# SCAPULAR AND THORACIC PLACEMENT IN KAYAKING

by

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## ABSTRACT

Anatomical understanding is needed in kayaking scapular and thoracic placement, key elements to the forward stroke, to provide a more insightful understanding of the frequent amount of injuries to these areas, and hopefully quell them. What can be done to help serious kayakers see the forward stroke from a biological standpoint with limited resources to address this topic directly? With more information and references, kayakers will have a better chance of breaking down kayak motion and be able to use that knowledge to enhance their kayaking life. With adventure sports, the body is an especially vital tool. Kayaking performance becomes very poor with shoulder and back dysfunction; this is like a car with flat tires. A well-functioning body, aided by relevant human biological knowledge is useful to the adventurous kayaker to help propel the craft forward. Kayakers typically have very limited understanding of human anatomy and physiology. They tend to have a strong outdoor knowledge yet a weak knowledge of their own indoors. Once hurt, or anatomically displaced, the kayaker knows he or she has a shoulder problem but may not know how to solve it. This is detrimental to their careers, expeditions, and sense of self. Kinesiology specializes in human motion but does not normally know what motions, forces, and other technical involvements are particular to kayaking. This paper aims to bridge a barrier so that the kayaker can understand how "their tires are aerated."

Keywords: forward stroke, injury prevention, scapula, thoracic, kayak, biomechanics

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## Introduction

Kayaking is a demanding sport that requires repetitive use of the shoulder and upper back. Mechanical dysfunction at the shoulder is a major contributing factor to developing shoulder pain in paddlers "by understanding the normal humeral and scapular movements during the kayak stroke, inferences about the relationship of kayaking technique and shoulder injury may be established" (Wassinger 2011, p.99). This lack of knowledge between normal scapular movements and kayak technique leads to the many injuries that occur, which is agreed by Fleming "analysis of the upper limb kinematics during the kayak stroke cycle revealed several findings of potential importance for training, biomechanical performance and injury prevention" (2012, p.436). Finding ways to mitigate these injuries is beneficial to the sport. "An understanding of shoulder injuries in kayakers is best obtained from an appreciation of the kinesiological, biomechanical, and physiological demands of the sport" (Hagemann, 2004 p.413). Recognition and prevention to the shoulder and thoracic column are of large enough consequence in the forward stroke that education surrounding scapular and thoracic pain is worth covering, particularly in advanced levels.

Kayaking has always been a forceful method of travel. It originated as a tool for hunters in pursuit of seals, whales, and walrus. If modern sea kayakers face strain from towing seasick or exhausted paddlers, the Inuit certainly faced strain in towing 100-lb seal carcasses or dividing a load between a group to haul a dead walrus, small whale, or caribou back to shore. The kayak (pronounced in a considerable number of Inuit regions ha-yak and variations of spelling qajaq or Kajak) is responsible for Inuit travelling across the Arctic. There are recordings of people paddling distances of over 100-km. The kayak represents a pinnacle of self-reliance. Historically one made their own kayak and that freedom granted independence. The late arctic explorer

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legend, Nansen, called the kayak the best one-man boat in the world (Petersen, 1982), truly a boat that allows an individual to access almost anywhere there is water in a self-sufficient manner.

Today kayaking continues to be challenging, with some commercial guides working 100 plus days in a season, sea kayakers paddling 1000 km plus distances and white water kayakers paddling intensely turbulent waters. The kayak continues to be a craft that allows kayakers to continually test themselves in extreme situations and considering the environment, duration, and intensity, it is not a surprise that injuries happen as often as they do.

There are three sub-disciplines to kayaking: sea kayaking, white water kayaking, and racing. The forms water takes is very different for each, with different experiences required to adjust to each sub-discipline. Of the three kayaking arenas, flat water and white water racing courses, are by far the most scholarly studied. Sea kayaking focuses less on the forward stroke as it is practiced in a larger arena, the ocean, which has a wide variety of factors such as weather. In sea kayaking, the forward stroke may be used 98% of the time, and in flat water racing, 99% of the time. However, white water, known to be more turbulent, requires much more steering, bracing, and rolling with the forward stroke used roughly 70% during white water slalom racing (Wassinger 2011, p. 99). Despite the differences between the sub-disciplines, it is important to note forward stroke maneuver sees little alteration; "the general pattern of humeral kinematics found in the current study was like previously documented reports of flatwater kayaking techniques" (Wassinger, 2011, p. 103).

