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Biomimetic Dolphin-Inspired Fin Designs and Underwater Prosthetic Applications

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Abstract. This study synthesizes contemporary research on dolphin-based fins and applies the acquired concepts to the design of prosthetic limbs for amputee swimmers. Three specific studies are assessed, namely: 1) The fluid–structure interaction of bionic dolphin tail fins reveals that flexible fins with greater dynamic thickness at the leading edge and varying thickness profiles offer enhanced propulsion and efficiency at biologically relevant Strouhal numbers, when compared to uniform rigid non-biomechanical fins; 2) an adaptive fin featuring a shear-stiffening gel "compound joint" fin, which dynamically alters between relatively soft and stiff states, generates propulsion comparable to that of rigid fins while exhibiting significantly less fluctuation in the applied force; and 3) a fin emulating the stiffness gradient of a sunfish provides approximately 25 - 26% greater propulsion for a constant input power compared to a uniform stiffness control, indicating that stiffness gradients are advantageous over constant stiffness. Collectively, these studies illustrate the benefits of biomimetic fins, including tailored flexural properties, optimized geometries, variable material properties, and organized vortex shedding, which contribute to an increase in propulsion, efficiency, and stability. The latter part of the report applies these concepts to real-world instances, such as The Fin, AMP Fins, and prosthetic animals like Winter's dolphin tail, demonstrating how biomimetic fins not only enhance speed and maneuverability but also improve comfort and satisfaction for gene-reduced systems in comparison to conventional paddle-type devices. Overall, the available evidence suggests that biomimetic fin architecture represents a feasible approach for the design of next-generation underwater prosthetics.

Keywords: Biomimetic fins, Prosthetic limbs, Fluid–structure interaction, Stiffness gradient, Propulsion and efficiency

1. Introduction

Dolphins and other marine animals are capable of efficient propulsive motion due to the evolution of their fin and fluke designs. The engineering of swimming devices to support human underwater propulsion has garnered much interest and inspiration from biomimetic designs that mimic the fins of biological creatures. This interest is due in part to the advantages of oscillating fins as thrusters compared with propellers, which tend to be stiff and rigid. Oscillating fins can produce thrust in both rigid and flexible orientations more efficiently and with greater maneuverability than propellers, and

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they completely avoid the risk of entanglement. The research has centred on shapes and materials similar to dolphin fins that maximize fin thrust, allowing for swimmer stability, and further exploring means of translating dolphin performance through biomimicry into engineered technologies. The report will focus on three studies, all of which utilize biomimetic or dolphin-like fins (with non-biomimetic fins serving as controls). Additionally, it will explore the application of biomechanical physics to underwater prosthetic limbs, considering both biomimetic and non-biomimetic fin designs for swimming applications [1].

2. Research on dolphin-inspired fin designs and performance

Several research teams have developed dolphin-inspired fins and measured their performance against conventional designs or alternative stiffness configurations. Here, we summarize three credible studies and their findings [2-4].

Flexible vs. Rigid Dolphin Tail Fin (Fluid-Structure Simulation): Wang et al. used fluid–structure interaction (FSI) simulations to research a bionic dolphin tail fin. They developed six fin designs by altering film thickness profile and material stiffness (from flexible “biomimetic” materials to rigid. The control design had uniform thickness and stiffer material, while biomimetic designs had a thicker leading edge with more elastic material. The fin was oscillated up and down at different flapping frequencies, and thrust force and efficiency were calculated through simulation and experiments using force sensors. Key findings: At higher flapping frequencies (0.8–1 Hz), the most flexible, biomimetic-material fins produced higher thrust force and propulsive efficiency than stiffer fins. For variable-thickness (V) and equal-thickness (E) configurations, the ranking was most flexible > medium > stiff, showing greater flexibility enhances propulsion at higher frequencies. Fins with variable thickness profiles had higher thrust coefficients than those with equal thickness. The authors attributed this to leading-edge suction, where the thicker leading edge creates a low-pressure region and additional suction thrust. They concluded it's a dolphin-like morphology that causes the fin to move forward while pushing water backward. Vortex shedding from fin oscillation was the most significant source of thrust. The biomimetic design produced greater net forward movement than non-biomimetic ones. The most biomimetic design (“VF”) produced the highest average thrust and efficiency, especially at Strouhal numbers of 0.3–0.4, while the control fin (“ES”) produced the lowest. Overall, the study suggests altering fin flexibility and shape based on dolphin physiology increases propulsion, and increased uniform stiffness limits propulsive potential at a specific oscillation frequency [4].

