

Design of Swimming Fins to Treat Patellofemoral Pain Syndrome

by

Helen Tsai

Submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the Degree of

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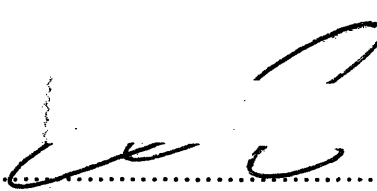
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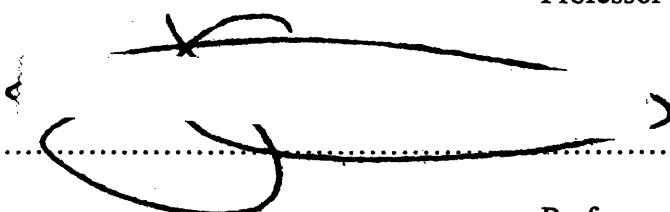
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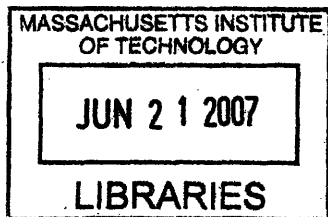
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Abstract

This thesis project involves developing a pair of swimming fins to strengthen the Vastus Medialis, or inner quadriceps muscle, to help patients with *Patellofemoral Pain Syndrome*. Configurations of mock up fins, made from Lexan, were designed based off of a known dry land exercise that consisted of leg lifts with the feet turned out 45 degrees that work the Vastus Medialis. From the feedback of a swimmer, new design iterations were made to compensate for how a person's body moves in the water as opposed to on land. An optimal design was chosen based off of testing.

Thesis Supervisor: Alexander H. Slocum
Title: Professor of Mechanical Engineering

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1. Introduction

This project aims to allow injured runners with *Patellofemoral Pain Syndrome (PFPS)*, also known as Runner's Knee Syndrome, to strengthen their Vastus Medialis, or inner quadriceps muscle, in the pool. The pool environment allows runners to continue to train and exercise with less pressure applied to the knees than when running. Current swimming fins available on-the-market serve a wide range of users, but do not meet the requirements of a runner with an injured knee that is looking for a way to strengthen his or her Vastus Medialis in the pool. The only option for treating PFPS in the pool is with aquatic biofeedback treatment that consists of aerobic exercises with a trained physical therapist. Although effective, this treatment requires the runner to hire a physical therapist and accumulate expensive equipment. For the runners that might not be able to afford such a treatment, or do not have that severe of an injury, a different option to work the Vastus Medialis in the pool should be available to them; hence, the objective of this thesis.

1.1 Motivation

Professor Alex Slocum, having pre-PFPS and being a triathlete, asked to have swimming fins developed that would help work the Vastus Medialis while training in the pool.

1.2 Current Fin Designs

There are many swimming fins already on the market, ranging from normal swimming fins, power fins, scuba fins, and more. Normal swimming fins work the down stroke of the kick, which mainly works the lower leg muscles and the outer three quadriceps muscles. Power fins such as the Zoomers and the Z, shown in Figure 1, were developed to balance a swimmer's kick and work the upstroke for the swimmer (same motion as the down stroke for a runner's stride)^[13]. With shorter fin tips, the power fin develops the upper leg muscles, focusing on the hamstrings, which is opposite of what this thesis desires to accomplish. Working the hamstrings will aggravate PFPS. New scuba fin designs, such as the split fins, also shown in Figure 1, propel a person forward with less exertion. The split fin geometry is designed for better efficiency to

allow users to go further distances without tiring him or herself. This particular design is not intended to provide an exercise workout, and therefore would not be suited for a design of a fin to work the Vastus Medialis.



Figure 1: Left two pictures are power fins: Zoomers and the Z, Right is a split fin ^[4,5]

Speedo's newest training equipment is a breaststroke fin, shown in Figure 2. The design has a unique side fin located on the outer side of the foot pocket that allows the swimmer to maintain the whip kick motion to provide a similar thrust as traditional fins would for the flutter kick.



Figure 2: Speedo's Breast Stroke Fins ^[7]

The breaststroke kick itself requires the knee to be positioned in a way that the whip motion would aggravate PFPS. If used as instructed, this fin design would not be a candidate for alleviating PFPS; however, these fins have the potential of yielding another result if used with a different kick.

Overall, fins that are on the market do not address the needs of runners with PFPS.

1.3 Treatment of Patellofemoral Pain Syndrome

A possible treatment of PFPS is an aquatic biofeedback treatment, Figure 3, developed by Ronald A. Fuller, a physical therapy assistant at HealthSouth Rehabilitation Hospital in Concord, NH ^[9]. The treatment consists of water-based aerobic exercises with feedback from a surface electromyography (SEMG) that measures the electrical potential generated by muscle cells when muscles contract. Although the treatment is promising, the amount of time, energy, man power, and equipment needed for this treatment is excessive if the injury is not too severe.



Figure 3: Aquatic Biofeedback treatment where the injured does aerobic exercises with a surface electromyography ^[9]

Figure 4 shows a common physical therapy exercise for PFPS patients: leg lifts on land with the feet turned approximately 45 degrees outwards ^[15]. The leg lifts help to strengthen the Vastus Medialis. The proposed thesis aims to integrate the leg lift exercise in the pool.



Figure 4: Leg lift treatment of PFPS with the feet turned out at 45 degrees

Most runners continue to exercise with pool workouts if they have knee injuries. The pool, having the properties of buoyancy, viscosity, and hydrostatic pressure, provides an excellent environment to treat injuries. Buoyancy helps alleviate the amount of forces acting on the knees, yet the viscosity provides enough resistance to still allow a work out. The hydrostatic environment allows the forces to be distributed across the body, and improves the muscle blood flow ^[18]. Swimming fins that aid in strengthening the inner quadriceps would allow runners with PFPS to strengthen their Vastus Medialis, recovering from their injury, as well as continuing to workout. No such fins yet exist and this is thus the subject of this thesis.