It has been suggested that the shoulder is too mobile and perhaps the human body is not designed for paddling (Fisher, 2015 p.123), as it is for walking. The ligaments, muscles, bones, and overall design are much more reinforced for walking (Lunn & Stewart, 2016). In a study by

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Krupnick, Cox, & Summers (1998), *Injuries sustained during competitive white-water paddling: a survey of athletes in the 1996 Olympic trials*, the back was the most frequent site of injury, with strain being the most common complaint. The upper extremity was frequently injured, with the shoulder reported as the most frequent site of injury. Another study by Powell (1998), *Injuries and Medical Conditions Among Kayakers Paddling in the Sea Environment*, focused on general sea kayakers opposed to Olympic athletes, found common health impacts to be sprains and pulled muscles. The back was identified as the single most commonly injured part of the sea kayaking body, accounting for 19% (Powell, 2009). According to the Outdoor Industry Association, in 2000, there were 6.5 million kayakers (Fiore, 2003). With a growing number of kayakers worldwide, physicians should be expecting to see more patients who are injured by this activity as this sport grows in popularity.

Table 1. Incidence for musculoskeletal injury associated with paddling

Kayaking Activity	Shoulder injury	Back injury
Flatwater kayaking (Edwards, 1993)	53%	Not specified
White water kayaking (Fiore & Houston, 2001)	31%	Not specified
Marathon race (Abraham & Stepkovitch, 2012)	36%	23%

## Rationale

Other published papers share similar desires in building paddlers for expeditions by giving them anatomical solidity, yet my paper is less on exercises prescription and more on understanding the various movements through description. The primary audiences are kayakers who train for long distances and more difficult waters. Secondary audiences are recreational paddlers or health professionals seeking to understand an exploding sport. Often kayak guides deliver a "paddle talk" to their clients. However, this paper could be thought of as an extensive, perhaps intensive, paddle talk for serious kayakers. Analysis and recognition of commonly

injured regions help prevent musculoskeletal injuries, allowing athletes to continue at higher standards, and reduce economic burdens that comes with injury (McGill, 2002). This is more useful than "train hard" or "be strong." A solid base of anatomical knowledge and fitness is a great asset in any sport (McGill, 2002). To use the most important stroke, the forward stroke, the paddler should make maximum usage of anatomy responsible for it. Each sport has its own particular fitness. For example, I have sea kayak guided marathon runners, gymnasts, raft guides, double black diamond skiers, military personnel, Royal Canadian Mounted Police, competitive swimmers, and other active people. While they were more fit than I was, none of them could keep up with me on the ocean because my body was trained for sea kayaking.

In the kayaking world, large sums of money are spent undertaking research on the newest experimentally designed crafts and paddles yet Hagemann points out in his unique article, *Shoulder pathoanatomy in marathon kayakers* "little research has been conducted on the pathoanatomical changes in the bodies, and more specifically the shoulders, of endurance kayakers" (2004, p.413). While this paper cannot classify physiological stance, physical ability, or level of kayaker's expertise it again agrees that "There is a need to identify, classify, and profile athletes at risk to implement appropriate preventative measures" (Hagemann, 2004 p.413)

## Discourse within the Kayak World

In terms of purposeful steps to understanding shoulder or upper back injury, little exists in the kayak world but this shows signs of changing. Have you ever heard a kayaking partner say "I stretched my supraspinatus, responsible for arm abduction, and I understand that's throwing off my paddle stroke when I lift my arm away from body." The author worked for two different kayaking companies, traveled with both kayak instructors and avid recreational kayakers and heard little specific information to shoulder and back injuries. The most relevant information to overuse prevention picked up by the author's contact with senior paddlers was to use a Greenland paddle and paddle two hours daily a month before an expedition to train for it. While useful, it can be taken a step further. A possible lack of motivation to learn more may be that many modern kayaker's own vehicles and are normally within driving distance of health professionals, reducing the need for self-reliance.

# **Known Discourse in the Health Professions**

More publications on kayaking are taking place particularly for flat-water racing. A notable researcher is Dave Fleming, main author of *Effect of kayak ergometer elastic tension on upper limb EMG activity and 3D kinematics* (2012) and *A biomechanical assessment of ergometer task specificity in elite flatwater kayakers* (2012), both of which are heavily cited in numerous literature articles. Fleming and his perspective are unique because of his three-point qualifications: former national kayaking champion, PhD in Exercise Physiology, and research interest in body-to-kayak biomechanical analysis. In the 21<sup>st</sup> century, health professionals have written reports using advanced paddlers, about muscle recruitment, muscles most needed to paddle, and muscles that stabilize bone structures.

