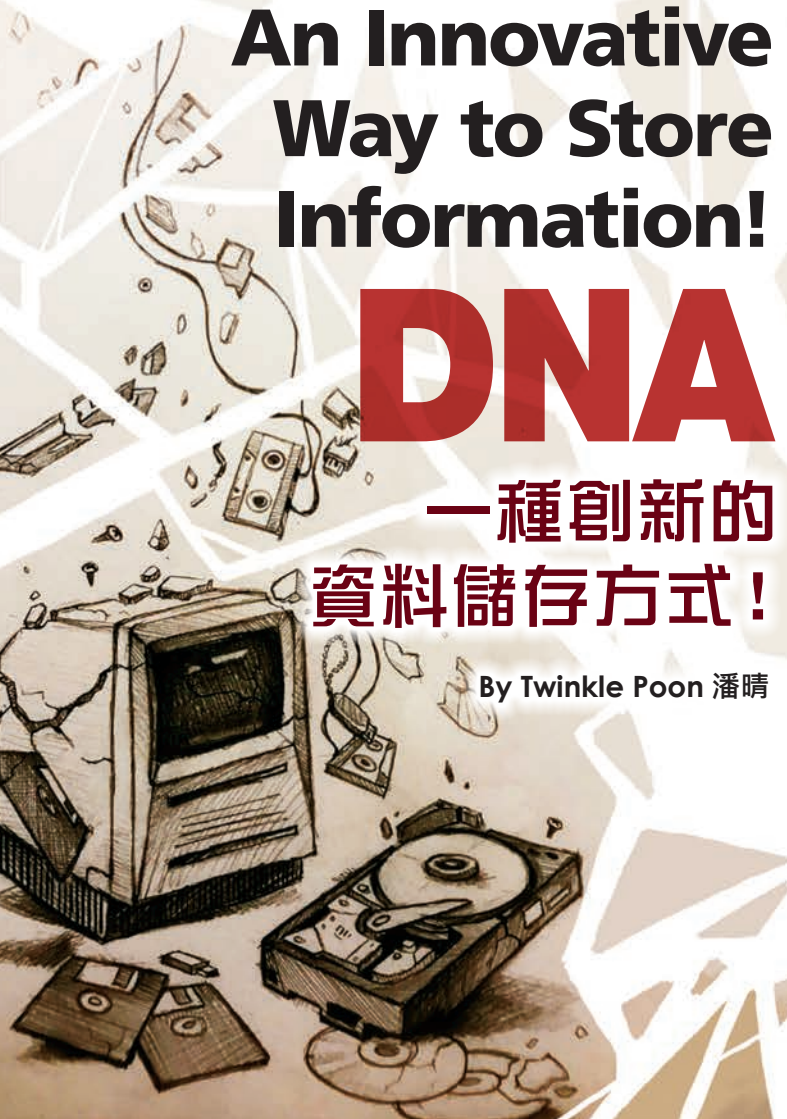
An Innovative Way to Store Information!

DNA

一種創新的資料儲存方式！



By Twinkle Poon 潘晴

Our ancestors have recorded and preserved their knowledge and history through characters and materials like bones and papers. However, is there a better way to do so in the 21st century?

It is true that we can store information in a printed or a digital version. However, printed paper will eventually decompose; computers may break down and the hard drives may fail. About two decades ago, scientists realized that "deoxyribonucleic acid" can overcome all these physical hurdles and properly store information.

Deoxyribonucleic acid, also known as DNA, is the fundamental molecule for storing genetic information. DNA is made of four organic bases: Adenine (A), Guanine (G), Cytosine (C), and Thymine (T). In nature, these bases are arranged sequentially to store and provide instructions to our cells to make proteins, which then control many functions and features of an organism. Scientists wondered whether these "genetic characters" can be utilized to create secret messages in DNA cryptography, in order to effectively store information.

DNA cryptography can encode much more than simple text. By translating the 1's and 0's of binary code into DNA code, digital data can be programmed into synthetic DNA, which can then be decoded back into its original form. Since this form of information storage allows a large degree of parallelism[1], the computing speed for DNA encoded information could reach 1 billion times per second. Moreover, DNA molecules have a high storage density: one gram of DNA can encode 215 petabytes (PB; *i.e.* 215 000 TB) of data.

In 2012, UK scientist Nick Goldman encoded a total of 739 kilobytes of different file types (ASCII, PDF, JPEG and MP3) into strands of DNA. The content encoded includes all 154 Shakespeare sonnets, the classic 1953 Watson and Crick DNA structure paper, a color photograph of the European Bioinformatics Institute, and a 26-second excerpt from Martin Luther King's *I Have a Dream* speech. Goldman held the record for the amount of information encoded in DNA until April 2016, when researchers at Microsoft and the University of Washington broke the record by capturing a whopping 200 megabytes (MB) of data with the help of binary coding. In their ground-breaking feat,

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我們的祖先透過文字和不同的物料，例如骨頭或紙張等，把他們的知識和歷史記錄，並保存下來。但是在 21 世紀，我們能找到一些更好的方法嗎？

我們的確可以把資料儲存在印刷本或電腦系統，但是，紙張終究會分解、電腦可能會失靈、硬碟也可能會故障。大約在二十年前，科學家們意識到「脫氧核糖核酸」可以克服以上所有的物理障礙並妥善保存資料。

