Malacopedia

São Paulo, SP, Brazil
Volume 8(1): 1-6

ISSN 2595-9913
06/February/2025

Molluscan “Hulk effect”

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Abstract

This study explores the mechanism in certain mollusks that allows a large, extended body to retract into the shell during activity, reducing its size. This phenomenon is termed the “Hulk effect.” The change in mass before and after contraction is regulated by muscle contraction and the kidney’s action on haemocoelic blood. Inflation is primarily driven by blood pressure from the heart and the intake of environmental fluids, which also explains the physical connection between the digestive tubes and the pericardium in mollusks.

DOI:

Keywords: anatomy, organic function, taxonomy, phylogeny, evolution.

Introduction

I may belong to a previous generation, but by today’s standards, I would easily be classified as both a *nerd* and a *geek*. While nerds tend to be more academically inclined and geeks more passion-driven and pop-culture-oriented, the two often overlap and are difficult to separate. At the same time, I am also a dedicated formal academic scientist. These identities are not only compatible but even interdependent—an exciting synergy that shapes my approach to science.

Of course, there are moments when the nerd/geek in me clashes with my passion for scientific principles and physical laws. A perfect example is the classic *X-Men* hero Angel (Fig. 1). As a comic book character, I love him—but as a scientist, he is a complete nightmare!

1: Angel, hero of Marvel
https://www.writeups.org/angel-marvel-comics-classic/

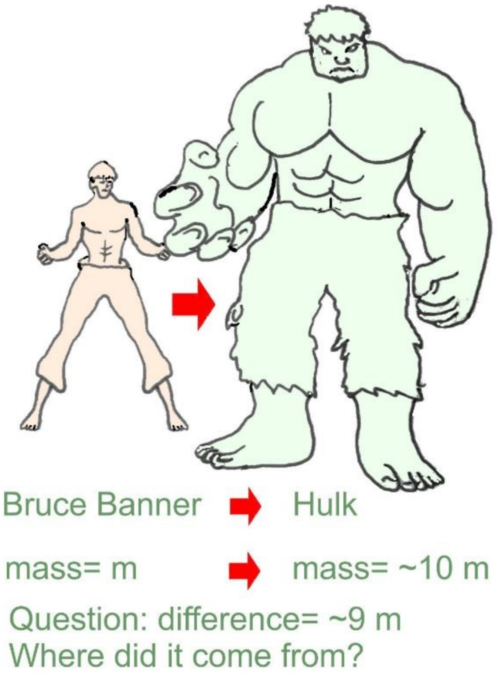
1. How could his mutation break the fundamental *Bilateria* rule of having two pairs of limbs, a trait that has remained unchanged

for approximately 375 million years?

2. How can his wings have feathers—an exclusive synapomorphy of *Aves*? Achieving such a level of evolutionary convergence is impossible.
3. All flying tetrapods (e.g., birds, bats, pterosaurs) have centrally positioned wings to maintain balance, yet Angel's wings are attached near his shoulders. This would make his flight completely unbalanced, with his legs hanging awkwardly below him.
4. Flying creatures require powerful muscles to flap their wings—where are his? The issue worsens when considering that he lacks pneumatic bones and air sacs, adaptations that make birds lighter. Without these, he would need even more muscle mass to stay airborne, further complicating his flight.
5. Any engineer could calculate that his wings would need to be significantly longer and wider to generate enough lift for such a large body.

And the list goes on if we let our critical imagination take flight: What sustains and propels Superman in the air? How much food must Cyclops consume to generate the immense energy required for his optic blasts? The questions are endless.

This issue parallels a fascinating phenomenon observed in some mollusks—the ability of a large body to compress itself into a shell much smaller than its own size. This, in turn, brings to mind another comic book paradox: the case of the Hulk (Fig. 2).



2: The Hulk paradox when Bruce Banner becomes Hulk, he gains mass. Where did it come from? When he reverses the process, where does the mass go? The Hulk mass "~10m" is only an average.