The shoulder and upper back are heavily researched topics, with whole departments of medical staff studying them in detail (European Society of Thoracic Surgeons, 2017; European Society for Shoulder and Elbow Rehabilitation 2017). Other notable researchers include Kibler for his work such as *The Role of the scapula in athletic shoulder function* (1998), on scapular mechanics, and Oxland for his work on the thoracic spine *Fundamental biomechanics of the spine-What we have learned in the past 25 years and future directions* (2015). Both works are heavily referenced within other papers. Even with this research force, there is a push within the

literature for future contributions to find further answers. Though rehabilitation is for a more advanced paper, the concepts of anatomy and physiology are still useful, even if used for different reasons.

## Methods

As with any research project it was necessary to see what data already exists. This secondary research analyses both qualitative and quantitative data. Given the time frame and scope of a bachelor levels paper primary research is not expected or encouraged as it is as a graduate or Masters level. Admittedly, there is a great deal of data on shoulders, thoracic spine and even kayaking. Information in scholarly articles relating either to shoulder, thoracic spine or kayaking was mainly used. The most succinct information comes from articles that contain all three. Some of the articles do not directly match the kayak concept, so only occasionally inferences are made.

Throughout this paper I bring an epistemological viewpoint that may be different from other authors. This comes from numerous kayak training courses, Inuit heritage and kayak journeys. Occasionally I've made comments that come from presence in the sea kayak world or comments about Inuit because I am Inuit. Personal kayaking experience also provided a methodology in shaping what I believed would be effective in the time allotted to write this project. Kayak injuries and expedition travel as well as knowledge of and connections to the kayak world allowed another lens.

I used scholarly-peer-reviewed articles but also ran general searches to see what someone not using scholarly sources might come across. Identifying material and shaping a research question was an ongoing process, even with a laid out framework. Data collected was kept as recent as possible, though there are key studies from 1970's, heavily cited throughout literature sources. As in Bloom's Taxonomy the aim was not necessarily creating new knowledge but analyzing and evaluating sources to create a new application of using and analyzing the knowledge (Adams, 2015).

The main search engine was primarily the Thompson Rivers University Library search engine as recommended by our research methods class. This provided the majority of the articles reviewed. Extensive use of the Thompson Rivers University interlibrary loan system was used. Google Scholar was used as well and it provided more of an overview look of the articles and had a comprehensive reach. Initially as the research began, terms or title involvement were hard to define, but as the research progressed finding articles became easier. Search terms as "kayak scapula stroke," "scapula rehabilitation," "shoulder biomechanics," "kayak injuries," "chiropractic relationships," "muscular fatigue," "massage foam roller," "muscle physiology" as well as others were entered into search engines. Sometimes it was necessary to step back and find properties of the shoulder itself because anatomy itself does not change. Despite careful search methods and consistent use of the two search engines, the best articles or theses were sometimes discovered randomly, without structured search intention. Reading the articles gave ideas for other specific search term combinations that otherwise would not have been thought of.

At the end of my research project a thesis was recently published online by Fisher. Her thesis, *Revealing complexities within flat-water kayaking: injury prevention and biomechanical analysis*, has a similar goal to mine but quite a different audience, with many presumptions and different way of reaching her thesis goal. Her main goal was to use a proactive approach in prescribing exercises for injury prevention because the shoulder "clinically has predisposition for shoulder injury (2015, p. 141). The time span of searches influenced article results. After, a recap search in early April 2017, a few papers had been published that had not turned up in September

2016 searches.

The information available has a gap for kayaker use. A quick search will find limited information that has no background reference check or demonstration of methodology. General resources do not examine anatomy in enough detail to provide a useful mechanical breakdown of the stroke. YouTube searches and general internet searches on a variety of terms, as well as library visits and tips in magazines are useful but wanting. A general idea does not reflect careful thought or understanding whereas an understanding of the shoulder and thoracic column anatomy allow paddlers to understand the parts to a paddle stroke. In this sense, kayaking is behind other sports (Wassinger, 2007).

Interestingly, there are a few doctorate-level kayak dissertations available (Brown, 2009; McDonnell, 2013; Fisher, 2015; Wassinger, 2007) but they are acutely scholarly and more information laden than here. There are kayak maneuver videos in dynamic waters; however, the forces transferred by or onto the body are not explained. Physical aspects are more instinctual rather than explained out, for example, explicit versus implicit memory. However, to achieve a high implicit learning it is necessary to look at explicit. Physical practice is vital, along with an understandable technical document explaining the theory of the forward stroke. Many kayakers will not have personal coaches to access this knowledge.