Adaptive Variable-Stiffness Fin (Shear-Stiffening Gel vs Rigid vs Flexible): Kobayashi and Jonishi designed an innovative bio - inspired oscillating fin with variable joint stiffness, similar to real fins at high speeds. They embedded a shear - stiffening gel in the fin base. The gel is “soft” at low speeds and stiffens at high speeds. The design mimics fish/dolphin fins that are flexible at low speeds and stiff at high speeds. The authors tested three fin configurations on a robotic flapper: the Compound Joint (with shear - stiffening gel at the base), the Rigid Joint (no base flexibility), and the Urethane Joint (fully elastic base). All had the same fin blade shape, varying only in joint stiffness. They oscillated the fins in a yawing motion in a water tank and measured thrust forces. A “speed - ratio control” drive pattern was used, with higher speeds during positive - thrust phases and lower speeds during negative - thrust phases, mimicking real swimmers.

Conclusions: The rigid fin had the highest peak forward thrust but also the highest negative thrust as it couldn't flex. The fully flexible urethane fin had minimal negative thrust but the lowest average forward thrust due to excessive deformation. The compound gel fin showed a balanced response, producing more forward thrust than the flexible fin on the return stroke by stiffening at high speeds

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and retaining low negative thrust at slow speeds. In fast - oscillation trials, the rigid fin had the highest average thrust but the most variable output. The gel - based fin produced average thrust nearly equal to the rigid fin with less variability, resulting in more stable propulsion. Overall, the compound design offered the best performance balance, achieving near - thrust performance like the rigid fin while maintaining the flexible fin's stability. The original study provided visual evidence, showing the compound fin had a smoother and more consistent output curve. Forces were calculated. Thrust was directly measured in Newtons using a load cell connected to each fin's base. Fins were tested under controlled motion, with angular position and velocity recorded. Net thrust was computed per oscillation cycle using thrust - time data for performance analysis, followed by a statistical analysis for thrust repeatability. Trials were done across cycle durations of 3.0s, 2.5s and 2.0s at different speed ratios. As flapping frequency increased, thrust output rose, but not at an equal rate. The flexible fin reached a performance ceiling quickly due to excessive bending and had limited useful force. The rigid fin produced the highest overall thrust but had significant variation, indicating perturbation. Compound fins produced stable thrust with less variation compared to regular and rigid fins even at higher fin speeds. These findings support the effectiveness of the biomimetic approach, especially for flexible structures that can morph under oscillation propulsion like dolphins. A fin with variable stiffness may provide some systems with the most power and stability compared to stiff or uniformly soft fins.

Biomimetic vs Uniform Fin Stiffness Distribution (Sunfish Fin Study): Riggs et al. Meyer was an earlier but still intriguing comparison of a biomimetic flexible fin to a non-biomimetic fin. They did not use a dolphin for inspiration, but rather a pumpkinseed sunfish (a bony fish), which has a fin stiffness profile where the leading edge is stiffer and the trailing edge more flexible. They made two artificial fins that had the same external shape (a NACA0012 airfoil design) – one at uniform stiffness across the chord (front to back) and one with a biomimetic stiffness gradient (stiffer front edge, more flexible rear, with measurements of the fish fin bending stiffness profiles). Both fins were oscillated sinusoidally in the water at varying frequencies and amplitudes, during which static thrust, input torque, and other forces were recorded. The "uniform" fin in this case is statistically the control design of a typical engineered foil constructed of a uniform material, and the biomimetic fin is structurally representative of a fin of a fish. Most notably, Meyer reported that the biomimetic stiffness profile fin gave superior performance to the uniform fin. Summarily, across all tested conditions, the biomimetic fin produced more thrust, specifically more static thrust (the forward force measured when the fin is oscillating in place), for the same oscillation parameters.Furthermore, the total thrust produced by the biomimetic fin possessed less variation in instantaneous force across the entire flapping cycle, indicating more uniformity in propulsive mode. Lastly, in the analysis of propulsion efficiency, it was reported that the biomimetic fin generates thrust exceeding 26% more than a uniform-stiffness fin per unit input power, indicating that the fin produces more thrust while using less energy, thereby corroborating the notion of "propulsive efficiency." The apparent improvement of ~26% in thrust-to-power was an impressive validation of the value of mimicking nature's internal fin design. The researchers further validated that this was not simply due to changes in the overall flexibility of the fin or its rigidity, but rather to the distribution of stiffness within the fin. All assessed fins, which exhibited differing absolute stiffness but retained the biomimetic profile, exhibited accelerating performance. Conversely, fins that did not mimic the profile could not accelerate beyond that of the uniform fin, suggesting that stiffness patterning, and not stiffness per se, presents opportunities for engineering enhanced fin performance. These results corroborate prior work, which shows that the non-biomimetic design (uniform stiffness) compromises the performance outcome relative to natural structures. In contrast, bio-