脫氧核糖核酸，也稱為 DNA，是儲存遺傳信息的重要元素。DNA 由四種鹼基組成：腺嘌呤 (A)，鳥嘌呤 (G)，胞嘧啶 (C) 和胸腺嘧啶 (T)。在自然界中，這些鹼基會連續排列成一序列，以保存及提供細胞製造蛋白質的指令，從而控制生物身體上的多種特徵和運作。科學家希望了解這些「基因字元」是否可以用於 DNA 密碼學，創造出加密信息，以便有效地儲存資料。

DNA 加密法又豈止能把簡單文字編碼？通過將 1 和 0 的二進制代碼翻譯成 DNA 密碼，便可以把數據寫入合成 DNA 中，及後可以把其解碼回原來的二進制代碼。這種資料儲存方式容許很大程度的平行性 [1]，因此 DNA 訊息的計算速度可以達到每秒 10 億次。此外，DNA 分子具有很高的儲存密度：1 克 DNA 可以編碼 215 PB（即 215 000 TB）的資料。

they encoded the Universal Declaration of Human Rights in over 100 languages; a seed database; and the top 100 books of Project Gutenberg, in strings of DNA.

Since modern day hard drives have limited storage capacity, DNA stands out because of the massive amount of information it can hold in a tiny space. As mentioned above, the current theoretical limit of DNA's storage capacity is 215 000 TB in a single gram of DNA. It is conceivable that we could store the entire world's data in one single room thanks to DNA.

Information in computers and the magnetic tapes and discs can last at most a few decades before they break down. In contrast, DNA has a half-life of 500 years; in other words, DNA takes 500 years for half of it to degrade. DNA could potentially be preserved for hundreds of thousands of years if it is stored in a cold and dark atmosphere.

Scientists are also trying to find a "super-container" to host the DNA. Nicknamed Conan, the super-bacterium *Deinococcus radiodurans* can survive in various extreme environments, and therefore is one of the candidates. It is reported that Conan can withstand high doses of radiation and survive in a vacuum environment for six years. Scientists have successfully placed a song's lyrics into the Conan's genome. The only concern is that random mutations may occur, causing the saved information to be corrupted.

One day, we may be able to create a living container which stores all the knowledge in the world. We can hide it in our own room. Perhaps one day, the hidden data can reach outer space! Even though we might one day disappear, our legacy can still live on.

[1] It means that various information stored in the densely packed DNA can be processed at the same time, instead of piece by piece in a series.

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2012 年，英國科學家 Nick Goldman 將 739 KB 的不同檔案（ASCII、PDF、JPEG 和 MP3）編碼成 DNA 鏈。編碼的內容包括 154 首莎士比亞十四行詩、1953 年 Watson（華生）和 Crick（克拉克）的經典 DNA 結構論文、歐洲生物資訊研究所的彩色照片，以及 Martin Luther King（馬丁路德金）「我有一個夢想」演講的 26 秒摘錄。Goldman 因此打破了利用 DNA 儲存最多資料的記錄，直到 2016 年 4 月，紀錄才被微軟和華盛頓大學的研究人員再次打破，他們在二進制編碼的幫助下，用 DNA 記錄了高達 200 MB 的資料。在這個更具突破性的壯舉中，他們成功把 100 多種語言的「世界人權宣言」、一個種子資料庫和古騰堡計劃中首一百位的書籍寫進 DNA 鏈內。

現代硬碟的有限儲存容量是 DNA 可以脫穎而出的原因。DNA 可以在極小的空間內容納大量信息，上文曾經提及，在一克 DNA 中，目前理論上最多可儲存資料為 215 000 TB。可以想像得到的是：靠著 DNA，我們可以將整個世界的資料儲存在一個細小的房間裡。

電腦、磁帶和光碟內的資料最多也只能保存數十年。相比之下，DNA 的半衰期為 500 年，換句話說，DNA 需要 500 年的時間才會被降解一半。如果將 DNA 儲存在寒冷和黑暗的環境下，DNA 更有可能可以把資料保存數十萬年。

科學家們也在努力尋找一種能夠保存 DNA 的「超級容器」。綽號「柯南」(Conan)，一種名為耐輻射奇異球菌 (*Deinococcus radioduran*) 的超級細菌可以在各種極端環境中存活，因此成為候選的「超級容器」之一。研究指出，柯南可以承受高劑量的輻射，並在真空環境下存活六年。科學家們亦成功將一首歌的歌詞放入柯南的基因組中，但唯一的問題是隨機突變可能會導致保存的資料受到破壞。

或許有一天，我們能夠創造一個「生物容器」，把世界上所有知識都儲存起來。我們可以把它藏在自己的房間裡。又可能有一天，你所收藏的資料能夠到達外太空！即使我們可能有一天會消失，但我們的歷史、文化和知識仍可能會繼續被保存下來。

[1] 這是指密集地儲存在 DNA 內的各種信息可以被同時處理，而不是一件一件地逐一處理。

Ice-Skating **is a common leisure activity that usually takes place at large shopping malls. I believe many of you must have skated before. However, have you ever wondered why we can move freely on ice with a pair of ice skates? What are the mechanisms and theories behind? Let us explore!**

Extraordinary Science: The Mechanism of 科學不一樣：

You may have heard of "solid-liquid phase equilibrium" when you studied thermodynamics at school [1]. As shown in ***Figure 1***, you may notice from the phase diagram that the freezing point (*i.e.* the melting point; the red line in ***Figure 1***) of water decreases as the pressure increases. As we skate, the contact area between the blade and the ice surface is very small, and the body weight would concentrate on that contact surface. This exerts a great pressure to the ice surface (greater than the standard atmospheric pressure, *i.e.* 1 atm, or 101 325 Pa in SI unit), and allows the ice in the ice rink to melt, even when the temperature is lower than 0 °C. In this case, the friction between us and the ice becomes especially small, akin to having a thin layer of water as lubricant. We can therefore skate freely on ice.