Everyone knows the Hulk—one of Marvel's most iconic heroes—who emerges from the incredible transformation of Bruce Banner. This ordinary man, weighing around 70–80 kg, morphs into a towering green beast weighing anywhere from 500 kg to nearly a ton of pure muscle (Fig. 2). Like many, I love the Hulk.

However, if we analyze Banner's transformation scientifically, a major question arises: What happens to the difference in mass (*m*)? Where does the extra mass come from when Banner becomes the Hulk? And where does it go when he reverts to his original form? This presents a fascinating paradox!

Well, obviously, I don't have the answer to this question—or to any of the others mentioned above. These are all examples of poetic license and artistic freedom, allowing us to escape into a world of fantasy. After all, this departure from realism is precisely what we seek when choosing to watch a work of fiction.

What matters in the malacological context is the analogy to certain mollusks that, despite having a large body when active, can retract into a shell several times smaller when disturbed. Since this ability in some mollusk groups, discussed below, resembles the transformation of the

Hulk, I introduce the term “Hulk effect.”

However, unlike the fictional case of the Hulk, the gain and loss of mass in mollusks can be scientifically explained, as will be detailed in the following sections.

The molluscan “Hulk effect”

3: *Neverita lewisii* (Florida) exemplifying the Hulk effect. A, specimen totally retracted inside its shell (courtesy José Coltro, Femorale) (W 30 mm); B, active specimen outside its shell (only seen in its middle region) (courtesy José Leal, Balley Matthews National Shell Museum), body volume is much larger than in retracted condition.

This phenomenon is particularly noticeable in gastropods living in unconsolidated substrates. For example, naticoideans are commonly observed crawling through sandy and muddy marine areas in search of prey, usually other mollusks (Fig. 3). They consume their prey by perforating the shells with the accessory boring organ (ABO), located at the ventral tip of the proboscis.

When active, naticoideans are massive creatures; their shells appear as little more than a central hump, surrounded by a large foot and its accompanying structures. They move through the sediment like a plowshare, with their large propodium (the anterior region of the foot) carving a path through the ground (Fig. 3B).

However, when disturbed, the animal can completely withdraw into its shell (Fig. 3A), occupying a space several times smaller than its extended body. Of course, this retraction is not instantaneous—it’s a relatively slow process, akin to an intricate ballet, and the speed of the movement depends on the severity of the disturbance.

A similar phenomenon occurs in other gastropods beyond naticoideans. While the degree of difference between the contracted and extended body varies considerably, it is always distinct. Examples can be found in vetigastropods, such as certain haliotids and fissurellids; other caenogastropods, including some cypraeoideans, volutids, marginellids, cysticids, and harpids; and in heterobranchs, such as several cephalaspideans.

Other mollusk classes also exhibit variations of the Hulk effect. In polyplacophorans, for example, the acanthochitonids display this phenomenon. In bivalves, a similar process occurs in myids and galeommatids. While the physiological mechanism behind the Hulk effect in mollusks is similar across these groups, it is explained here primarily in gastropods. In this taxon, the process of retraction into the shell is better understood and will be discussed further below.

Physiological mechanism of the Hulk effect

The following explanation is not necessarily based on focused experiments but rather on empirical observations and indirect results from parallel studies (e.g., Potts, 1967; pers. obs.). A generic shelled gastropod is schematized in Fig. 4A, where the topology and names of the key structures relevant to this discussion are shown. Some structures are located in the head-foot (brown, labeled ft, hd, he), while others are situated at the intersection of the visceral mass (pink, vm) and the pallial cavity (white, py), forming the reno-pericardial structures, including the kidney and the heart.