1.2 Background of Patellofemoral Pain Syndrome

Runners frequently injure their knees, and if not treated early, can lead to permanent damage. In a study conducted in 2002, the most common injury was Patellofemoral Pain Syndrome (PFPS), also known as Runner's Knee Syndrome ^[18]. Between 25–34 percent of the worlds population at one time or another will suffer from PFPS ^[14]. PFPS occurs from working the down stroke of the stride causing a muscle imbalance around the knee. Working the down stroke causes strong hamstrings and outer quadriceps muscles to overpower the Vastus Medialis (Figure 5), the inner quadriceps muscle, which runs along the inside portion of the thigh bone, causing the patella, or kneecap, to be pulled to the left or right. The patella protects the knee joint and under normal usage is able to slide vertically on a groove in the cartilage. The horizontal motion associated with the muscle imbalance causes the cartridge under the patella to grind away, resulting in pain.

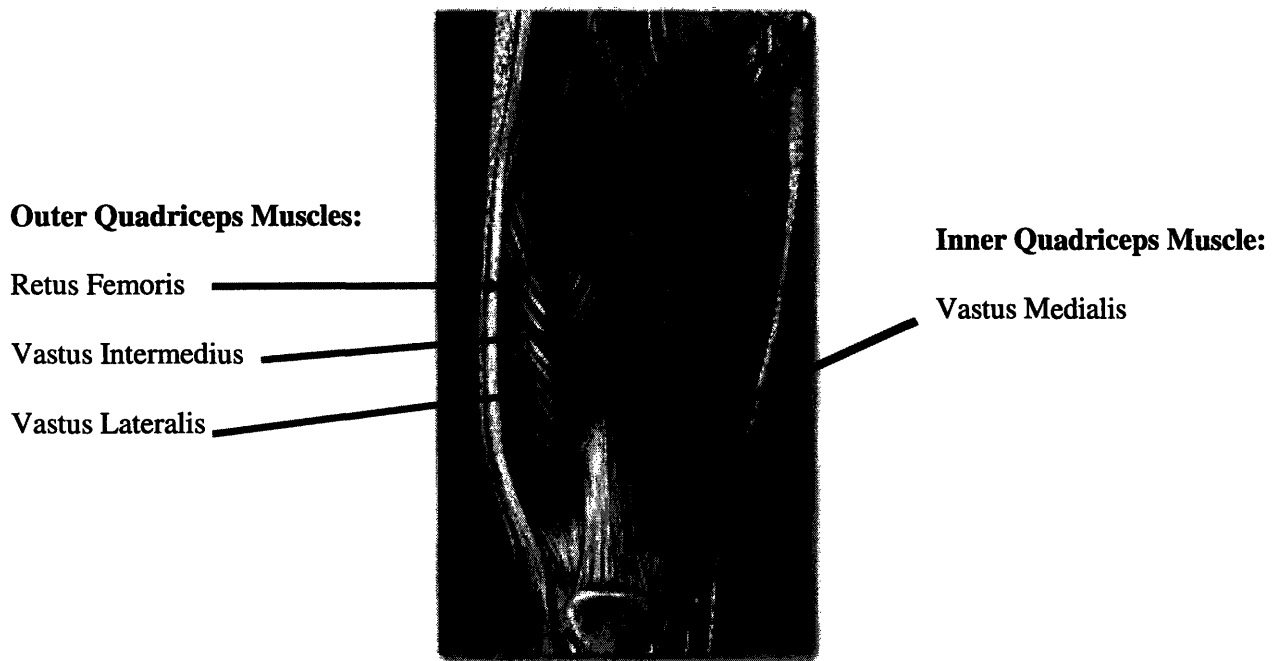


Figure 5: The Outer Quadriceps Muscles: Retus Femoris, Vastus Intermedius, Vastus Lateralis and the Inner Quadriceps Muscle: Vastus Medialis muscle ^[11]

The four quadriceps muscles maintain an overall force on the knee to help the leg extend. The effective angle at which the quadriceps pull the kneecap is known as the quadriceps angle, or Q angle, shown in Figure 6.

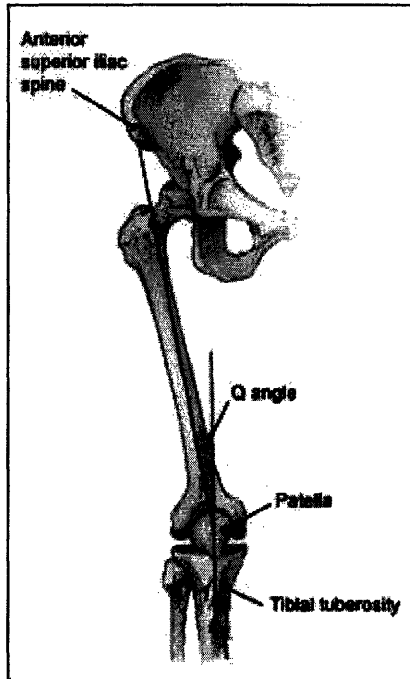


Figure 6: Quadriceps angle (Q angle) ^[12]

The Q angle is determined by drawing a line from the Anterior Superior Iliac Spine, to the center of the knee cap and a second line from the center of the knee cap to the insertion of the patellar tendon. A healthy male knee would have a Q angle of 14 ± 3 degrees and a healthy female knee would have a Q angle of 17 ± 3 degrees ^[21]. Higher Q angles would suggest in possible knee abnormality.

Running strengthens the hamstrings, which pulls the patella laterally and increases the Q angle. Due to its location, the Vastus Medialis is able to counter the hamstrings to stabilize the knee cap by pulling it medially, maintaining a normal Q angle. Other factors of a large Q angle include having: wide hips, knock knees, high patella, subluxating patella, and pronation of the feet ^[16].

As with all injuries, traditional treatments include rest and strengthening exercises at an early stage. The Vastus Medialis is worked during the last 30 degrees of a leg extension ^[1]. Leg lifts

with the feet turned outwards are recommended to PFPS patients to strengthen the Vastus Medialis. Along with leg lifts, patients are told to stretch their hamstrings and calf muscles.