There are books for kayak expeditions and how to pack for them, navigational books, choosing the right kayak, building your own kayak, how to perform rescues, et cetera. Avid recreationalists, guiding associations publishing and clinics are all making available these bodies of knowledge. There is information about nutrition, use injuries but not a focus on prevention and recognition of common bigger muscular skeletal injuries. What is also missing, is when many high-level kayakers are asked for thoughts on kayak body preparation, none seem prepared

how to answer. In other words, common discourse or narrative about this subject is lacking. From this one can garnish it is not yet part of the training.

# **Background to Paper**

Kayaking is a way of life that originated without manuals or written knowledge. I am descended from the Inuit, who created the kayak. The last kayaker in my family was my great grandfather Simeonie Nochasak, who paddled a sealskin kayak in the Torngat Mountains to provide food for his family. I was reluctant to receive training under a Canadian system until a narrow escape shook me mentally. A few years later after a moderate injury, there was a possibility of giving up paddling which would cause me to lose my identity, at least in part. I adapted to become more flexible, which included rearranging university courses for the opportunity to research human mechanics, which I could then transfer to my outdoor movement training.

I have paddled 2500 km and built three skin-on-frame kayaks before my first kayak course or formal lesson. In that distance, I had taken on 10-foot waves off the Kiglapait Mountain range and 20-foot-high waves off Gulch Cape. One day, I paddled 73 kilometers, while experiencing violent sea-sickness, which pushed me to the limits of endurance; paddle or die. I also made numerous crossings of 40 km or more with a high-powered rifle strapped onto my deck for polar bear defense. Earlier that traveling year, I limped 300 of a 550-kilometer journey because my 200-pound sled slid past me on a hill and torqued my hip. Yet I resolved to finish. My left leg was completely covered in tensor bandages and on a daily dose of pain medication. Yet I committed to hobbling the remaining distance and sleeping in snow banks if need be.

After another trip, mentally worse than this, I concluded I needed technical training to

make traveling safer and easier. I applied for a guide program and was accepted the following year. The first week of the guide program, students were told "be fit and don't spend energy recklessly." In kayaking courses, we were taught maneuvers of bracing, rolling, navigation and rescues. The water stages advanced very quickly. At Christmas, I signed up for the three-week white water kayak expedition that would happen in spring. Just before this expedition, I finished 35 days of back-to-back field courses. On a small rapid, part way through the white-water expedition I heard a 'kkkaahh' sound in my back. Suddenly I was crying out at nearly every paddle stroke. There was an option of completing the expedition by going down class IV rapids in a raft. On serious contemplation, I decided not to because I would be helpless if the raft flipped. This occasion, the injury was more serious than my usual history and my mind could not match my body.

I returned to campus, easily a thousand kilometers away, dragging not lifting my bag. Suddenly everything was in question. What was effortless and carefree now took calculated thought. Later that summer, I left my raft guide job because of the shoulder and back injury. To an extent, I was excluded from the athletic community. I attended chiropractic and physiotherapy care over the next year involving minor physical manipulations, and I militantly followed prescribed exercises. The physiotherapists used terms I did not comprehend and were quick to rush through appointments. Despite athletic use and many appointments, I knew little of what was happening other than I wanted to achieve the mobility and strength I was used to. My goals whittled from planning a 100-km day paddle down to gratitude for 10 km. I started reading books on anatomy in my spare time but could not make associations to kayaking. I had never seen nor heard of this topic explored for kayakers. My kayak partner Rod and I turned \$25,000 worth of sponsorship down from a company, Pharmaflex, because I did not trust my back and shoulders on hard expeditions anymore.

I came to Thompson Rivers University to build my kayaking career and when I graduated, still wanted one. I changed the focus of my degree to learn about human anatomy. I would not become the paddler I could possibly be in the Guide Diploma. Yet I would pursue school with the same commitment I approached traveling, and set up for expeditions and a kayaking future in a less direct though still important way. By coming from this position of a moderately injured, committed kayaker I feel it has influenced my research position by searching for genuine outcomes that I would think of and use in practice.

After graduating the adventure program and a year of rehab, I went onto continue my formal training by obtaining my Level 3 Skills with Paddle Canada and Level 2 Instructor Certificate. I am also a Level 2 Guide under the Sea Kayak Guides Association of British Columbia. I aim to continually hone kayak skills and want to train further in undergraduate and graduate anatomy courses. If the language of kayaking now includes English in addition to Inuktitut, some additional terms in anatomy and physiology are sparing, comparatively.