Nevertheless, if it's true, why wouldn't all the ice in the ice rink turn into water when there were a lot of skaters? This is because the pressure exerts on the ice surface would return to normal after the blade passes. As a result, the freezing point would return to 0 °C, which is the one under standard atmospheric pressure again. The water membrane freezes again and the ice rink won't become a pool of water.

The description above sounds reasonable, based on what we've learned from school. However, investigations by many physicists revealed that the mechanism of skating was much more complicated, which could be explained in more than one way.

According to the article, "Pressure Melting and Ice Skating", published by a geophysicist, Samuel Colbeck in 1995 in the *American Journal of Physics*, the decrease in friction could not be due to high pressure-induced reduction of the freezing point. He explained that at 0 °C, for every additional pascal of pressure exerted, it would only cause a decrease of 7.37×10^{-8} °C in the melting point of water, due to the pressure-melting effect. Therefore, if we are skating on a -1 °C ice surface and we want to lower the melting point to -1 °C, by calculation, a pressure of 1.4×10^{7} Pa (around 140 atm) is necessary. Assuming that the contact area between the blades and the ice surface is 10 cm^2, to exert the equivalent pressure [2], the weight of the skater must reach 1400 kg. We clearly know that it's impossible, and that's why the melting caused by pressure change is not a convincing reason to explain why we can skate freely on ice.

溜冰，一個常見於各大商場的休閒運動，相信很多讀者皆有溜冰的經驗吧？那麼，請問你們有曾經想過，為什麼穿著冰刀的我們可以輕鬆地在冰上滑行嗎？它背後的機制與原理究竟是什麼呢？就讓我來帶大家解密！

Ice-Skating
探討溜冰的奧秘

By Chih-yu Lee 李致宇

一般認為，這是一個我們在中學時可能會學到，「熱力學」中的「固、液相平衡」(solid-liquid phase equilibrium) 的相關問題[1]。說明如下：如附***圖一***，我們可以藉由三相圖清楚看到水的凝固點 (亦即熔點；見圖中紅線) 隨壓力增大而降低，而溜冰時，因為冰刀與冰面的接觸面積十分小，而人體的重量便會集中落在冰與冰刀的接觸面上，相當於在冰面上施予很大的壓力 (大於標準大氣壓力，即大於一標準大氣壓 (atm) 或國際單位制下的 101 325 帕斯卡)，使得溜冰場的冰就算在低於攝氏零度的狀態下，仍能融化成水。在這樣的情況下，我們與冰之間的摩擦力會變得特別小，就像冰與我們之間有一層薄薄的水作為潤滑劑，讓我們能夠輕鬆地溜過。