The phenomenon of the Hulk transforming into Bruce Banner—where the massive head-foot structures retract into the shell, reducing their volume to fit inside—is depicted in Fig. 4B. The forces and fluid flow involved are represented by red arrows. The first step is the contraction of the head-foot (step 1), along with the contraction of the columellar muscle (cm). This generalized contraction of the head-foot increases blood pressure, particularly in the haemocoel (he).

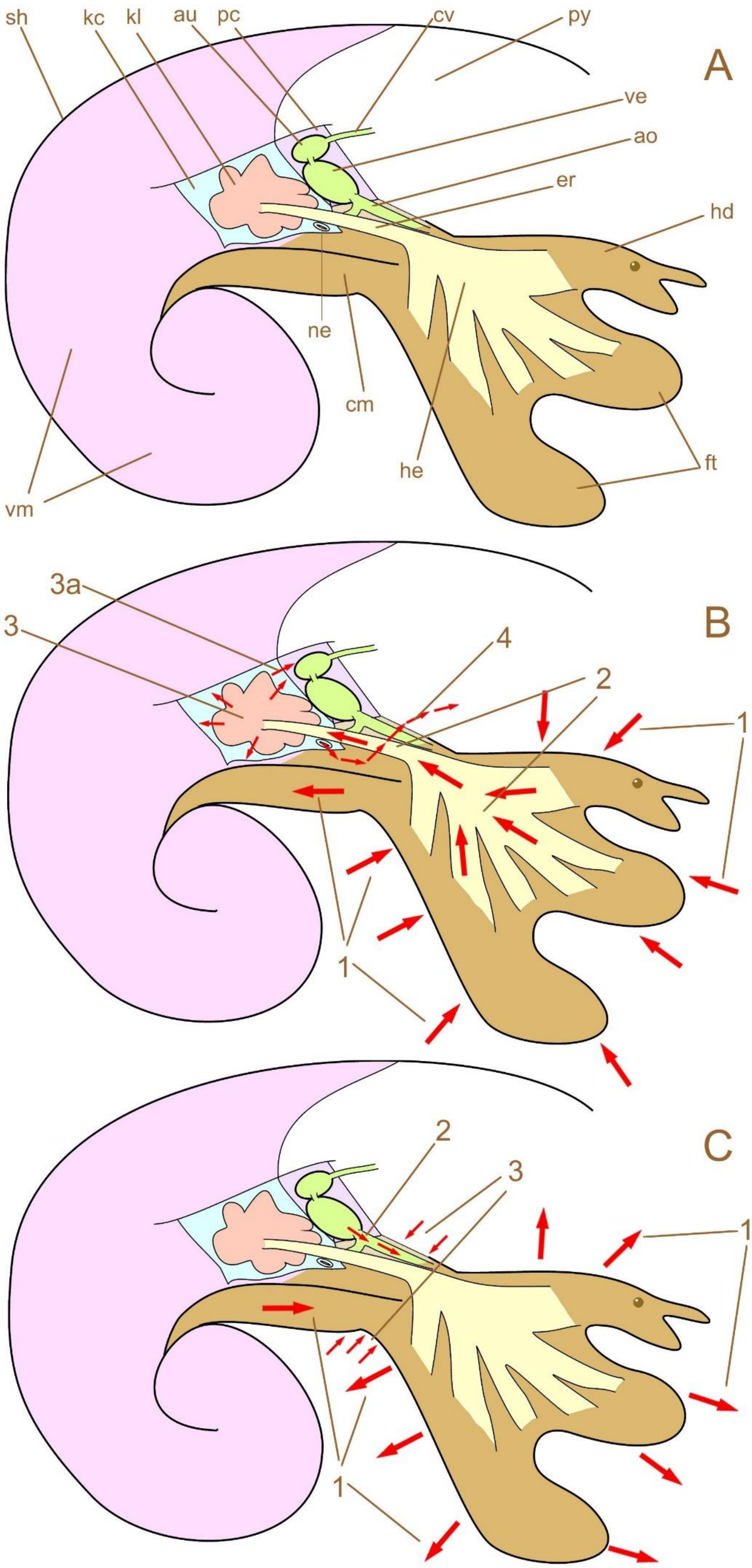
The only way for the haemocoelic blood to escape is through the efferent renal vessel (er) (step 2). The efferent renal vessel has several branches that extend along the renal lobe (kl). The renal lobe filters the blood, capturing as many electrolytes, nutrients, and other important substances as possible, depending on the urgency of the situation (step 3). Some of this filtered blood transudes into the pericardial cavity and is used by the organism (step 3a). The remaining fluid is excreted into the renal cavity (kc) as urine, or emergency urine, which is then expelled into the pallial cavity via the nephrostome (ne) (step 4) and released into the environment.

