The umbrella algae's crazy caps

Acetabularia is several centimeters long – and consists of a single cell. Joachim Hämmerling from the Kaiser Wilhelm Institute for Biology in Berlin-Dahlem and Hans-Georg Schweiger from the Max Planck Institute for Cell Biology in Ladenburg dedicated most of their research life to the umbrella algae. One of their goals was to find out about the role of the nucleus.

TEXT **ELKE MAIER**

Berlin-Dahlem in 1931. It was a rather peculiar little plant that the biologist Joachim Hämmerling was contemplating. It did not really look like a plant at all, but more like an umbrella or a small mushroom. A thin stalk the length of a finger was equipped with a flat, ribbed cap on one end, and a root-like holdfast on the other end which the plant used to anchor itself to the substrate in the surf zone of the sea.

Hämmerling's object of study was a type of umbrella algae known as *Acetabularia mediterranea*. From a research trip to the Mediterranean Sea, Max Hartmann, the Director of the Kaiser Wilhelm Institute for Biology in Berlin, had brought back a number of specimens of these algae that grow to a length of up to six centimeters. His postdoc Joachim Hämmerling was now supposed to find out how the algae reproduced.

Pioneers of cell biology: Joachim Hämmerling (left) and Hans-Georg Schweiger.

It was especially the fact that the entire organism consists of a single cell that made *Acetabularia* interesting for scientists. In the course of his studies, Hämmerling discovered that the gigantic cell also contains just one nucleus throughout its entire growth period, and that this nucleus is bigger than in most other organisms and is always located in the holdfast. Hämmerling recognized the marine plant's great potential for cellbiological research.

In multicellular organisms, the individual cells differentiate and take over different functions. But how does a gigantic cell like this organize itself and manage to reproduce? How does it ensure that the cap is formed at one end, and the holdfast at the other?

Hämmerling was unwilling to believe in the assumption that was popular at the time, according to which appearance was determined by mysterious life forces. He was convinced that material information carriers were behind all this. To prove his theory, he began to systematically cut umbrella algae into pieces. Thanks to their large size, he did not even need any special instruments – scissors and a pair of tweezers were enough.

The algae survive, even when they are cut apart repeatedly: provided that the nucleus remains intact, the cut off top section is regenerated time and time again. The nucleus can be isolated and transferred into another *Acetabularia* fragment, even a foreign one, without losing its functionality. The little plant was the perfect model organism to tackle fundamental questions of cell biology.

In order to find out more about the function of the nucleus, Hämmerling removed the nucleus of a young specimen that had not yet formed a cap. And lo and behold: against all expectations the plant did not die – quite the contrary. Without a nucleus it even lived for longer than with a nucleus; however, it lived life on the back burner. The specimen remained in its development stadium at the time, and it never reproduced. It appeared to be the case that the nucleus transmits information that is vital to a normal life.

Hämmerling continued to conduct countless experiments in which he cut up umbrella algae, removed their nuclei and replaced them with foreign ones. In this context he also experimented with exchanging nuclei across different species of *Acetabularia*. This caused the cell to produce the form of cap typical of the species the nucleus came from. If Hämmerling placed nuclei of two species inside the same cell fragment without a nucleus, he could even create mixed cap designs.

However, he made his most astonishing discovery when he removed first the cap and a week later also the nucleus of a cell: the cut off side was able to form a new cap, even though the nucleus was gone! It had to be the case that the building instructions for the cap had moved from the nucleus to the cell plasma and survived there.

Through his experiments, Joachim Hämmerling gained fundamental insights into the interaction between the nucleus and the cell plasma. He recognized that shaping is controlled by the nucleus by transmitting "morphogenetic" (relating to formation) substances to the plasma. Nowadays, it is known that these substances are messenger ribonucleic acids – transcripts of the ge-

Model plant: the umbrella algae *Acetabularia mediterranea* are at home in many places in the Mediterranean Sea, and they gave rise to fundamental insights into the interior of cells.

netic code that are channeled from the nucleus into the plasma, where they are used as instructions for protein production.