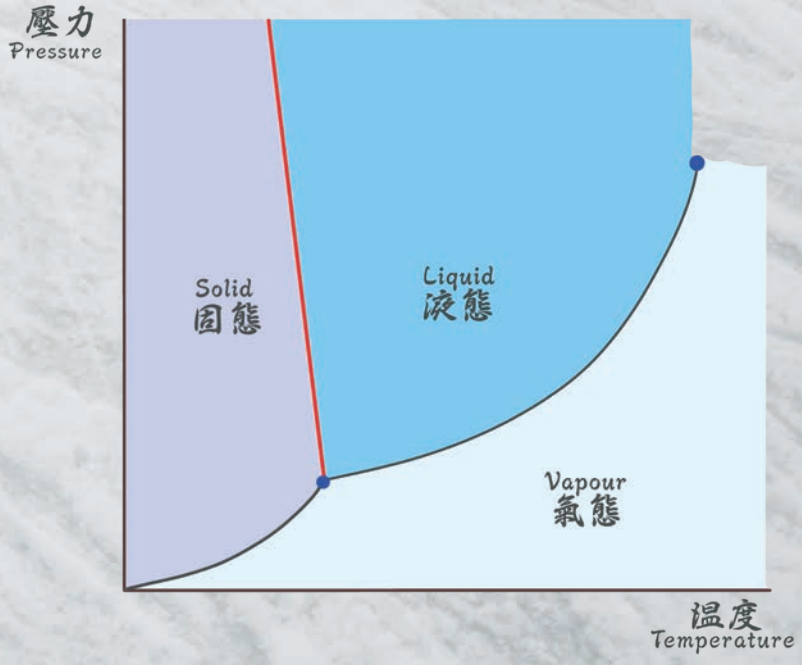

Figure 1. *Phase diagram of water.*
圖一 *水的三相圖*

Extraordinary Science: The Mechanism of 科學不一樣：

Are there alternative explanations? It was suggested that frictional heating could be another key to ice melting. According to Bowden and Hughes's paper published in 1939, they experimented with wood and metals in a research center, which was located at 3 346 m above sea level in Switzerland. They found that the coefficient of friction [3] and its corresponding heat conduction can provide a novel explanation to the melting of ice. However, Colbeck rebutted this theory in his abovementioned article. In Colbeck's formula, the contact length between the blade and the ice surface is conversely proportional to the rate of heat generation by frictional heating per unit area. The numerical result shows that, if the rate of heat generation by frictional heating has to be equivalent to that of pressure melting, which is already negligibly small, the length of blade which is in contact with the water membrane must be 15 μm (*i.e.* 15 x 10^{-6} m), assuming that the skating speed is 5 m/s. The length of a normal blade is 30 cm, and 15 μm is only its 0.005 % (no one would skate with a 15 μm long blade, right?). The numerical analysis has proven that the effect brought by frictional heating is much smaller than that resulted from pressure melting. It can thus only be also one of the mechanisms that allows us to skate on ice.

Then, what is the main reason for the ice to melt? Conventional wisdom suggests that water doesn't melt below 0 °C, but such an ingrained belief is indeed the culprit that hinders us in finding another possible reason! From 1850, Faraday, a British physicist, has started a series of experiments about regelation. He put two pieces of ice together so that they are in contact with one another. The two pieces of ice then adhere together and become one. Faraday therefore discovered that there is a liquid-like film, which plays a key role in the freezing of ice, on the ice surface subsequently. This also leads to the subsequent research on the thickness of liquid-like film on the ice surface [4].

A century after Faraday's discovery, another scientist, Prof. Gurney, suggested in 1949 that the intrinsic liquid-like film surrounding the ice is a key factor that affects the slipperiness of ice. In addition, not only did Prof. Weyl from the Pennsylvania State University accept Faraday's idea, but he also raised a model in 1951 to explain the arrangement of water molecules in both the core and surface of an ice cube. From there, different research laboratories conducted various quantitative research to test this idea in 1950s. This enables theoretical and experimental physicists to investigate how much pressure, frictional heating and the liquid-like film on the surface contribute to ice melting respectively under different temperatures.

In 1969, Prof. Orem and Adamson from the University of Southern California further discovered that the premelting of the ice surface starts from -35 °C through the analysis of the physical absorption of vapors. This confirms the existence of a liquid-like film on the ice surface. With the advancements in technology, its existence was further confirmed by nuclear magnetic resonance (NMR), proton backscattering and X-ray diffraction. Nonetheless, the role played by the liquid-like film in ice skating is yet to be confirmed by further research.

Ice-Skating
探討溜冰的奧秘

然而，這樣的話，為什麼在很多人溜過後，溜冰場的冰沒有全部都融化成水呢？這是因為當冰刀劃過之後，壓力會隨著冰刀的離開而在原本加壓的地方降低，而此時的凝固點又會隨之恢復為標準大氣壓力時的攝氏零度，此時，水膜又會結成冰，而不會使得整個溜冰場的冰都融化成水。

上面這些敘述聽起來都符合我們所能預測跟學習到的知識，然而，科學就是如此的奧妙，在經過一些物理學家的研究之後，他們發現溜冰的機制根本就不是我們所想像的那樣簡單，而是另有其他機制。

根據地質物理學家 Samuel Colbeck 於西元 1995 年被收錄於美國物理期刊（*American Journal of Physics*）的文章〈因壓力而融化與溜冰〉（Pressure Melting and Ice Skating）中所寫：因壓力變大而凝固點降低的熔化現象不能作為摩擦力減少的原因。文中說明在攝氏零度時，在壓力融化效應（pressure-melting effect）下，每一帕斯卡的壓力使水的熔點降低 7.37×10^{-8} 攝氏度；在這樣的情況下，根據計算，我們可以知道如果我們要在攝氏零下一度的溜冰場溜冰，需令熔點降至攝氏零下一度的話，其所需要的壓力約為 1.4×10^{7} 帕斯卡（即約 140 atm），假設冰刀的接觸面積是 10 平方厘米，要製造相等的壓力，溜冰者的體重需達到 1400 公斤[2]，我們可以清楚地了解這是不可能做到的，因此因壓力變化而導致的熔化並不是造成我們能夠輕鬆地在冰上滑行的有效機制。

科學家們為了解釋壓力不是唯一的機制，因此提出了「摩擦加熱」（frictional heating）的假設，意思是因摩擦而產生的熱力，可能是熔化冰的原因。在 1939 年 Bowden 和 Hughes 的論文中，他們在一個海拔高度 3 346 米的瑞士研究中心以木頭和金屬進行實驗。實驗中，他們發現摩擦係數[3]及其所影響的熱流傳導亦能夠提供一個對於冰得以融化的新的解釋。但這個理論亦在前述 Colbeck 的文章中以數值計算的方式予以反駁，在 Colbeck 提出的公式中，冰刀與冰面接觸的長度與每單位面積摩擦加熱的率成反比。數值的計算得出若摩擦加熱要與本來已經微不足道、因壓力熔化所造成的效應等量的話，假設溜冰速度為每秒五米時，與水接觸的冰刀長度需為 15 微米（即 15×10^{-6} 米），產生熱能的效率才能與因壓力熔化所造成的效應相比。假設一般冰刀長度為 30 厘米，15 微米只是其 0.005 % 而已（而世界上應該沒有人用只有 15 微米的冰刀溜冰吧！）。這項數值分析證實了摩擦加熱比壓力融化效應顯得影響較小，只能是眾多可能使我們能夠溜冰的機制之一。