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inspired designs produced flexibility at appropriate locations along the fin, resulting in greater thrust and improved propulsive efficiency [2,3]. Force was calculated from Torque. Input power was estimated from the rotating pitching motor: measured as the torque applied from the pitching motor against its angular velocity. Thrust-to-power is often vernacularly termed "thrust per watt," which serves as a measure of propulsive efficiency. Although the abstract did not include explicit equations, thrust can certainly be inferred from well-established fluid dynamics, including lift and momentum transfer. A 26% performance gain is a real improvement, based on the assumption that the biomimetic fin produced greater thrust, either by displacing more water or accelerating it faster than the uniform fins when provided the same energy input. Riggs et al. comments regarding what this gain in performance means as it applies to natural features inherent in the structural design, and originated specifically from a distribution of stiffness along the fin chord—not just flexibility or rigidity, stiffness distribution, i.e. flexibility patterning is what likely provided an engineered opportunity (and maybe the only one) to design fins and similar animal appendages to mimic potential natural flexes better. Fin designs can be purposefully designed such that gradient materials, structures or layering can mimic flex identical to nature, and specifically relate to thrust production and thrust return when all things are equal.

3. Research results summary

A definitive pattern across these studies (and throughout the relevant literature) is that biomimetic (nature-inspired) fin designs tend to outperform non-biomimetic designs in underwater propulsion. Some themes include:Structures with an appropriate amount of flexibility--Having the right amount of flexibility is a tremendous advantage to thrust and efficiency. Indeed, flexible fins can store and release elastic energy, developing hydrodynamic shapes (curvatures) that increase thrust, whereas rigid designs cannot. However, flexibility must be tuned--too much flexibility, unopposed (as with a uniformly flexible fin), means thrust will be diminished. Nature's structures exhibit multiphase stiffness, which has been demonstrated to be superior to using rigid structures [2,4]. Geometric shape profile--Whether the uncertainty is due to gross shape (outlines) or even thickness, there is an advantage due to shape, much more significant than the stiffness. Dolphin-like fins have a thick leading edge and a tapering, thin trailing edge, and take advantage of the leading-edge suction phenomenon where there is more mass that accounts for thrust, even more than a flat, even fin or uniform structure. The planform (side outline) of dolphin flukes and fish tails (often swept-back triangular) may also lower tip vortices and improve efficiency. Still, the studies primarily focused on the intersection of thickness and stiffness [1,4]. Adaptive/variable properties--Nature's swimmers can change dynamically how stiff or how they move their fins. Biologists and engineers mimic this performance (like with innovative materials such as shear-thickening gels and effective timing) and often increase balance, e.g., high thrust only when needed, but drag is minimal in recovery. Herein, a non-biomimetic design can only choose between two options: high thrust or stability. The study of the compound fin indicated that a rigid fin with a single pattern can produce the maximum high-thrust, but with large fluctuations in forces experienced by the fin. A biomimetic variegated fin was able to dampen fluctuations in thrust while making a substantial high-thrust output.Thrusting Mechanisms: Fins generate thrust by pushing water backwards, in accordance with the third law of Newtonian motion. In a fin that flaps, that backward force is usually achieved by inducing vortex pairs into the water surrounding each half-stroke. A biomimetic fin based on the morphology and motion of natural-world swimmers, such as dolphins and many fish, typically generates a classic pattern of highly organized vortices, known as a vortex street, which effectively directs momentum towards the rear of the fin and enhances forward propulsion relative to those drag forces. Non-

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biomimetic fins tended to produce less organized water flows or dissipate energy when moving laterally, thereby reducing overall thrust effectiveness [2,3]. Researchers evaluating the complaints or effects of thrust on animals and structures often use the concept of Strouhal number, which is a non-dimensional number that links stroke frequency and amplitude of oscillation to the velocity of forward swimming. In nature, efficient swimmers operate within a narrow range of Strouhal numbers, approximately 0.2 to 0.4; this range represents an ideal balance between fin motion and swimming speed for producing thrust with minimal drag. The dolphin fin shape used in this study exhibited peak performance when occupying the same range, demonstrating distinct advantages in not only reproducing the joint shape of biological systems but also considering the repetition of motions. This highlights that both the shape and the kinematics of a fin are essential factors to consider for maximizing swimming thrust efficiency. Having established that biomimetic fins produce greater force output and efficiency, we now turn our focus towards the application of these design principles to underwater prosthetics. These devices support humans (or other animals) who swim following limb loss [4].