2. Design Objectives

The objective of this thesis is to create swimming fins that increase the amount that the Vastus Medialis is worked compared to the other three quadriceps muscles by replicating the leg lift exercise in the pool. The leg lifts work due to having the back against the ground and gravity working to bring down the leg and rotating the feet 45 degrees outward. The dynamics of doing leg lifts in the pool differs greatly. This thesis first requires the study of how the body moves and rotates through a water environment to determine if it is possible to generate the feet turned out leg lift motion to work the Vastus Medialis with a swim fin device. If the motion can be replicated in the pool and is effective, the fin is then engineered and fabricated, accomplishing the objective of the thesis.

2.1 Constraints

2.1.1 Water Environment and SEMG sensors

Due to the nature of the thesis, all experimental tests of constructed fins need to be conducted in the pool. The wet environment provides significant constraints to using SEMG sensors to detect the electrical activity in the Vastus Medialis.

SEMG sensors need to be powered by electricity, either from a battery or an outlet depending on its capacity. It is a safety concern to have devices that require power around water environments because of the risk of electrocution. To limit this danger, only a nine volt hand held SEMG sensor should be used around the pool ^[10]. This way, even if water makes contact with the SEMG sensor, the user would only experience a light tingling sensation. On the other hand, if the SEMG electrode does come in contact with water, it would be ruined. Waterproofing the sensor

can be fairly difficult, and if not done well, hinders the cause. The best way to waterproof the sensor, providing the best water resistant barrier and saving setup time, is by using the Thought Technology's AquaSense™, as shown in Figure 7.



Figure 7: Think Technology's AquaSense™ with a SEMG sensor on a swimmer^[8]

The AquaSense™ is a plastic covering that slips over the leg and integrates a SEMG encoder. Although AquaSense™ provides a watertight barrier, it compromises the test because it interferes with the natural kick of the swimmer. In addition, the placement of the sensor, even with the AquaSense™ is variable each time. Therefore, even if it is found that a certain way of kicking that would work the Vastus Medialis using the SEMG and AquaSense™, the results are cannot be compared to each other consistently might change altogether if the AquaSense™ is not used.

The SEMG sensors can only examine muscles from the surface so it may not even represent the true muscle activity, especially with noise, artifacts, and crosstalk^[17]. Therefore, instead of using a SEMG sensor, testing relied on using the muscle itself as a sensor.

2.1.2 Facilities

Having foot pockets would eliminate several sources of discrepancies between various prototypes when testing because the feet would be positioned the same way in each case. They would also support the feet similarly in every trial. However, MIT does not have any rubber molding facilities to inject rubber foot pockets. Therefore, the Lexan prototypes that were developed were secured onto the feet with a variety of straps, silicon tubing, and shoelaces.

3. Design Analysis

3.1 Dynamics of Swimming

The first goal of the thesis is to understand human dynamics in water. Kicking is a means for a swimmer to gain thrust and propel himself or herself forward and it is also important for stabilizing the swimmer. It is nearly impossible to change how a person kicks because the body naturally will rotate the hips, knees, and feet to allow the kick to balance the rest of the body, as shown in Figure 8.



Figure 8: The rotation of the hips, knees, and ankles of a swimmer while swimming^[3]

The rotation of each joint allows the swimmers to achieve better streamline motion to move through the water efficiently as well as achieving the most power out of each kick and pull. When doing leg lifts on land, the hips are held unmoved by the ground, which in turn causes the knee to be oriented vertically. It is not possible to fully replicate the leg lift motion because the

hips, knee, and ankles are free to rotate in the pool, but a similar motion can be achieved if the swimmer kicks on their back. It is easier to stabilize the hips and still maintain a fairly natural kick if on the back. In addition, on the back, swimmers tend to bend their knees less, which is important because the Vastus Medialis is worked only during the last 30% of the leg extension, while the outer quads are used for the other 70%. Kicking on the back allows the swimmer to keep their legs straighter, allowing them to utilize their inner quadriceps more than their outer quadriceps. Therefore, the prototypes were all used and tested by kicking on the back without bending the knees much.

The natural tendency during the kick is to rotate the knee and ankle a little to have the feet semi-vertical and flexed, shown in Figure 9, so that the dorsal part of the feet is parallel to the surface of the water, allowing for maximum thrust. However, to work the Vastus Medialis, the leg lifts on land require the feet to be turned outwards, about 45 degrees, also in Figure 9. Rotating the feet out causes the feet to slice through the water, which does not provide forward momentum. A device is needed to maintain the outward rotation of the feet by creating resistance in the proper direction to force the feet to turn out, yet still provide the same thrusting force as when swimming normally.



Figure 9: Left: Normal kicking position with flexed feet Right: Fins aim to rotate feet out 45 degrees like in the picture

4. Designs

A variety of two dimensional and three dimensional designs were explored to determine the best shape of the fin. Surface area placement and amount were investigated to rotate the feet in the correct direction to work the Vastus Medialis.

4.1 Two Dimensional In-Plane Fins

4.1.1 Round 1: Training Paddles

Normal fins can only be worn a specific way because of the foot pockets do not allow variation of feet placement. Therefore, simple Speedo Training Paddles, shown in Figure 10, were used to begin bench level testing to see how the location of the surface area affects the rotation of the feet. These training paddles were chosen to mimic the power fin concept because they do not extend much past the tip to the toes.

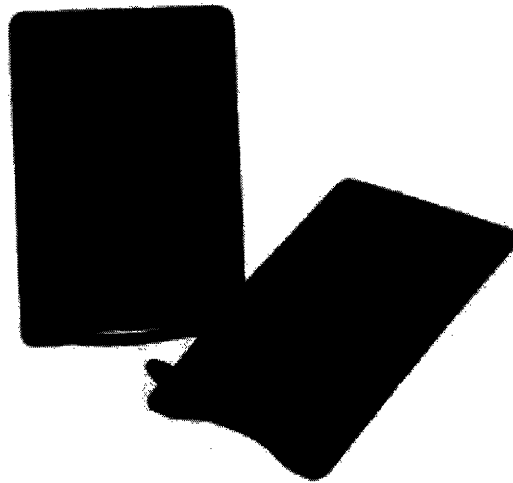


Figure 10: Speedo Training Paddles ^[6]

Two main configurations, shown in Figure 8, were used to understand the how the location of the surface area of the fin, medially or laterally of the foot, affects the rotation of the ankle.