那麼，究竟什麼是造成冰得以熔化的主要原因呢？我們以往認知水在攝氏零度以下是不會融化的，然而這個我們長期相信的概念便是使我們無法想像真正原因的癥結點呢！自從 1850 年後，英國物理學家 Faraday 開始執行了一系列復冰現象（regelation）的研究，他將兩塊冰塊緊貼在一起，兩塊冰會因而合成一塊，因此發現在冰上的一層性質較接近液體的類液相膜（liquid-like film）在凝固時扮演了重要的角色，而這也開啟了科學家對於冰上的類液相膜厚度的後續研究[4]。

直至 Faraday 發現這個有趣現象的 100 年後，亦即 1949 年，當今的科學家 Gurney 教授提出冰上固有的類液相膜是影響冰的滑溜性的重要因素；1951 年，賓夕法尼亞州立大學的 Weyl 教授不但接受了 Faraday 的概念，更提出一個模型來解釋水分子在冰塊及表面的排列方式。此後，1950 年代，各個不同的研究團隊針對這個想法執行各式定量的研究，物理理論學者與實驗學者進而得以了解因壓力的效應、摩擦加熱與冰上原有一層類液相膜的存在於不同的溫度下各自對熔化貢獻多少。

更在 1969 年時，美國南加州大學的 Orem 及 Adamson 教授更藉由蒸氣分子吸收的方式，發現冰塊表

Extraordinary Science: The Mechanism of Ice-Skating

科學不一樣：探討溜冰的奧秘

It may come as a surprise that such sophisticated physical mechanisms underlie a simple leisure activity. Next time, when you are enjoying some other leisure activities, don't forget to think of their "hidden" mechanisms! Perhaps, the mechanism can be complicated, but intriguing. Perhaps...you may spot some interesting physics in a simple life!

[1] Remark: The writer is a Taiwanese, and the topic of "phase equilibrium" is not included in the current senior secondary curriculum in Hong Kong.

[2] Pressure formula: $P=\frac{F}{A}$ (where P is pressure, F is exerted force and A is contact area)

[3] Coefficient of friction: The rougher the surface, the greater the coefficient of friction.

[4] Liquid-like film: The actual mechanism is still a hot topic for many scientists to investigate. If you are interested in this topic, you may refer to "Rosenberg, R. (2005). Why is ice slippery? *Physics Today, 58*(12), 50-54" in the reference list.

面熔化(premelting)現象會在攝氏零下 35 度時開始，這也更加證實了冰表面有一層類液相膜的真實性；隨著科技的進步，核磁共振(nuclear magnetic resonance, NMR)、質子反向散射(proton backscattering)及 X 光繞射(X-ray diffraction)等方法更加地證實了冰表面有一層類液相膜的存在。但對於解釋溜冰的機制，類液相膜扮演的角色卻有待進一步的研究確認。

由此可見，即便是生活中看似簡單的休閒娛樂，其背後的物理原理都是如此的奧妙且複雜的。雖然至今溜冰尚未有被科學家公認的理論，但也就是這樣的過程，科學才如此地吸引著我們吧？下次從事其他休閒活動時，不妨也想想其背後的原理呢，說不定其背後的原理也是十分複雜但有趣的。說不定，你也可能對簡單的生活提出有趣的物理喔！

[1] 編按：作者為台灣人，「相平衡」並不在香港現時的高中課程內。

[2] 壓力公式：$P=\frac{F}{A}$（P 為壓力、F 為施力、A 為接觸面積）。

[3] 摩擦係數：表面越粗糙，摩擦係數越大。

[4] 類液相膜(liquid-like film)產生的實際機制仍是一個科學家爭相探討的議題；如對於相關機制有興趣，可以參閱「參考資料」中的 Rosenberg, R. (2005). Why is ice slippery? *Physics Today*, *58*(12), 50-54。

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"Flatus" refers to the excess gas in the intestine, and the act of releasing said gas is called "flatulence", also known conventionally as farting. I know many people laugh immediately when speaking about this topic, but we actually know very little about it, especially the health warnings it may contain. There are many folklores about farts that are not scientifically accurate. Let us break down the myths one by one!

Myths and Facts about Farts 屁的迷思

By Eunice Lam 林杏妍

「腸胃氣（flatus）」是指由腸胃產生的多餘氣體，而把這些氣體釋放的自然生理反應被稱為「flatulence」，亦即是我們俗稱的「farting（放屁）」。相信很多人談及這個話題時都會情不自禁地竊笑，但是我們真的認識屁嗎？其實不然，有時我們甚至會忽略了它所帶來的健康警號。讓我們一起分析各種關於屁的「都市傳說」吧！

Myths and Facts about Farts

***Question 1:* "Loud Farts are Not Smelly, Smelly Farts are Silent"(「響屁不臭，臭屁不響」)?**

Have you ever farted so loud that your classmates kept laughing at you, so you try to defend yourselves by saying "It wouldn't be smelly"? Or you are taking a test where you didn't hear anything but suddenly smell your classmate's silent "biochemical weapon"? In fact, loudness and odor of the farts are independent of each other.

Loudness is determined by the amount of gases produced. People who fart loudly are probably experiencing indigestion – undigested carbohydrates are fermented by the bacteria in the gut, producing gases such as carbon dioxide and nitrogen. These gases are mostly odorless.