In a typical, non-stressful situation, the animal can contract slowly, allowing the renal lobe to process the blood adequately so that only water, unnecessary electrolytes, and metabolites are excreted in the urine. However, in an emergency—such as an attack by a predator or a biologist—the animal prioritizes survival and may be less efficient in capturing vital blood components. This can be likened to the "lizard losing its tail to save its body" strategy seen in these mollusks. Even so, as previously mentioned, the retraction of the large foot inside the shell is not an immediate action. It is relatively slow, as it relies on the mechanism described above.

Gastropods, and mollusks in general, with smaller feet exhibit quicker and more effective retraction into their shells. This is because their structures are sheltered in a permanent hollow provided by the pallial cavity. The pallial cavity is usually large enough to accommodate exteriorized portions of the mollusk. This is particularly evident in land snails, which possess large mantle cavities (lung) and cannot afford to waste fluids.

However, it's important to emphasize that this discussion pertains to mollusks, specifically gastropods, where the foot is much larger than the shell itself, yet they possess the ability to retract it fully inside the shell.

Of course, the evolution of large-footed gastropods and bivalves has often led to taxa that no longer have the ability to retract fully into their shells. For example, the naticoideans, which gave rise to the subfamily Sininae, include genera such as *Sinum*, where the shell serves only as a



4: Schematic representation of a generic shelled gastropod showing the organs and structures important for retraction of head-foot inside the shell. A, indication of the structures only (no for proportions, topology in average localization); B, representation during retraction. C, representation during protraction. Explanations in text. Lettering: ao, aorta; au, auricle; cm, columellar muscle; cv, ctenidial vein; er, efferent renal vessel; ft, foot; hd, head; he, haemocoel kc, kidney chamber; kl, kidney lobe; ne, nephrostome; pc, pericardial cavity; py, pallial cavity; sh, shell; ve, ventricle; vm, visceral mass.

central appendage to protect the visceral mass. The foot has grown so large that it no longer fits inside the shell.

In bivalves, the Pholadidae provides another example: genera like *Martesia* allow the entire specimen to fit inside the shell, while related genera like *Cyrtopleura* have evolved so that the foot and siphons remain permanently outside the shell (Stakowian & Simone, 2021). The evolutionary trajectory continues in the related family Teredinidae, where the shell is reduced to a vestigial structure.

In gastropods, this evolutionary path is part of the limacization process, as discussed in Simone (2018).

The reverse process of Bruce Banner becoming the Hulk—that is, the expansion of the foot after its retraction inside the shell—is represented in Fig. 4C. The first step is the complete relaxation of the head-foot musculature and the columellar muscle (step 1). The inflation of these structures is driven by hydraulic inner pressure. The main force behind this process is the heart, as large-footed gastropods also possess large hearts, particularly the ventricle (ve) (step 2).

The gradual pressure within the haemocoel causes the head-foot structures to expand. However, at a certain point during inflation, more internal regions of the foot also contract to help distribute the blood to more peripheral areas (step 3). The expansion of the head-foot is also supported by the uptake of environmental water, primarily through the digestive tubes. For this reason, there is always a physical connection between the digestive tubes and the pericardium in mollusks.

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