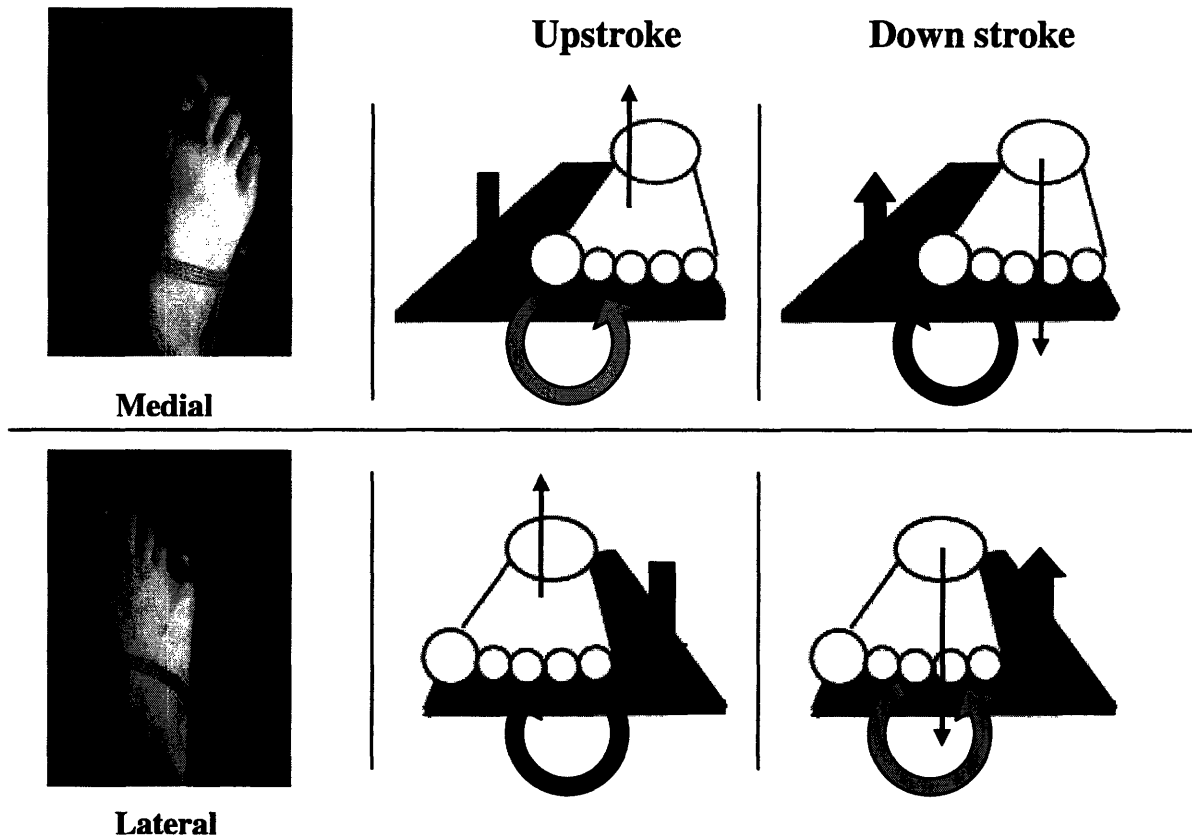


Figure 11: Top row shows scenarios with the fin’s surface area located mainly medially to the feet and the bottom row shows the surface area located laterally to the feet. The first column depicts the actual mockup. The second and third columns show the initial analysis of the fins when used in the water.

The second and third columns in Figure 11 depict the ankles as a free pivot with no other external forces acting upon it besides the force on the water upon the fin. From this analysis, no matter which side the surface area is most toward, there is one stroke direction, down or up, that will be favorable to rotate the feet out, while the other stroke direction is unfavorable and rotates the feet in.

During testing though when the training paddles assist in turning the feet outwards, the Vastus Medialis is not worked as much as when doing leg lifts on land. The buoyancy in the pool opposes the force of gravity so the Vastus Medialis does not need to exert as much effort. On the other hand, the instances where there is a negative inward rotation in the ankles, the quadriceps were able to push back against the rotation by rotating the leg outwards during the stroke. When the surface area is concentrated medially, the Vastus Medialis is worked. When the surface area is concentrated laterally, the other quadriceps muscles are worked. The quadriceps can only counter the inward rotation of the feet if the kick remains vertical. Otherwise, the fins have the tendency to slice the water, which does not provide thrust. To maintain a vertical kick, the feet can leverage the added surface area of the fin to counter the negative rotation.

From this bench level experiment, it was determined that the Vastus Medialis can be worked in the pool environment when the surface area located medially to the feet. However, this particular design is not very intuitive. The swimmer has to concentrate on every kick to maintain feet positions to work the Vastus Medialis. If the swimmer kicks normally, his or her feet would end up rotating in unwanted directions with the potential to aggravate his or her PFPS.

4.1.2 Round 2: Exploration of Surface Area Medially to the Feet

Several prototypes, shown in Figure 12, continued to explore having surface area concentrated medially by varying the surface area extending medially to the feet. They were made to determine the preferred amount of surface area to work the Vastus Medialis efficiently and safely.



Figure 12 Three prototypes to test for the best location and amount of surface area medially to the feet.

The first prototype utilized another swimming paddle with a different geometry than Speedo's Training Paddle. Testing showed no significant improvements mainly because the holes in the paddle countered the added resistance. Therefore, fins were made from Lexan Plexiglass to test new designs. The amount of surface area on the first custom designed fin's design was determined by rotating the feet position from that of the training paddle by approximately 10 degrees outward. The added surface area created too much torque, which the Vastus Medialis was not able to counter. Scaling back on the amount of surface area, a second Lexan fin was made. This one was made by doubling the amount of area medially on the training paddle. Even though this fin had less surface area than the prior design and had a different shape, it still

created too much torque. The original training paddles proved to have the best amount of surface area exposed medially. Still, because it is not an ideal design, other configurations were devised.