Most of the time, the odor in farts comes mainly from hydrogen sulfide, a gas with rotten egg smell [1]. Individuals who eat more dairy products and meat typically produce more hydrogen sulfide because those foods contain proteins that are rich in sulfur. Interestingly, the hydrogen sulfide produced due to large consumption of sulfur-containing foods is always smaller in volume compared with the carbon dioxide produced by carbohydrate fermentation. Therefore, smelly farts usually build up less gas pressure and are quieter. However, the farts can be both smelly and loud if a person is suffering from indigestion but at the same time consumes too much proteins. Therefore, this saying is not totally correct.

***Question 2:* Vegetarians Fart More?**

In terms of frequency, this is correct. Vegetables and fruits are rich in dietary fiber. Speaking of dietary fiber, there are many kinds apart from cellulose that you may have heard of. Non-digestible oligosaccharides[1] are a kind of dietary fiber that humans don't have enzymes to digest, so they will end up undigested in the large intestine. Interestingly, certain types of bacteria in the large intestine do have the ability to digest these oligosaccharides, and the fermentation process does produce gas, so it is possible that vegetarians generally fart more.

Are vegetarians' farts smellier then? Apart from meat and dairy products, some vegetables, like cabbage and broccoli, are also rich in sulfur [2]. Since odor depends on the amount of hydrogen sulfide produced, if vegetarians eat a lot of vegetables that are rich in sulfur, their farts could be smelly too. In other words, flatulence from vegetarians and omnivores can be equally smelly!

***Question 3:* Smelling Farts is Good for Health?**

This saying sounds suspiciously like nonsense, but there are some interesting facts that led to the perpetuation of this myth.

As mentioned above, hydrogen sulfide is one of the gases that gives the distinctive smell of farts. Interestingly, extensive research suggested a range of beneficial effects of hydrogen sulfide when it is made within a cell. Hydrogen sulfide can modulate reactions which occur in mitochondria to provide protections to cells under certain conditions, such as high blood glucose caused by diabetes [3]. Mitochondrion is often known as the "powerhouse" of cells because it is the key organelle of energy production in a cell. Mitochondria also play a key role in regulating cell survival. Inspired by the natural protective mechanism, scientists in the University of Exeter have identified a small molecule, AP39, that can direct hydrogen sulfide to the mitochondria of the stressed cells, and release the gas in a very slow manner [3]. This enables us to administer hydrogen sulfide from outside the body and mimic the natural process.

Notably, the scientists remarked at end of their press release that they have never claimed that sniffing hydrogen sulfide can bring any health benefits. This is because for the treatment to be effective, the hydrogen sulfide must be delivered to the right cells at the right dose. Smelling farts is likely not at all effective or beneficial as a form of disease treatment or prevention, because we can neither lead the hydrogen sulfide to the mitochondria of the stressed cells nor control the dose.

Next time when you fart, while having a laugh about it, you should also pay attention to them. If you are constantly farting too much or your farts are abnormally smelly, it may be warning signals from your body that warrant a visit to the doctor's office.

[1] Oligosaccharide: A saccharide polymer that consists of 3-10 monosaccharides as monomers

屁的迷思

迷思一：「響屁不臭，臭屁不響」？

你們有沒有試過在課室放了一個很響的屁，然後因為忍受不了同學的取笑而自辯：「響屁一點也不臭！」？或者在極度寧靜的試場內，突然嗅到你鄰座同學的「生化暗殺武器」而害你不能專心做題目？事實上，屁的聲量和臭味並沒有直接關係。

屁的聲量取決於所產生氣體的量。放響屁的人很可能正受消化不良的問題困擾：未被分解的碳水化合物被腸道裡面的細菌發酵，產生出二氧化碳、氮氣等氣體，但這些氣體大多都是無味的。

那屁的臭味是來自哪一種物質呢？很多時候，屁的臭味主要來自硫化氫 (hydrogen sulfide)，它的氣味多被形容為像腐爛的蛋 [1]。進食大量乳製品和肉類的人通常會製造出更多的硫化氫，因為這些食物當中含有很多硫含量高的蛋白質。有趣的地方是，在體積上，因大量進食硫含量高食物而產生的硫化氫，通常比因發酵碳水化合物所產生的二氧化碳少，因此，臭屁累積的壓力通常會較小，所以會較靜。可是，如果一個人既有消化不良的問題，而又同時攝取大量蛋白質，他 (她) 放的屁是可以又響又臭的！所以，「響屁不臭，臭屁不響」的說法並非完全正確。

迷思二：素食者放屁比平常人多？

論次數，這個說法是正確的。蔬菜和水果都含有豐富的食用纖維 (dietary fiber)。說到食用纖維，除了經常提到的纖維素 (cellulose) 外，其實還有很多不同的種類。「不可消化寡糖 [1] (non-digestible oligosaccharides)」是其中一種食用纖維。可是，由於人類缺乏能把其消化的酶，所以它被送到大腸時依然保持完好而不被消化。有趣地，大腸內剛好有一些細菌可以消化這類纖維，而發酵的過程中會產生氣體，這令素食者放屁的次數可能比平常人多。