"Hämmerling succeeded in showing with simple means that properties such as outer appearance are determined by the nucleus, before people even knew about the genetic material DNA that is located inside the nucleus," says Horst Bannwarth, a former *Acetabularia* researcher of the Max Planck Institute for Cell Biology in Ladenburg near Heidelberg, who now holds a professorship at the University of Cologne. "It was not until 1944 that the Canadian Oswald Theodore Avery demonstrated that information about hereditary characteristics is stored in the DNA."

Hämmerling's classic experiments paved the way for the umbrella algae to enter the laboratories. Scientists around the world were soon examining the processes inside the gigantic cell. The medical expert Hans-Georg Schweiger worked with the giant algae at the Max Planck Institute for Cell Biology. Schweiger had previously conducted research on red blood cells with and without nuclei. He used new and refined methods to examine the umbrella algae that can be easily manipulated and gained many new insights into the interrelations between the nucleus and the cell plasma. In this research work, he was particularly interested in biological rhythms.

Whether it be behavior or metabolic processes – there are many vital processes that are characterized by specific regularities. Photosynthesis in *Acetabularia* follows a daily rhythm, with large amounts of oxygen being produced during the day and smaller amounts at night. The algae maintain this rhythm, even when exposed to permanent lighting. This means that there must be an internal clock. But where is it? And how does it work?

To find out, Schweiger and his staff members once again took the cells apart. The researchers measured oxygen production in

Augsburger Allgemeine newspaper on 14 September 1977

» The algae that the local Italian lagoon dwellers lovingly refer to as "umbrellas", and that were introduced as research objects 50 years ago by Professor Joachim Hämmerling, who is meanwhile retired, have attracted a lot of attention for a long time now.

individual cells and cell fragments to determine photosynthetic activity. They found that the "sense of time" exists across all parts of the plant, and that the clock must therefore be located somewhere in the cell plasma rather than in the nucleus. What was interesting, however, was that an *Acetabularia* specimen whose nucleus had been removed adopted the rhythm of a foreign cell whose core was implanted into it and that had been modified to follow a different schedule by means of artificial lighting. Here, too, the nucleus therefore played an important part.

The methods had meanwhile become much more sophisticated than had been the case when Hämmerling was a postdoc. The researchers were now able to use specific inhibiting substances to block either transcription – the copying of the genetic code – or subsequent translation – the synthesizing of proteins based on the code. The internal clock would stop whenever the scientists interfered on the translation level. The clock must therefore be controlled by one or multiple substances that are produced in this process – by specific proteins.

Schweiger and his team were able to identify a protein called P230 as a key element of the internal clock. In *Acetabularia* it is located in the chloroplasts, and it controls the circadian rhythm of photosynthesis. Together with his brother Manfred Schweiger, who held a professorship in biochemistry at the University of Innsbruck at the time, Hans-Georg Schweiger published the so-called coupled translation-membrane model in 1977, which explains the underlying mechanism and can also be applied to other organisms.

This work made Hans-Georg Schweiger one of the pioneers of chronobiology – a field of research that has gained significant momentum over the past few decades: in 2017, three Americans – Jeffrey C. Hall, Michael Rosbash and Michael W. Young – received the Nobel Prize for researching the period gene that controls the circadian rhythm in the fruit fly *Drosophila*.

Following the publication of his model, Hans-Georg Schweiger set about examining the protein P230 more closely. However, he died suddenly in 1986. His mentor Joachim Hämmerling had died six years earlier. The international *Acetabularia* community had thus lost two extraordinary scientists.

The giant algae gradually disappeared from the laboratories in the 1990s. Their cultivation is an elaborate process, and even under ideal conditions their life cycle takes several months, and without bacteria colonizing their cell walls, they remain rather frail. They cannot compete against model organisms such as baker's yeast, roundworms or thale cress. This is particularly true in our contemporary fast-paced world, where scientists are expected to present results as quickly as possible.

The possibility of a comeback cannot be excluded, though: *Acetabularia* belongs to the order of *Dasycladales* that have existed on earth for close to 600 million years. "There are now only 19 living species," says Sigrid Berger-Seidel, Professor at the University of Heidelberg, and a former staff member of Hämmerling and Schweiger. "It would be interesting to compare species of different evolutionary ages, and to use new methods to examine the relationship between the nucleus and the organelles." So it is quite possible that the primitive giant algae will return to the laboratories one day.