4.1.3 Round 3: Power Fins

Another avenue of design that was explored was to take on-the-market fins and see if slight modifications to them could result in a pair of fins that work the Vastus Medialis. If a design could be created, the manufacturability of the fin could be guaranteed. Power fins were selected because the shorter blades increase the workout level and the amount that the upper leg muscles are used.

The geometry of the Keifer Power Fins was replicated using Lexan Plexiglass, shown in Figure 13, to act as a control for this set of tests. Knowing from the training paddles that concentrating the surface area medially works the Vastus Medialis, a modified geometry of the Keifer Power Fin base focusing on limiting the area on upper outer corners of the fin geometry was made, also in Figure 13.

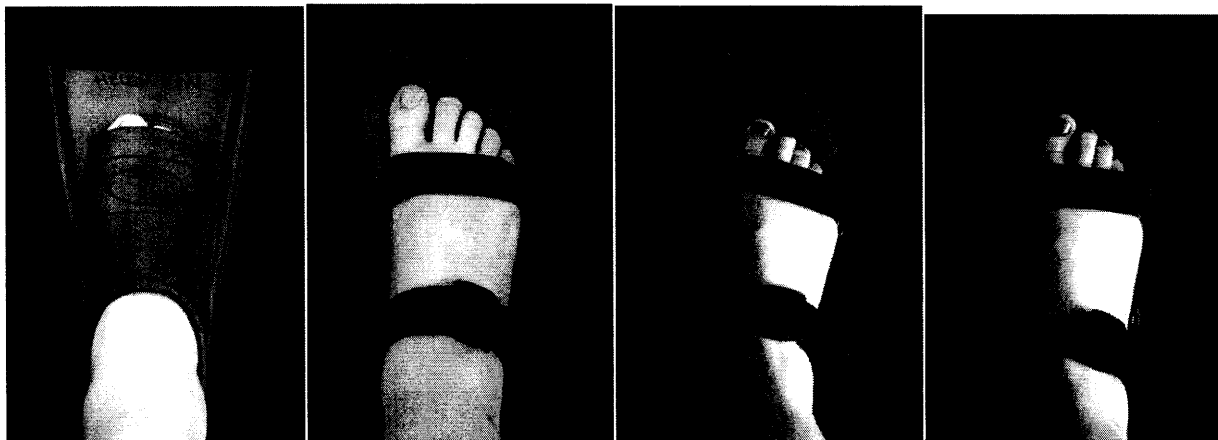


Figure 13: Most Left: Original Kiefer Power Fin, Second: Replica of Kiefer Fin's Geometry in Lexan Plastic, Third: Modified Kiefer Fin's Geometry concentrating area medially on the fin, Most Right: Modified Kiefer Fin's Geometry concentrating area laterally on the fin

Although the modified geometry was created to see if concentrating the area above the toes medially works the Vastus Medialis, the construction was also tested with the area located

mainly above the outer toes by swapping fins. There were not any major differences in the three sets of configurations when tested. Changing the area that extends beyond the feet on a power fin, work the upper leg muscles less than when the surface area was modified on the side of the feet.

4.2 Three Dimensional Fins

Having exhausted many two dimensional design choices that attach to the bottom of the feet, three dimensional fins were developed.

4.2.1 Out-of-Plane Fins

Exploring a different method to achieve the rotation of the ankle, the one of the Lexan prototypes was redesigned so that it could be attached to the side of the feet, shown in Figure 14, perpendicular to the plane of the feet. The idea came from supposing that the feet are able to rotate out completely (forming a 180 degree angle). Although the general concept was correct, the prototype failed because the feet are not able to rotate that far when kicking in the pool. Additionally, attaching the Lexan design to the side of the feet with shoelace was not very stable. The fins tended to slide around and reposition themselves so that they were not perpendicular to the plane of the feet.



Figure 14: Mock up of a perpendicular fin

4.2.2 Bent Fins

Modifying the prototype, a new attachment method was developed to test to see if the rotation of the feet can be controlled with an angled surface area off of the plane of the feet. The new design consisted of a base, much like the original training paddle, that the feet are strapped onto.

Multiple designs were then created by bending the fin at various angles that could be positioned medially or laterally to the feet, bent up or down. Both the surface area of attachment and the surface area of the angled surface were altered and tested.

To begin, four set of fins were designed, water jetted, and bent, allowing for sixteen different configurations. Two of the four sets had the original geometry of the training paddle, and were bent at 45 degrees and 90 degrees. The other two had the geometry of the fin that doubled the amount of area medially on the training paddle. Figure 15 depicts where the bend line is on the fins.

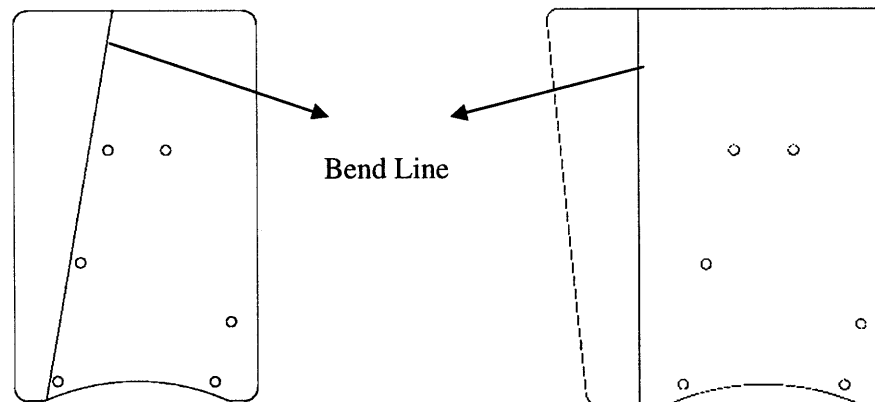


Figure 15: Lines of where the two fin designs are bent with 45 degree of 90 degree angles

The lacing attachment allows the pair of fins to be worn on either foot or the whole fin can also be flipped so that the tester can wear the fins on either side of the attachment surface. Therefore one pair of fin can be worn in four configurations as shown below in Figure 16.

