

Creating carbohydrates: how can synthetic carbohydrates improve modern medicine?

For plants, creating carbohydrates is as simple as breathing. Using sunlight, water and carbon dioxide, they spend their days quietly making glucose, a carbohydrate that is essential for life on Earth. However, for us humans, creating carbohydrates is much more challenging. At the **Institut National de la Recherche Scientifique** in Canada, **Professor Charles Gauthier** and his PhD student **Oscar Gamboa** are using state-of-the-art techniques to synthesise carbohydrates in the lab and explore their potential for use in biomedicine.



Professor Charles Gauthier



Oscar Gamboa

PhD Student

Institut National de la Recherche Scientifique (INRS), Canada

Field of research

Carbohydrate chemistry

Research project

Developing new methods for synthesising carbohydrates and exploring their biomedical potential

Funders

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All around the world, from your local park to the Amazon rainforest, plants are constantly creating carbohydrates through the process of photosynthesis. Using energy from the sun, they transform carbon dioxide and water into glucose, a simple carbohydrate that is the primary source of energy for much of the life on our planet, including us.

Talk like a ...

carbohydrate chemist

Assay — a laboratory test used to find out if or how much of a substance is present in a sample, or to learn about the substance's behaviour

Bioavailability — the ability of a drug or substance to be absorbed and used by the body

Carbohydrate — a sugar molecule found in plant and animal products, made of carbon, hydrogen and oxygen atoms. Carbohydrates are one of the three main nutrients (alongside proteins and fats) that provide the body with energy

Functional group — a group of atoms that has distinct

chemical properties, regardless of the exact molecule they are found in

Glycosylation — a laboratory technique used to attach carbohydrates to other molecules, including other carbohydrates

Lipids — a group of organic compounds that includes fats, waxes and oils

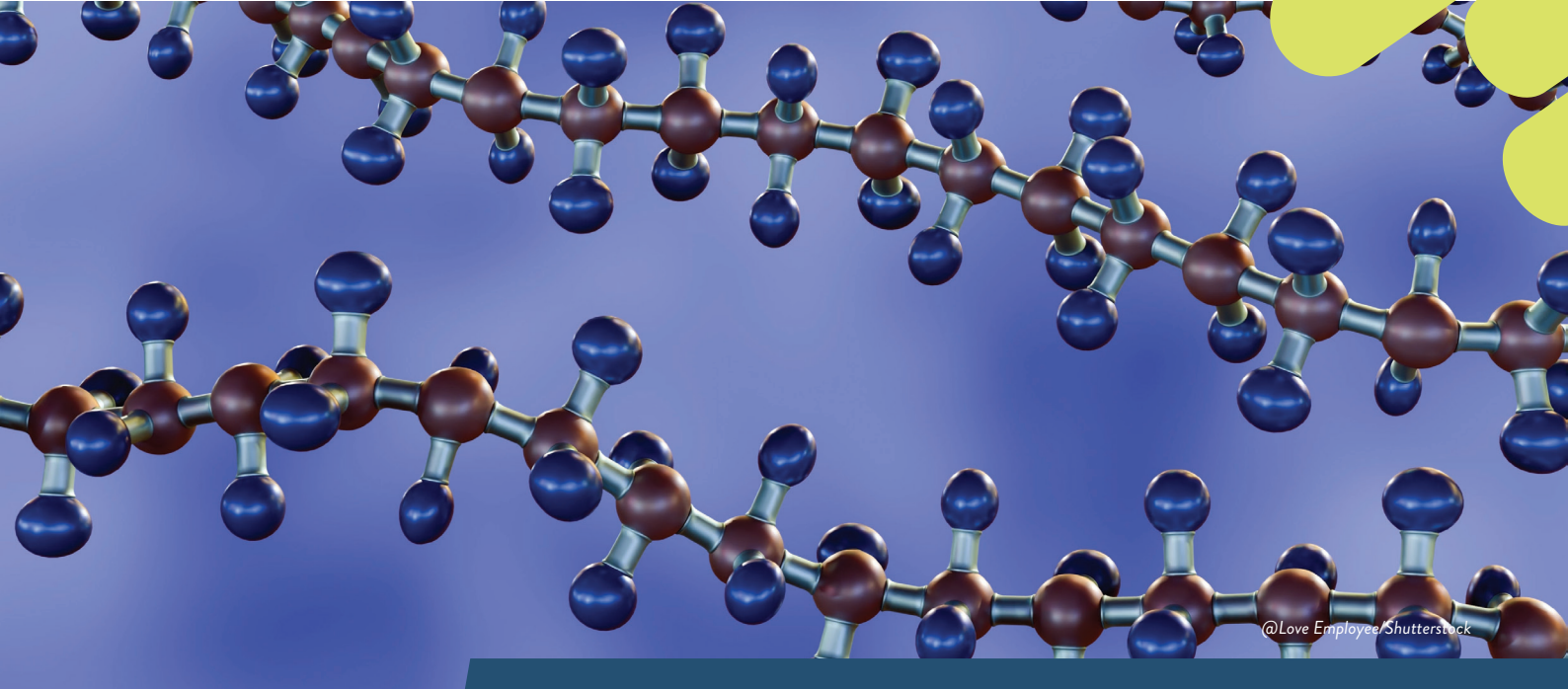
Saponin — a natural chemical compound found in plants which supports the work of the immune system