## **Literature Review**

This section has several aims and covers six areas relating to the forward stroke in kayaking: adventure studies, shoulder, thoracic column, stroke biomechanics, muscle physiology, and training. The idea is to break down these kayak injuries into the components such as which make up kayaking, the areas that may be injured, and why they may be injured. The author believes from formal academic training, experience, and meetings with faculty that these are the important areas to look at.

Adventure Studies provide a lens on the bodies which formally regulate courses which are needed to obtain professional kayak levels or those which are endorsed by the public. Another aim is to establish that scapular and thoracic kayak injuries are not isolated incidents but occur significantly throughout the kayak community and explain why this is a matter that needs addressing. Adventure Studies is the setting for how scapular and thoracic placement fit together. Shoulder and Thoracic Column cover the anatomy necessary to have a better grasp for the paddler. Stroke Biomechanics explains paddling form detectable at eye level as well as some description of stories with numbers for clarified perspective. Muscle Physiology explains the muscle's important details at microscopic which are critical but often not commonly understood. Training explains how muscles can be used in power or endurance movements and adapted to reduce the risk of injury.

# **Adventure Studies**

Three regulating kayaking bodies in Canada are Paddle Canada, Sea Kayak Guides Alliance of British Columbia (SKGABC), and CanoeKayak Canada. Reducing a dislocated shoulder, putting an injured person inside a kayak, and towing their kayak to shore are examples of injury management techniques which are covered in courses. For example, in the Paddle Canada manual, for the particular topic of injury prevention there are no direct references or suggestions for further readings (Sea Kayak Program Development Committee, 2012). Nor is it a focus of a 70-hour wilderness first aid course (Isaac & Johnson, 2012), in which most guides and advanced recreationalists are certified.

Kayaking has a broad range of techniques and situational placements and comes with its own specific situations different from other adventure sports. In this case, we can mitigate the lowest possible risk level by understanding what moves us through water both long distances, extreme conditions and in more remote locales. The environment of adventure takes people to remote areas such as the High Arctic, where physiotherapy or chiropractors are completely inaccessible.

White water injuries fall into four main categories: trauma from striking an object, traumatic stress from interaction of the paddler's positioning, equipment and the force of water, overuse injuries. Two studies, *Injuries Associated with Whitewater Rafting and Kayaking* (Fiore, 2003) and *Kayak stroke technique and musculoskeletal traits in shoulder injured whitewater* (Wassinger, Myers, Oyama, Sell & Lephart, 2010) found the upper extremity, especially the shoulder, to be most commonly injured part of body. Paddlers often extend their stroke distally, and externally rotate at the shoulder. Keeping elbows tucked in, or adducted, is common advice by instructors though Fiore was not able to find scientific evidence proving its effectiveness (2003). Chronic injuries make up 25% to 40% of total injuries found in paddlers.

There are contrasts to normal training information. An illustration of the usefulness of kayaking as well as intensity, is Aleksander Doba who paddled 7,716-miles across the Atlantic Ocean. Aleksander was neither an Olympic athlete or general kayaker, nor did he specifically train, yet he achieved a very incredible journey. Aleksander's rode through 30-foot waves, paddling a 23 feet long, three foot wide kayak (Altschu, 2014). Although the literature encourages training, and this journey could certainly make strong case for micro cumulative trauma, it is not definitive.

Rigoni's dissertation (2000) on risk in white water kayaking, shows a focus on positive risk in contrast to negative risk. Though aware of going into a dangerous environment, paddlers create options to reduce the risk of injury. One avenue kayakers can use to make smart decisions are courses and training because courses teach proven techniques (Rigoni, 2000).

The Canadian guidelines for recreational kayakers and skill assessment criteria come from formal bodies such as Paddle Canada and the Sea Kayak Guides Alliance of British Columbia. Topics, for example cover equipment and certification levels within areas of similar sea state and exposure. However, in Paddle Canada teaching manuals there is not an in-depth stroke breakdown, only efficiency guidelines with a European paddle (Sea Kayak Program Development Committee 2012). Training and literature cover topics such as camp craft, self-rescue, assisted rescue, navigation and equipment, but no mention of the injury rates in kayaking or why those rates occur (Sea Kayak Program Development Committee 2012, SKGABC Manual 2016).