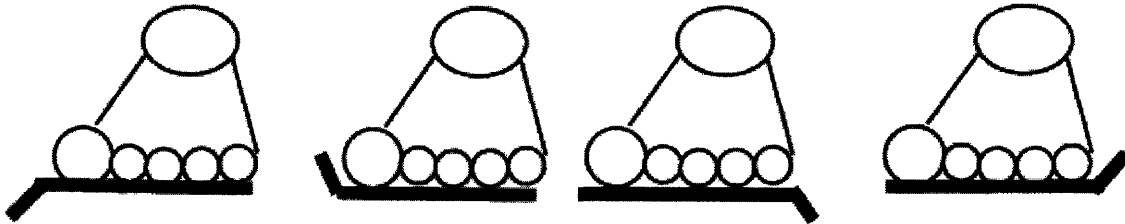
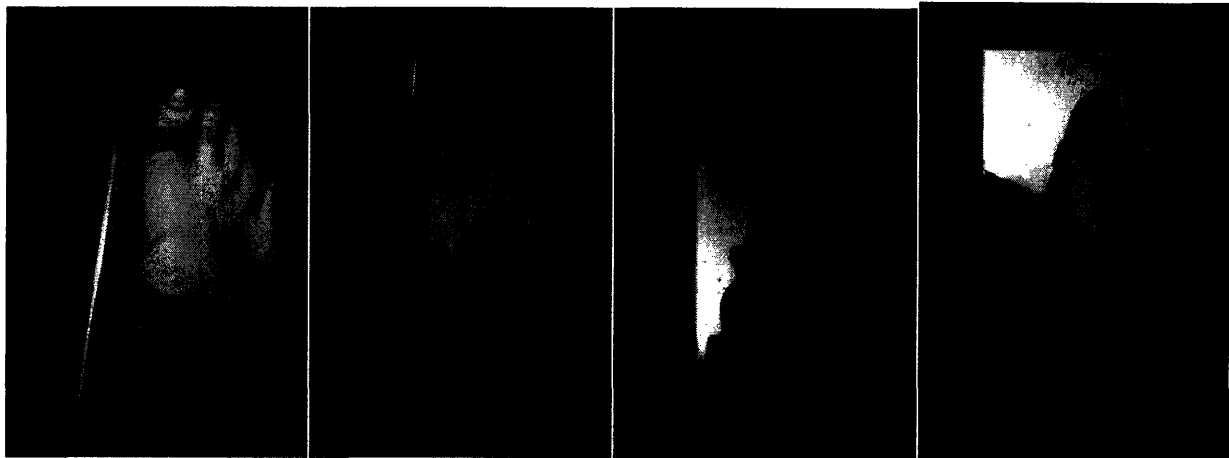


Figure 16: Four possible configurations from one set of fins

The first test began with the four configurations that had a medial downward bend, as shown in Figure 17.



Configuration a)

Configuration b)

Configuration c)

Configuration d)

Figure 17: Fin configurations with a medial downward bend

Configuration a), the original training paddle bent at 45 degrees, works the down stroke of the kick, unlike the original training paddle set up. The bend grabs the water and provides some resistance to feel the Vastus Medialis, but not enough to work it. There is no resistance on the upstroke which allows a normal up kick. This design is considerably more intuitive than the configuration with the training paddles.

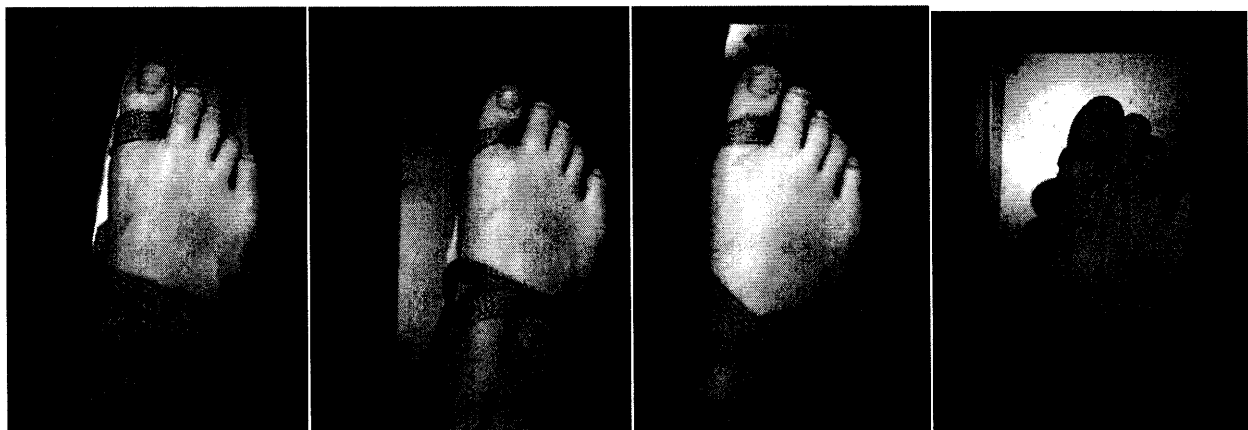
Configuration b), the original training paddle bent at 90 degrees, did not grab the water as much as the 45 degree angle in Configuration a) providing even less resistance to work the Vastus Medialis.

Configuration c), the added attachment surface area design bent at 45 degrees, provides more resistance than that of Configuration a). It combines Configuration a)'s down stroke from the bend with the training paddles' upstroke from the additional surface area on the plane of attachment, thereby working the Vastus Medialis in both directions. However, by having an upstroke like that of the training paddles', the kick is once again non-intuitive, where the user has to think about each kick to counter the negative rotation inward.

Configuration d), added attachment surface area design bent at 90 degrees, is hard to maintain a vertical kick with. The added surface area on the plane of attachment caused the feet to turn in and kick toward each other. Overall there was too much torque to be countered.

From this set of four configurations, it seemed that Configuration a) and b) provided not enough resistance to really work the Vastus Medialis, while Configuration c) and d) were non as intuitive, and had too much torque to counter.

The next set of four configurations had a medial up bend, as shown in Figure 18.