3.1. Biomimetic fin designs in underwater prosthetics

Underwater prosthetics are custom-designed artificial limbs or attachments for amputees (or even injured animals) that enable efficient swimming coordination. Underwater prosthetics used to be very basic, such as plastic "flippers" or paddle-like attachments. Engineers are now incorporating features inspired by nature, such as those found in dolphins, fish, and marine life, into their designs by utilizing biomimetic fin features [1].

An example of a biomimetic swim prosthetic is The Fin, a 3D-printed amphibious prosthetic leg/fin designed by Northwell Health for amputee swimmers [5]. The Fin is constructed to be an ergonomic fin-like shape with properties of effective fin materials (carbon fibre reinforced nylon) to simulate the strength and flexibility of a natural fin. Essentially, the Fin is designed so an amputee can walk on the ground and jump back into the water without having to change out their prosthetic. This is possible due to the ingenious, flexible adaptations of the leg and fin components working in sync. The Finfeaturess features an A-shaped blade that can effortlessly attach to the socket portion of the prosthetic leg, thereby acting as an artificial fluke when entering the water or using a monofin. The anatomical nature of the V-shape displays like a dolphin tail or a pair of fins working in conjunction to perform what is commonly referred to as a dolphin kick. In practical terms, this has enabled amputees, such as Dan Lasko, a veteran, to swim powerfully using a dolphin-like motion, which is extremely difficult with any standard prosthetic limb [6]. The prosthetic is made of lightweight carbon fibre and features a dynamic shape, allowing it to be stiff enough to walk on while also forming a hydrofoil for efficient swimming [5].

Another example is AMP Fins LLC, which designs and manufactures swim fins for amputees. The AMP fin is attached to the socket of the leg prosthesis after the user removes their regular foot from the leg prosthesis, turning the leg into a large flipper. The design focuses on a high-performance fin blade design that likely employs biomimetics (for example, the design likely utilizes a wide surface area and/or flexible materials in the fins' blades to simulate the fin of a fish). The convenience of the end-user design is undoubtedly a bonus: it takes just two screws for a user to switch their walking accessory foot from one pedal option to another. Once the AMP fin attachment is added, the amputee can dive into the water, swim, and propel themselves through the water with significantly more ease than without the fin. By mimicking some of the properties of aquatic fins, the design significantly enhances the range of motion of the amputated limb while providing an excellent and healthy range of motion. These companies are effectively applying the biomechanical

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lessons from aquatic organisms to prosthetic design, allowing users to enjoy swimming as a natural human capability while also providing therapeutic benefits [5,6].

It should be mentioned that it is not just humans who benefit from biomimetic fin prosthetics: aquatic animal rehabilitation groups have used biomimetic fin prosthetics, and an iconic example is Winter the dolphin, who lost her tail and was fitted with an artificial tail; Winter was equipped with a synthetic tail that was based on a shape and flexibility of the natural dolphin tail, and, more importantly, led her to relearn a natural down and upward swimming motion. Another biomimetic design innovation with Winter was the creation of a soft silicone sleeve (or liner) to attach the artificial tail without irritating contact to her skin. The soft silicone sleeve design is a biomimetic material solution (the soft sleeve is designed to mimic the soft cushion and compliance of biological tissues of aquatic organisms) but has a broader impact; the special silicone gel sleeve is utilized for human amputees (such as American war veterans) to improve comfort fitting with their prosthetic Swedish incidence surface images. This type of cross-application is ironic when considering the origins of biomimetic design ideas [1].

3.2. Benefits of prosthetic design

The application of biomimetic fin designs to prosthetics offers several advantages over conventional fin designs.

More Thrust and Speed: A fin that has a shape that resembles a dolphin's tail or a fish fin will create more thrust in the water than a flat paddle fin or foot, thus allowing amputation swimmers to swim faster and with less effort. The study regarding the biomimetic stiffness-profile fin from study #3 showed that it generated 26% more thrust per watt than the uniform design, demonstrating its efficiency. For a prosthetic user, this could translate to swimming farther with each kick. Furthermore, users of the fin have reported a stark increase in swimming ability, essentially gaining dolphin-like propulsion power [2,3].