In Paddle Canada, six days of formal training, as well as significant practical water time, must be spent before progressing onto intermediate courses (Paddle Canada Manual, 2016). On average, a season of fairly intense practice is essential to build experience between each course. In advanced courses verbal stroke refinement and using water to one's advantage, frame stroke explanations. There are also many other training and mentorship opportunities to reach instructor than instructor trainer level.

The mission of the Sea Kayak Guides Alliance of British Columbia (SKGABC) is to "establish, promote and maintain high standards of sea kayaking safety, conduct and representation through an alliance of professionals" (SKGABC Guide's Technical Manual, 2016). The training period is a minimum of five days for a Day Guide and an additional five days training for an Assistant Overnight Guide (SKGABC, 2016). To become a Level Two Guide, 30 commercial days must be spent and an additional 50 commercial sea kayak guiding days to reach full guide status. It should be remembered all these day numbers are absolute minimum requirements.

In Canoe Kayak Canada, a body that builds paddlers for community level sports leaders, instructors, and also Olympic paddlers and coaches, there is explicit rubric for the forward stroke (Canoe Kayak, 2017). In Canoe Kayak Canada's instructor level, the closest course subtopics to preventing back and shoulder musculoskeletal damage, are risk management and common paddling injuries. At a coaching level, the depth is higher with body mechanics and stroke mechanics covered as well as injury prevention.

Adventure may be loosely defined as whatever comes, but to every person whatever comes needs a reasonable threshold. Therefore, whatever comes, must be mitigated to have the lowest possible risks or suit the acceptable risk tolerance of the individuals in question (Cloutier & Garvey, 2000). These mitigations should hold true on mechanics of the forward stroke as well.

## Shoulder

To address shoulder issues in kayaking one has to break down shoulder architecture into manageable chunks. The shoulder is classified as a synovial joint that has the widest range of motion of all joints in the body. Where there are more possibilities, more variables, naturally more things can also go wrong. Two criteria set up the shoulder for its mobility. One is the humeral head, the top end of the upper arm, is larger than the socket part of the scapula. The other is a full extent of muscle attachments that attach from all directions. These attachments allow the head of the humerus to move up, down, sideways, forwards and backwards in relation to the shallow socket, the glenoid cavity of the scapula.

The idea of this section is to provide the groundwork information on the scapula that can be revisited. Though there is a general agreement on how the forward stroke should be performed there are variances for speed, endurance or size. This forward stroke variance will result in people using slightly different, though noticeable, strokes which means they are recruiting muscle groups and even muscle fibres differently. By the end of subtopic review one should be able to understand what part of their shoulder may be strained or injured and make associations to stroke mechanics.

The glenohumeral joint is a shallow ball-and-socket joint made up of the scapula meeting the humeral head with clavicle support. The part of the scapula that forms the groove for the humeral head is known as the glenoid cavity. (Trvithick A., Ginn K., Halaki M., Balnave R. 2005). The glenoid cavity (figure 2) is only one-quarter of the surface area of the humeral head and offers little bony stability (Lucado, A. M., 2011). Most of the shoulder joint stabilization is provided by specific soft tissue components like the joint capsule, the glenoid labrum which is a cartilaginous extension of the joint cavity, and the rotator cuff muscles (Provencher et al, 2010). Additionally, while the arm is in motion, glenohumeral and superior ligaments help to keep bone-to-bone position.



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Figure 1 Ball-and-socket joint (Martini, Nath & Bartholomew, 2015)



Figure 2 The Right Scapula (Martini, Nath & Bartholomew, 2015)



Figure 3 The Right Humerus (Martini, Nath & Bartholomew, 2015)

The kayak motion is a unique sequence. People can often unmistakably convey kayaking through a set air motion. Muscles are given by their name for clarity and consistency. Anatomical diagrams are provided to give the reader a visual association to the name.

Coordinated scapular and humerus movement is necessary to achieve a full range of movement at the shoulder while maintaining dynamic stability. Table 2 outlines specific muscles that allow the shoulder to support weight and move through its wide range of motion (Trevithick, Ginn, Halaki & Balnave, 2007). Though there are many muscles, some are more important in kayak strokes including the upper trapezius, supraspinatus, latissimus dorsi, serratus anterior, subscapularis, and rhomboid major (Trevithick, Ginn, Halaki & Balnave, 2007). During the pull

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phase of the stroke, supraspinatus, upper trapezius, and latissimus dorsi all engage while the

glenohumeral joint rotates internally against the resistance of the paddle.