Configuration e)

Configuration f)

Configuration g)

Configuration h)

Figure 18: Fin configurations with a medial upward bend

Configuration e), original training paddle bent at 45 degrees, has no resistance on the down stroke. Although the bent surface area was not much, the bend itself allowed the water to grab a hold of the paddle to provide more torque on the upstroke that rotated the feet negatively inward. The design was uncomfortable to swim with.

Configuration f), the original training paddle bent at 90 degrees, is like Configuration e) with less resistance. It is not a comfortable design and does not work the Vastus Medialis.

Configuration g), the added attachment surface area design bent at 45 degrees, provides too much negative torque on the upstroke. The added surface area makes the feet pigeon toed and the fins end up hitting each other.

Configuration h), added attachment surface area design bent at 90 degrees, is also hard to maintain a vertical kick.

These four configurations were not as successful as the bends that faced downward. Figure 19 depict the rest of the eight configurations that had bends facing up and down laterally to the feet.

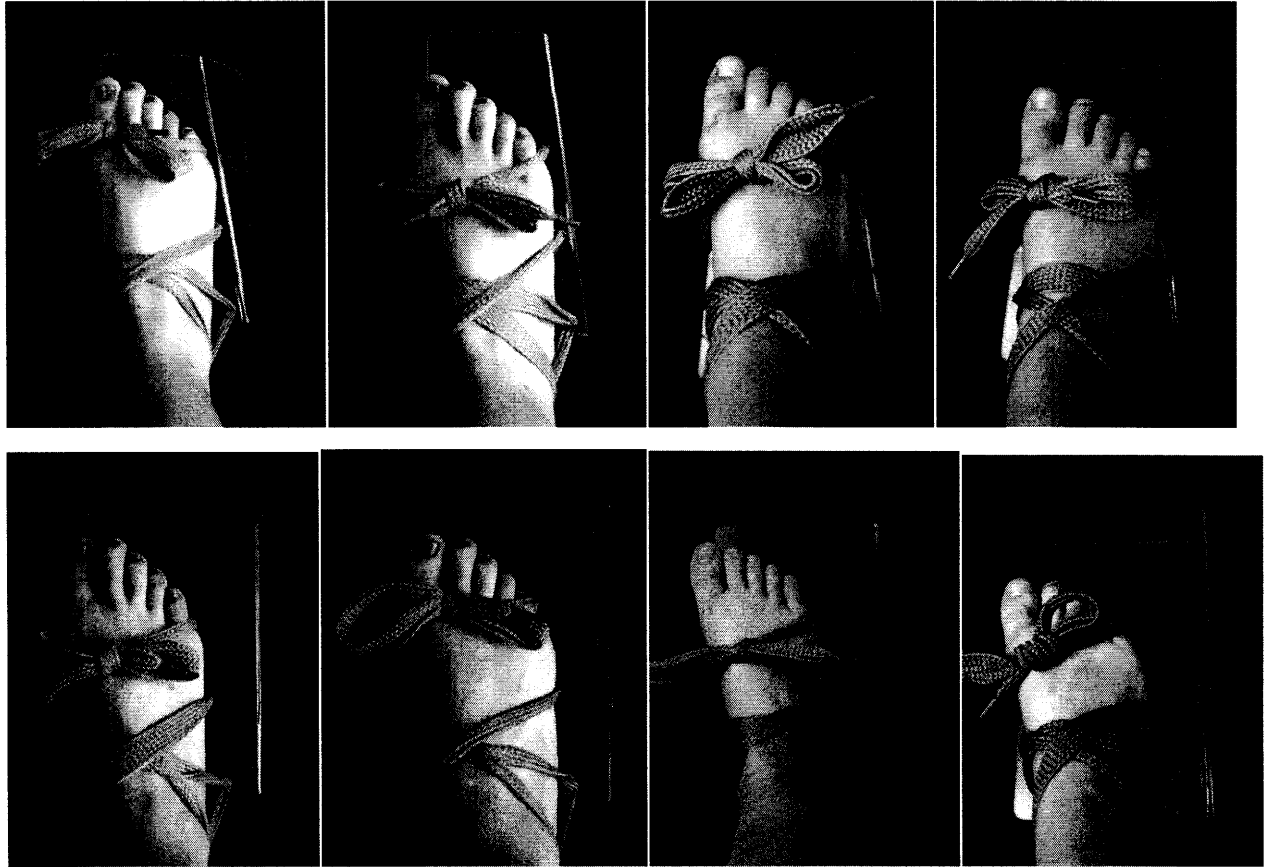


Figure 19: Other configurations of bent fins

Results from the lateral configurations were not as promising as the fins with the bend down medially to the feet. When the fin was laterally bent down, the only rotation achieved were ones that turned the feet in negatively. With the fins bent laterally up, the user does not have much control over how far the fin rotates. So even though the fins rotated outward as wished, many times they would over rotate, and if the user kicked for a long time with them, they could worsen their knee injury.

The best configurations were in the first set of tested configurations of fins that had medially downward bends. However, each design has its limitations and does not accomplish the objective of the thesis well. Taking the best parts of the configurations, two more fins were designed (Figure 20). The new fins use the base geometry of the training paddle with added attachment

surface area but bent the plastic where the training paddle configurations had, shown in Figure 20. This eliminated the surface area that made Configuration c) and d) non-intuitive, and added more surface area to the bend so that when the feet turned, grabs the water more and provides more resistance to work the Vastus Medialis.



Figure 20: Redesigned bent fins to incorporate the positive attributes found from the first round of testing.

The two both worked really well. The 45 degree fin has better positioned surface area to provide thrust, but it also seemed that the feet were rotating too much with this design because of the flow running off the edge, as shown in Figure 21, which created an upward lift.

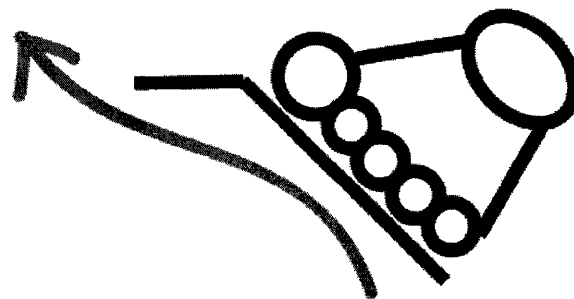


Figure 21: Motion of fluid that over the feet

To deal with this, one more bend was added to the fin. This bend causes the flow not to run off the edge of the fin creating a barrier to prevent the run off of the flow. This fin design, shown in Figure 22, works the Vastus Medialis, is intuitive, and achieves the objective of the thesis, and this design is hence called the InQuadFin.