Stability and Control: Biomimetic designs tend to provide a smoother thrust, which is crucial for maintaining balance in the water for a prosthetic user. A rigid fin can lurch with each kick or put strain on a user while swimming, while a flexible fin smooths out the force. The dynamic gel study demonstrated the importance of a variable stiffness fin, which was shown to decrease fluctuations in thrust. For a prosthetic user, establishing a more stable, comfortable swim may lead to increased distance without jolting strain extending through the leg. Users will feel more comfortable controlling their movements, as if with a real limb, because the fin would "give" according to the water's variable resistance [4].

Natural Motion and Lower Exertion: The design innovation restricts fins on natural leg or tail motion (i.e., dolphin kick or flutter kick), allowing fluid engagement of larger muscle groups while reducing exertion. For example, AMP Fins notes that a fin can increase strength in a residual limb and improve range of motion (as it is biomechanically sound), while strapping on a more conventional non-biomimic device (imagine strapping on a rigid board) can damage tissues or energy while misusing the leg without any of these properties. The ergonomic shape of The Fin, designed for users with lower limb amputations, enables them to dive and swim more naturally, rather than relying on unnatural techniques of propulsion through the water [5,6].

Natural Transition from Land to Water: Some biomimetic prosthetic fin designs are also created to be amphibious or interchangeable at will, or for practicality. For instance, The Fin has similar engineering insights; thus, the design incorporates flexing features based on stiffness in the engineering process, allowing it to switch between using the fin while walking or when swimming. Without considering stability, it has competently balanced adequate stiffness for walking, while also

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creating a flexible experience while swimming. Traditional solutions would require peri-prosthetic users to switch to less convenient substitutions and change to the "swim leg" [5].

In conclusion, biomimetic underwater prosthetics leverage the same principles that enable dolphins and other fish to move efficiently in water —flexible fins, surface-wise shaping, and actuated materials—and adapt them for humans to facilitate improved water movement. The following section examines the effectiveness of vor versus non-vor propelling versions of the fins in relation to the prosthetic users highlighted in this section [1,5].

4. Biomimetic vs non-biomimetic designs for underwater prostheses

When creating an underwater prosthetic fin, we can work with a biomimetic (a natural fin shape) fin and/or a more traditional model (a design that is purely non-biological).

Thrust and Efficiency: Biomimetic designs win easily here; as we just noted, a fin that mimics the shape and flexibility of a dolphin or fish fin will create more thrust for the same amount of work than a paddle or stiff fin design. Pragmatically, an amputee swimmer with a dolphin-like monofin will swim significantly faster and with significantly less effort than if equipped with a simple paddle attachment. Non-biomimetic designs often require a higher energy input (i.e., stiff, fast kicking) to achieve the same thrust level. For example, an amputee swimmer with a simple rectangular rubber fin would not realize the benefits of functional vortex dynamics (as I noted previously) that can be achieved with something dolphin-tail shaped with swept fin tips and an appropriate amount of flex. Wang et al. found that biomimetic structural elements, specifically in animals (and recommended they be used for underwater devices), produced better propulsion than non-biomimetic structural elements.

Control and Maneuverability: Additionally, a prosthetic fin that functions biomimetically will further allow for maneuverability. Dolphins not only make tight turns and make precise movements because of their fin structures, but also the manner in which their fin structures flex and bend, changing the water they are swimming through.

In a biomimetic prosthetic fin, it is possible to have a flexible fin that is often split as I describe above (like the two lobes of a fish tail or two halves of a whale fluke), which may allow the amputee to maneuver more easily with small movements of their leg or stump. In comparison to biomimetic fins, non-biomimetic fins, and exceptionally rigid non-biomimetic fins, the latter will actuate more like flat boards than fins and are less versatile in reorienting the user or adjusting the arms and legs under the water surface. The subsequent comparative study involving compound gel biomimetic fins revealed how variable stiffness properties (a feature of bio-inspired materials) also engaged a reasonable degree of thrust to improve speed and propulsion, but provided stability that can improve performance during the stroke. In terms of an individual using a prosthetic fin, a user can kick hard for speed while also having the inherent flexible material and resiliency of the fin help to sustain the position of the movement in the water and avoid a sudden side pull against the fin and/or excess lost balance disturbance in the limb or the user's limb. A more non-biomimetic fin with a basic mechanical construction or stiff nature could provide the hard kick. Still, in that stiff category of a fin, when pushed to the limit, the swimmer would either stop progressing forward immediately or experience a change in their balance due to the stiff fin's mechanical nature [2,3]. Comfort and Biomechanical Strain: Most biomimetic and bio-inspired fins work in concert with the stabilization of water and body, while non-biomimetic fins work against it. For example, the dolphin-inspired fin, with the passive flexing design at the base of the fin, activates both the limb that is initiating and/or supporting the stroke, then returns that energy with stability, with higher passive fluid drag just past the centre of the fin going to the tip of the fin, but aiding the forward propulsion. In some cases, for