*Table 2. Muscles of the Shoulder, Upper Back, and Upper Arm (Martini, Nath & Bartholomew, 2015)* 

Muscles	Actions
Rhomboids	Adducts scapula and brings downward rotation
Trapezius	Elevate, retract, depress, or rotate scapula upward. (2). Elevate clavic
Supraspinatus	Abduction at shoulder
Infraspinatus	Lateral rotation of shoulder
Teres Minor	Lateral rotation of shoulder
Subscapularis	Medial rotation at shoulder
Deltoid	Abduction at shoulder. Anterior part: flexion and medial rotation
	Posterior part: Extension and lateral rotation
	Extension, adduction, and medial rotation at shoulder
Latissimus Dorsi	Extension, adduction, and medial rotation at shoulder
Biceps	Flexion at elbow and shoulder
Serratus Anterior	Protracts shoulder, rotates scapula so it moves upward

By looking at a muscles tendon attachment points and the ways the muscle fibres run, one can associate the stroke techniques to the muscle. For example, by knowing the supraspinatus (Figure 8) originates on the supraspinous fossa and knowing it inserts on the greater tubercle of the humerus (Figure 3), one can understand that when it shortens it is very important in lifting the arm upward, before the arm places the paddle blade by the toes. Some of these muscles work

directly together to help achieve the same action, a process also known as synergistic contraction (Table 2). Other processes, named antagonists, reposition the muscle by activating opposing muscle to the main movement like in opposition to the pulling movement.

Rotator cuff muscles are the most important shoulder stabilizers while the arm is in motion and they are required to coordinate and support the arm throughout all motions. Specifically, the rotator cuff muscles include supraspinatus, infraspinatus, teres minor and subscapularis. Keeping ideal muscle position is important. Over worked muscles can shorten and then pull on the scapula, thoracic column and humerus, causing other muscles to use above average forces to compensate: "scapulothoracic dysfunction, defined as alterations in the resting position or dynamic motion of the scapula, and changes in muscle recruitment can affect many aspects of normal shoulder function" (Cools et al. 2007, p. 1744).

Due to the subscapular muscle's shoulder stabilization role in stroke movement and difficulty to physically touch we will examine it more closely. The subscapularis is sandwiched between the scapula and the ribs. The lower portion of the subscapularis muscles activates more than the upper portion of the subscapularis during arm actions calling for abduction (see figure 7 & 14), flexion and external rotation (Wickham, Pizzari, Balster, Ganderton, & Watson, 2014). These correspond to an importance for the arm reaching forward in the forward stroke as well as the other arm drawing the water back. In internal rotation, moving the arm forward, and or across the body, the upper and lower subscapularis use is the same.

One theory for shoulder balance, regarding the subscapularis is that the upper portion is less strong because it does not have to resist the strong deltoid muscle (Wickham, Pizzari, Balster, Ganderton, & Watson, 2014). More activity of the lower subscapularis in elevation may come from balancing the abduction of the deltoid muscle action. Overall the lower subscapularis

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plays an important role in shoulder elevation though this portion is mechanically weaker (Halder, Zobitz, Schultz, & An, 2000). Injury to the lower segment results in more functional limitations than the top subscapularis portion such as reducing forward flexion. Higher stiffness in the superior tendon region may explain the infrequent extension of rotator cuff tears into the subscapularis tendon. (Halder, Zobitz, Schultz, & An, 2000). The subscapularis tendon is more vulnerable during external rotation movements or the pull back phase of the forward stroke.

The scapula joins to a clavicle (collar bone) strut and chest wall by muscle attachment to both vertebrae spinous processes and ribs (Kibler, 1998). Reaching forward is achieved through the pectoralis minor and serratus anterior and reaching backwards occurs via the rhomboids and middle trapezius muscles. For example, if the rhomboid muscles are in a shortened position, the scapula motion would start off inferiorly positioned (Neumann, 2010) and would make reaching forward more difficult.



Figure 4 Deltoid (Muscles Used, 2017)



Figure 5 Trapezius (Muscles Used, 2017)

Figure 6 Latissimus Dorsi (Muscles Used, 2017)



Figure 7 Subscapularis (Kenhub, 2017)



Figure 8 Supraspinatus (Kenhub, 2017)



Figure 9 Infraspinatus (Kenhub, 2017)



Figure 10 Rhomboids (Kenhub, 2017)



Figure 11 Serratus Anterior (Human Motors, 2017)



Figure 12 Biceps (Kenhub, 2017)



Figure 13 Teres Minor (Kenhub, 2017)



Figure 14 Universal directional terms (Olgakabel, 2014)

Conditioning of the muscles that stabilize the humerus is important not only in injury recovery but also for training protection during an active lifestyle because "capsule and ligaments normally function only as a checkpoint" (Flatow &Warner, 1997, p.101). Rotator cuff and bicep muscle create socket compression in mid-range movement and share load reciprocally (Flatow, Warner, 1997).