那麼，素食者放的屁是不是比較臭呢？除了乳製品和肉類食品外，原來亦有一些蔬菜和它們一樣都是硫含量高的，例如捲心菜和西蘭花 [2]。由於屁的臭味取決硫化氫產生的量，如果素食者大量進食這類硫含量高的蔬菜，他們的屁也可以跟肉食者一樣臭！

迷思三：聞屁可以促進健康？

這個說法聽起來十分荒謬，但其實背後也有一個饒有趣味的緣由，令這個誤解得以流傳。上文提到，硫化氫是為屁帶來獨特氣味的氣體之一。不少研究指出，在細胞裡面產生的硫化氫可能是有益的。例如在糖尿病常見的高血糖情況下 [3]，硫化氫可以透過調節線粒體內的化學反應，從而保護細胞。線粒體是細胞的「發電廠」，因為它是主要負責製造能量的細胞器；它亦是決定細胞生死的要員。受此自然現象所啟發，艾克斯特大學 (University of Exeter) 的學者們成功研發了一個細小分子 – AP39，它可以直接把硫化氫帶到受壓力影響的細胞 (stressed cells)，以非常緩慢的速度釋放硫化氫 [3]。在 AP39 分子的幫助下，我們就可以透過從體外攝取硫化氫來模仿這個自然保護機制了。

值得注意的是，他們在新聞稿的結尾中提到，他們從來沒有宣稱過用鼻嗅入硫化氫可以為身體帶來任何益處。這是因為如果要令這個療法成功，我們必須準確地把正確分量的硫化氫送到特定的細胞，因此聞屁並不能有效地達到疾病治療或預防的功效，因為我們不但不能把硫化氫引導到受疾病影響細胞的線粒體，更不能控制其劑量。

下次你放屁的時候，在笑的同時，不妨也注意一下你的屁：如果你長期放太多屁，或者你的屁異常地臭，這可能就是身體發出的一些警號，提醒你要去看醫生了。

[1] 寡糖：又稱低聚糖，它是指由三至十個單糖分子聚合而成的多糖。

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If you've seen Marvel movies, you probably know about Baby Groot, the tree-like creature that has captured the hearts of millions of fans around the world with his cuteness. One of his most memorable moments was when he was blown into a million pieces but still made a miraculous comeback. This was because, a single twig fragment of himself was recovered and grown in a pot of soil, like a real-life sapling. This enabled him to regrow his tree-like body in the film. Given that it's a sci-fi movie, it might come as a surprise to you that plants in real life can indeed regenerate themselves from the tiniest of fragments. This process, already a robust technique used in contemporary biology, is known as callus induction.

To start off with, a callus refers to a ball of plant cells that have not been developed into a specialized cell type. Amazingly, these cells are capable of differentiating into many different cell types given the right conditions. With this knowledge in mind, callus induction is easy to understand. To do so, you take a few cells from a plant and culture it in a petri dish with medium containing plenty of nutrients. The most important of which are the plant hormones, auxin and cytokinin. When these two hormones are mixed in intermediate ratios, the cell will grow and divide, forming a ball of plant cells, the titular callus. Afterwards, once, the callus has been grown sufficiently, it is transferred to a new culture medium. When there is more cytokinin than auxin, the shoot growth of the callus is stimulated. Conversely, when there is more auxin than cytokinin, root growth is stimulated. By altering the ratio of auxin and cytokinin, the callus is eventually coerced to regenerate itself from the multicellular mass of cells to a fully grown plant that is genetically identical to the plant from which the original cells were taken. Thus, you have a complete clone of the original plant, just like how Groot regenerates himself in a pot in the movies. Indeed, in this instance, what seems made-up on the silver-screen is actually completely possible.

On its own, callus induction isn't very special. But its applications are quite diverse and useful. For one, it can be used to regenerate near-extinct species of flora, such as orchids, very easily. All one has to do is to pick some cells from said endangered plant and make some clones of it. Besides species preservation, a pivotal application of callus induction is the production of secondary metabolites. Secondary metabolites are organic substances that are produced by plant cells. They are not directly involved in plant development, but are medically valuable to humans. Again, scientists need only pick some cells from the plant and grow it in callus culture. The resultant cells or tissues can then be a source for extracting these important secondary metabolites. By doing so, the wild populations of those rare medicinal plants can be left relatively undamaged and conserved, while we can massively produce the secondary metabolites. One famous example of this is ginsenoside. Wild ginseng takes years to grow and has very low yield. However, with callus induction, roots of ginseng plants can be cultivated from calli in shorter periods and ginsenoside can be extracted from the roots with higher yields. In addition, callus induction can also be used in conjunction with plant transfection. To introduce specific changes to the plant genome, scientists use *Agrobacterium* to deliver genes into plant cells. The cell regenerates completely into a plant, with the genetic modifications, thanks to callus induction.

It is pretty amazing how callus induction is possible to begin with. While some animals may be able to regenerate damaged tissue by themselves like the planarian flatworm with adult pluripotent stem cells, few others do. Likewise, no other man-made machine can regenerate itself from the tiniest of fragments, making plants very special in this regard. This property, easily dismissed as fiction, indeed is fact. Who knows, maybe some other phenomena we imagined in movies or books can one day be realized in life. All we have to do is to look out for it.