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an individual amputee, it contributes to reduced peak total stress on the knee or hip of the residual limb. On the other hand, in the case of a stiff fin with residual limb forces acting on the joint surfaces surrounding the knee or hip, it will shock the joint for a more extended period with the use of a stiff fin in water, often resulting in discomfort or biomechanical injuries over time [6]. A siphoning effect, then, of a smooth or stable slippage that can occur with simple fins and more variable compostable and biodegradable materials, has real meaning in performance as one of the more critical comfort factors overall - it prevents the user from oscillating back and forth. Prosthetists frequently highlight that a design like The Fin reduces stresses on the residual limb by distributing loading forces amongst all points of the limb. User anecdotal evidence shows they can swim longer without pain. Non-biomimetic fins may present issues of chafing and/or pressure if not shaped “correctly," and the ergonomic shape of these biomimetic designs (curved to catch water, contoured for the user) assists with that issue [5,6].

Actual Outcomes: The ultimate test lies in the user experience. The Fin and AMP Fin (biomimetic designs) have enabled sustainable activity levels for some amputees of all capacities, allowing them to "dive back into the water" that was previously impossible without these devices. They have converted the use of the prosthetics to provide them with a means of locomotion that feels powerful and natural. Then consider if one were to try to strap on a non-biomimetic device (like a simple scuba diving fin, that could be bought at any store) that could be fitted to a prosthetic attachment. You would find it challenging to be efficient in your swimming, or at the very least, it would be helpful. The fact that there are companies actually specializing in these biomimetic swim prosthetics suggests that generic solutions were not adequate. Winter’s (the dolphin) pathed-tail prosthesis was a successful underwater application of a biomimetic shape and soft interface, indicating that if the human prosthesis could mimic natural designs, animals could functionally succeed. Winter was able to relearn the proper mechanics of swimming and returned to inspire prosthetics for humans. The complexity of design versus possible benefits: It should be noted that biomimetic designs can be much more complex as well (advanced materials, carbon fibre, smart gels), featuring thicker shapes that may require more consideration and are therefore more complicated to manufacture than a store-bought simple fin. However, the performance gains and user experience satisfaction typically justify the additional complexity when considering the design of a prosthesis, where the intent is to sustain activity and/or enhance user ability. Non-biomimetic fins are typically easier to manufacture and generally less expensive to use, due to their lower complexity; however, they also tend to result in a performance compromise. Advancements in modern fabrication (e.g., 3D printing, such as The Fin) have enabled the overcoming of complexity and the building of ergonomic, custom-shaped fins without incurring unnecessary costs. As technology continues to develop and we enter an era of increased biomimicry in designs through materials, shapes, and features, it is becoming evident that biomimetic features for underwater prosthetics have a viable future. At this point, high-end underwater prosthetic devices will likely incorporate them [1,6].

5. Conclusion

In summary, for underwater prosthetic solutions, biomimetic fin designs offer numerous advantages and features over non-biomimetic designs, including increased thrust, improved efficiency, enhanced stability, and a more positive user experience. By analyzing and mimicking the fin designs of dolphins, fish, and other aquatic creatures, designers and engineers have developed prosthetic fins that assist amputees in swimming with a sense of ease and power previously unattainable without these swim prosthetics. In addition, research has recommended that one utilize water propulsion

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design features like flexibility, proper fin contour and/or adaptive materials that increase force output dramatically (e.g. utilizing dolphin stiffness profiles has increased thrust (approx. 25%) per power produced compared to a simple fin design) in aquatic prosthetics that matter if someone is doggy-paddling or accurately using a dolphin kick. Therefore, biomimetics serve as a functional model for aquatic prosthetic devices, continuing to push designs towards a balance of human engineering and defensible development based on research into the effectiveness of quality of life and performance in water

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