Vaccine adjuvant — a substance that, when added to a vaccine, helps to boost the body's immune response

"Carbohydrates are found in a wide variety of foods, from fruits and vegetables to bread, pasta and even dairy products like milk and yogurt," says Professor Charles Gauthier from the Institut National de la Recherche Scientifique. "When we eat carbohydrates, our bodies break them down into glucose, which is then used by cells to produce energy. They also contain fibre (which helps with digestion and blood sugar control), support gut health (by helping to feed the good

bacteria in our guts), and are important for brain function (serving as the brain's primary source of energy)."

Carbohydrates play a vital role in many other processes within our bodies including cell-to-cell communication, cell growth and differentiation, immune responses, and gene expression. With such an impressive range of functions, carbohydrates have the potential to improve medical treatments and therapies. Along with his PhD student



Oscar Gamboa, Charles is developing new methods for synthesising carbohydrates and applying them to various areas of medicine, such as improving vaccines and fighting bacterial infections.

How to synthesise a carbohydrate

Although carbohydrates are constantly being created by plants, accessing them for medical purposes is not straightforward. “Carbohydrates are often found in complex mixtures with other biomolecules, such as proteins, lipids and nucleic acids, making it challenging to separate and purify them,” explains Charles. “The isolation process can also be complicated by the presence of similar carbohydrate structures, which makes it hard to distinguish and separate the desired carbohydrate.”

So, instead of isolating carbohydrates from natural sources, Charles and Oscar are developing synthetic carbohydrates which are similar to those found in nature, but created in a laboratory. “Chemical synthesis allows us to produce carbohydrates with specific structures and properties, which can be difficult or impossible to obtain from biological sources,” says Charles. “For example, they can be designed to have improved stability, bioavailability or potency, making them useful for a range of applications, including pharmaceuticals, vaccines and diagnostics.”

To synthesise carbohydrates and tailor them to specific functions, Charles and Oscar use techniques such as glycosylation reactions, which are used to attach carbohydrates to proteins and lipids, and functional group modification, which involves removing, adding or changing groups of atoms within a

molecule. They also carry out various assays to check their synthesised carbohydrates for a number of properties such as a lack of toxicity, the ability to trigger immune responses and prevent bacterial growth, and the tendency to bind to and interact with specific molecules such as proteins or antibodies.

These synthesised carbohydrates could be used for a variety of medicinal purposes. “For example, they can be used to develop new vaccines against viral infections or to inhibit the growth of microorganisms, such as bacteria, which could lead to new treatments for bacterial infections,” says Charles.

Creating vaccine adjuvants

Vaccines work by exposing us to a weakened or inactive form of a virus, allowing our bodies to develop an immune response that protects us if we become infected by the real thing. Oscar is using synthesised carbohydrates to create vaccine adjuvants, substances that are added to vaccines to enhance the body’s immune response. “Adjuvants can help to increase the production of antibodies, activate immune cells and enhance the memory of immune cells, leading to longer-lasting immunity,” explains Oscar. “We are using carbohydrates to create saponins as potential vaccine adjuvants.”

Saponins are naturally occurring carbohydrate-based compounds found in plants such as the soapbark tree. “They have been used for centuries in traditional medicine and have been shown to change or regulate the immune system,” continues Oscar. “In modern medicine, an adjuvant called QS-21, isolated from the bark of soapbark trees, is already used in some vaccines to boost immune response.” While QS-21 is a highly effective adjuvant,

extracting and isolating it from the bark is laborious and damages the soapbark trees.

Using glycosylation and functional group modifications, Oscar has synthesised a new saponin that is similar to QS-21. “Our research shows that this new adjuvant exhibits low toxicity, both in the lab and in mice, and so could be used as a potential vaccine adjuvant.” By synthesising alternatives to QS-21 in the lab, Oscar has developed a process that bypasses the slow, unsustainable process of extracting QS-21 from its natural source.