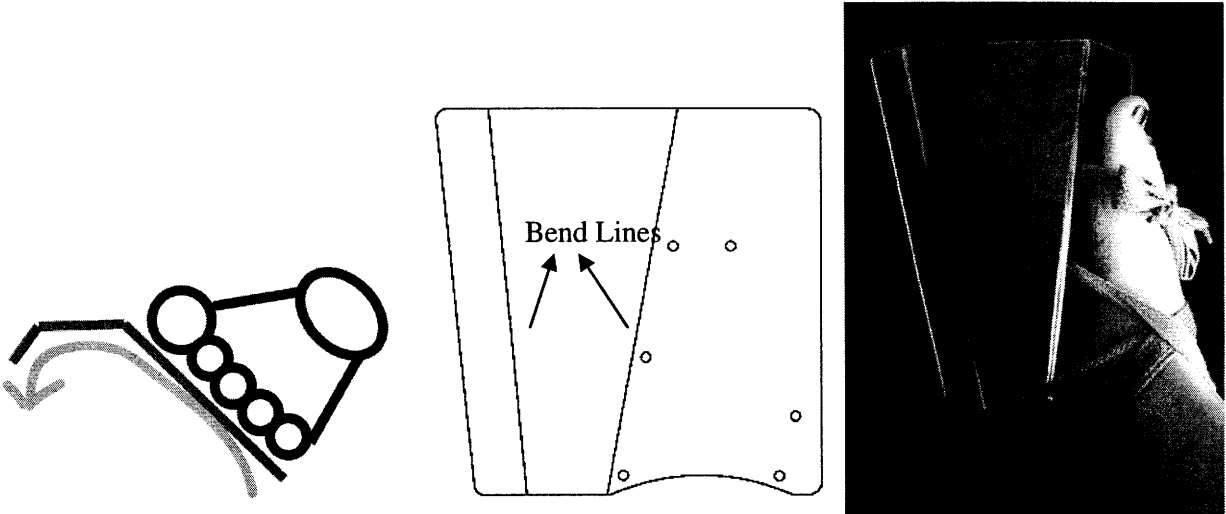


Figure 22: Left: Result of adding an additional bend to the fin design. Middle: Base configuration of the fin with bend lines, Right: Actual mock-up of fin

The illustration in Figure 23 shows the patient in the pool using the InQuadFin.

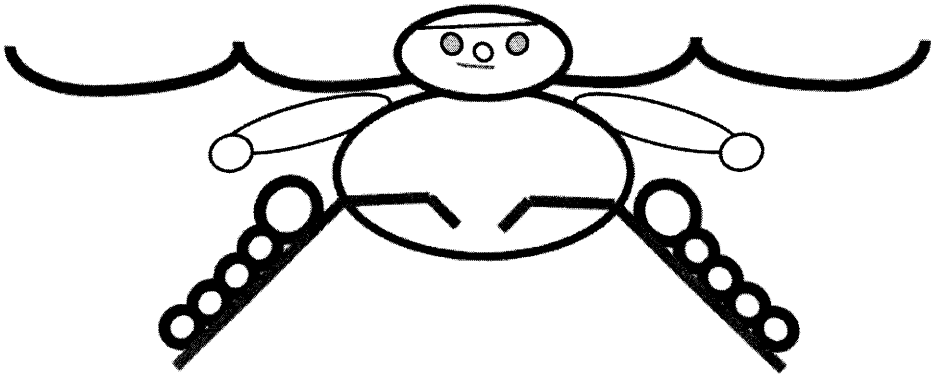


Figure 23: PFPS patient using the InQuadFin designed for strengthening the Vastus Medialis

5. Conclusion and Recommendations

To find a simple solution that would help runners with Patellofemoral Pain Syndrome, various treatments were looked into and swimming techniques studied. Combining these two pieces of information, many fins were designed and tested to see if they would strengthen the Vastus Medialis. In the end, an optimal design was found that was modeled after a dry land exercise: leg lifts with the feet turned 45 degrees outward. The prototype fin, known as the InQuadFin, made out of Lexan Plexiglass, had two sides that were bent to help rotate the feet correctly. These fins would allow many runners with PFPS to strengthen their Vastus Medialis and recover faster while continuing training in the pool.

For the next steps, the manufacturability and human factor details should be examined. First, foot pockets should be integrated into the determined design. The current design of attaching the fin to the feet with the laces is not a viable marketing solution. It takes too long to take on and off and is not as intuitive as foot pockets that are the norm on swim fins. By cutting up existing fins for the foot pockets and attaching them to the Lexan prototypes, the dynamics of swimming with the new feet attachment method can be observed and many sizes can be made to test on a larger sample size of runners and swimmers. After understanding how best to orient the foot pockets, the complete fin can be designed for manufacturing where the fin and foot pockets are integrated. Many aspects must be considered when selecting materials for a fin. The foot pocket cannot be too stiff or loose because of resulting blisters, which occur in many of the current fins on the market. If the fin itself is a different material than that of the foot pocket, the two materials must be able to be bonded properly. Newer fins have moved away from rubber to plastic compounds or silicon. The Speedo Breaststroke fin is made of soft durable thermoplastic rubber (TPR) material, after much research, Neofin Corp. decided on using thermoplastic elastomers (TPE), Force Fins use thermoplastic polyurethane, and other fins are made with silicone^[20]. My personal recommendation is to look into the design and manufacturing of the Breaststroke fin by Speedo. The overall design is similar to the one in this thesis to help runners with PFPS strengthen their Vastus Medialis. The difference is the location of where the bent fin is located. For the Breaststroke fin, the bend is on the outside of the feet, while fins that aim to help recover from

PFPS, the bend is on the inside of the feet. Overall, the fins work great! A provisional patent will be filed and we will try to license the design to a swim fin or sports fitness product manufacturer.

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