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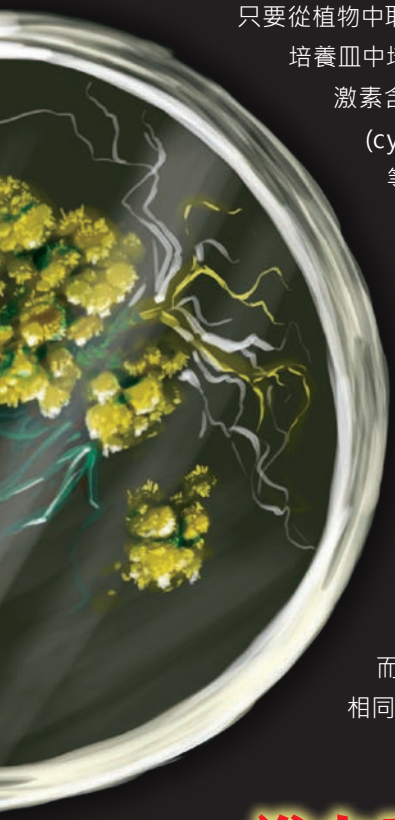
編按：「Callus」一字在香港的高中課程被譯為「胼胝體」。「胼胝 (callus)」原指「繭」，即增厚變硬的皮膚，但在植物上「癒傷組織」才是意思上更為貼切的翻譯。

在你看過的漫威 (Marvel) 電影中，你可能會看過格魯特寶寶 (Baby Groot)，這個樹狀的外星人，憑著可愛的造型，贏盡了全世界數以百萬粉絲的心。他最令人難忘的時刻，就是儘管被炸成上百萬塊的碎片，他還可以像奇蹟般捲土重來。這是因為，只要取得他身上其中一塊樹枝碎片，放在一盆土壤中培育，他就可以像現實生活中的樹苗一樣，重新生長。這使他可以重新長出他在電影裡的樹狀軀體。雖然說這是一部科幻電影，但在現實生活中，你可能會不相信：植物確實可以從最微小的碎片中再生。這過程已經是在當代生物學中，一個經常被使用、強大而穩健的技術，稱為癒傷組織誘導 (callus induction)。

首先，癒傷組織是指尚未分化成特定細胞類型的植物細胞球。令人驚訝的是，在適當的條件下，這些細胞能夠分化成許多不同的細胞類型。這樣，癒傷組織誘導就很容易理解。你只要從植物中取出一些細胞，在含有足夠營養素的培養皿中培養，其發育就取決於以下兩種植物激素含量：生長素 (auxin) 和細胞分裂素 (cytokinin)。當這兩種激素以大約均等的比例混合時，細胞將生長並分裂，形成植物細胞球，亦即癒傷組織。然後，當癒傷組織充分生長，再將其轉移到新的培養基中。當加入的細胞分裂素比生長素更多時，就會刺激癒傷組織分化成莖部。反之，當加入的生長素比細胞分裂素更多時，就會刺激癒傷組織分化成根部。通過改變生長素和細胞分裂素的比例，癒傷組織最終被「強制」由一團細胞球再生成一棵完整的植物，而該植物的遺傳基因更會與母株完全相同。因此，你獲得了一個完整的母株克隆，就像在電影中格魯特 (Groot) 如何在一盆土壤復生。所以在銀幕上表述的事情，原來在現實生活中亦完全有可能辦到。



癒傷組織誘導本身並不特別，但它的應用卻非常廣泛而且有效。首先，它可以很容易地使一些由瀕臨絕種植物 (例如蘭花) 組成的植物群重生。我們只需要從瀕臨絕種的植物中挑選一些細胞用來製造一些植物克隆就可以了。除了物種保存外，癒傷組織誘導的關鍵應用，是在於生產次級代謝產物 (secondary metabolites)。次級代謝產物是由植物細胞製造的有機物質，它們不會直接參與植物發育，卻對人類有著巨大的藥用價值。採用同樣的法門，科學家們只需從植物中挑選一些細胞，把其培養成癒傷組織。然後，所得細胞或組織可以用作為提取這些重要次級代謝物的來源。通過這樣的過程，我們可以把這些稀有藥用植物的野生種群相對完好地保存，同時我們可以大量生產出次級代謝產物。一個著名的例子是人參皂苷 (ginsenoside)。野山人參需要數年生長，而且產量很低。然而，通過癒傷組織誘導，我們可以在較短的時間內從癒傷組織培養人參植物的根，並且可以以更高產量從根中取得人參皂苷。此外，癒傷組織誘導也可以與植物轉染結合使用。為了對植物基因組引入特定的變化，科學家利用農桿菌 *(Agrobacterium)*，將基因送入植物細胞中。透過癒傷組織誘導，細胞可以再生成一棵完整植物，並具有經過基因改造後的理想性狀。

癒傷組織誘導是一個非常令人驚訝的過程。雖然有些動物，例如渦蟲 (planarian flatworm)，能夠用其成年多能幹細胞再生自己的受損組織，但這種情況並不常見。同樣，沒有其他人造機器可以從其最微小的碎片中，再造自身 — 使植物在這方面顯得非常特別。這個特性很容易被視為天方夜談，但在現實中，確實可以辦到。也許在電影或書本中想像出來的一些現象，終有一天也可以實現。我們只要多觀察身邊的事物，就可能找出這些現象。

浴火重生 II：癒傷組織誘導與植物再生
Rising from the Ashes II: Callus Induction and Plant Regeneration

By Henry Lau 劉以軒

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