Fighting bacterial infections

As well as his vaccine adjuvant research, Oscar is also using synthetic carbohydrates to study and fight bacterial infections. Gram-negative bacteria are surrounded by a complex matrix of membranes, making them difficult to kill and quick to develop resistance to antibiotics. In order to study these bacteria and develop new methods for killing them, Oscar has created a synthetic version of Kdo, a carbohydrate-based compound found in lipopolysaccharides in the outer membrane of gram-negative bacteria. Lipopolysaccharides support the outer membrane and control which substances enter and leave the bacteria.

“We can use synthetic Kdo to investigate how lipopolysaccharides are constructed and to develop new antibiotics that target this construction process, making the bacteria easier to kill,” explains Oscar. “We can also use it to create molecular probes that allow us to study the interactions between bacteria and host cells, leading to a better understanding of how bacteria infect their hosts and make them sick.”

About carbohydrate chemistry

Carbohydrate chemistry explores the structure, properties, reactions and synthesis of these versatile sugar molecules. Researchers in the field use different tools and techniques to study the behaviours of different carbohydrates and to develop synthetic carbohydrates which are tailored to meet specific needs. As well as medical applications, researchers in carbohydrate chemistry may also work to develop sustainable materials and green technologies, such as alternatives to fossil fuels and plastics.

“Carbohydrate chemistry is an exciting field to work in,” says Charles. “Its interdisciplinary nature, combining chemistry, biochemistry, biology and medicine, makes it a fascinating field that requires a broad understanding of multiple disciplines. Its relevance to human health can lead to the development of new treatments and therapies for various diseases.”

“Carbohydrate chemistry is a complex field with many challenges remaining in terms of synthesis, analysis and understanding the biological roles of carbohydrates, and this complexity provides opportunities for innovative research and discovery,” continues Charles. “It is a rapidly evolving field with new technologies being developed to study carbohydrates. This rapid evolution creates opportunities for researchers to explore new areas and develop novel tools and methods.” For example, artificial intelligence (AI) is being used to examine the best possible methods for designing and synthesising new tailor-made carbohydrates, and new enzymes are being created to improve the efficiency of reactions.

Pathway from school to carbohydrate chemistry

At school, engage with subjects such as chemistry, biology and mathematics. “Understanding the fundamentals of chemistry, including atomic structure, bonding and reactions is crucial,” explains Charles.

At college and university, study courses in organic chemistry, biochemistry and analytical chemistry, and then specialise in carbohydrate chemistry, glycobiology or medicinal chemistry. “Learning about various analytical techniques, such as chromatography and spectroscopy, used to analyse carbohydrates, is important,” says Charles.

Charles says, “Gaining hands-on experience in carbohydrate chemistry research laboratories and attending specialised courses and workshops focused on carbohydrate chemistry and glycobiology will be valuable.”

Explore careers in carbohydrate chemistry

“Studying carbohydrate chemistry could lead to careers as a research scientist, a medicinal chemist, a biotechnology specialist, a science writer, a patent agent, a regulatory affairs specialist or an academic professor,” says Charles.

Explore the websites of the Canadian Glycomics Network (canadianglycomics.ca), the American Chemical Society (acs.org), the Royal Society of Chemistry (rsc.org) or the International Carbohydrate Organization (ico.chemistry.unimelb.edu.au) for resources and information. You could even consider becoming a student member to gain access to conferences and networking opportunities.

“The INRS offers a fantastic public outreach programme called Apprentis Chercheurs (apprentisinsr.ca/Default1) which provides high school students with a unique opportunity to experience scientific research firsthand,” says Charles. Look for similar opportunities at universities and research institutions in your local area.



When I am not working, I like to relax and have fun with my wife and two children. I enjoy playing chess, playing piano and running. I am a big fan of winter sports like skiing and snowshoeing, and in the summer, I love going to the beach, hiking, fishing and picking wild berries. Gardening and helping my community are important to me, as they help me unwind and spend time with the people I care about.

1. Stay curious, be open-minded and keep asking questions; these are great ways to learn and discover new things.
2. Learn to persevere and adapt when faced with challenges.
3. Finally, find mentors and role models who can guide and inspire you.



I love playing videogames, which is my way of disconnecting from everything related to work and study. Other than that, I like travelling. I often visit my family back in Colombia and spend time with my sisters who I live with here in Canada.

1. Look for something you are really good at.
2. Follow your instincts.
3. Every choice you make is right, so long as you have fun and love whatever you are doing.