The scapulothoracic muscles correct length, strength, and sequence of recruitment are crucial in controlling scapular movement (Lucado, 2011). The humeral head position may move up from weakness, fatigue, or strength imbalance causing impingement below the acromion and further injury. Biomechanical issues such as bad posture decrease upward scapular positioning, which increases shoulder muscle fatigue through a reduction of serratus anterior and increase of upper trapezius. The findings are consistent with repetitive nature of paddling involving shoulder and spine rotations over long periods (Abraham & Stepkovitch, 2012).

# **Thoracic Column**

Without the thoracic column there would be no upper body rotation in the paddle stroke or resistance toward paddling motion, crumpling a kayaker forward. Without attachments to the

thoracic column the scapula would be near free floating and practically useless. The overall unit of the thoracic column plays an important role in paddling and is constantly enabling movement and resisting pressure. The thoracic portion of the spine does not have as many movement directions as the scapula. None of these muscles are as large or powerful as the muscles found in the scapula, yet they are critical for stabilizing the upper body and they require coordinated movement too.

Earlier in the paper there was an establishment of kayak back pain as a major musculoskeletal concern (Abraham & Stepkovitch, 2012; Fiore, 2003; Jackson & Verseheure, 2006; Powell, 2009). There is numerous thoracic and spine literature available, however, the information is quite technical. It is likely because the thoracic column encases the spinal cord, part of the central nervous system, which control all actions.



Figure 15 Thoracic Column (Ignasiak, Dendorfer & Ferguson, 2016).

Sitting motions such as in a kayak likely activate deep and superficial muscles during trunk rotation. Though mobility varies within the thoracic region; regions with fewer rib articulations such as T8 to T10 have potential for greater mobility (Lee, Coppieters & Hodges,

2005). Deep muscles would include semispinalis thoracis (figure 16), multifidus (figure 17),

rotatores (figure 18), and intertransversarii.

Deep Muscle	Action
Intertraversii	Laterally flexes the vertebral column
Multifidus	Extends vertebral column and rotates toward opposite side.
Rotator Breves	Extends vertebral column and rotates toward opposite side.
Semispinalis	Extends vertebral column and rotates toward opposite side.
thoracic	
Superficial	Action
Muscle	
Longissmus	Extends vertebral column. Alone produces lateral flexion to that side.
thoracis	
(Martini,	Nath & Bartholomew, 2014)



Figure 16 Semispinalis Thoracis (Kenhub, 2017)



Figure 17 Multifidus Muscle (Kenhub, 2017)



Figure 18 Rotatores breves and longissimus muscles (Kenhub, 2017)

Paddling forces are not evenly distributed, according to a study done by Fleming (2012). To go further, Fleming, Donne, Fletcher and Mahony (2012) found that stroke force transfers were higher at T4 than T1, T2, and T3. From Fleming's graphs, more tension means greater muscle movement, which alludes to stretch of opposing muscles (2012, p.21). Overhead paddling movement accounts for a high proportion (39 + 16%) of a racing stroke cycle, which means that paddling technique and style of boat influence forward stroke kinematics greatly. Though many experienced sea kayakers do not lift the paddle higher than their head (Wise,

personal communication, May 2015).

The forward stroke motion via the thoracic segment is rotational as well as extensional forces for posture. Thus, the spine relies on its ability to constrain movement between the vertebrae to patterns (Hansen, 2006). Paddling loads established by Fleming (2012) show that normal kayaking force is well below the failure rate of an elderly spine. A study testing 11 elderly cadaver thoracic spines found torsion failure averaged 151.7 +- 33.1 N (Borkowski et al., 2016). The magnitude of torsional loads safely applied to active paddling thoracic spines would be lower.

Stroke position on the back can be highly influenced by its position as well as other body parts. A study on thoracic loading differences between sitting and standing found "intradiscal pressure is about 40% higher for sitting" (Dreischarf, Bergmann, Wilke & Rohlmann, 2010 p. 2015).

A stiffer spine is more resilient to buckling allowing it to safely bear more load (McGill, Cannon & Andersen, 2014). This is important when kayakers paddle larger waves or drops. Sitting upright will help in water descents, loading a paddle blade, and to maintain form at all times even in exhaustion or sea sickness. It also allows the bones to be optimally spaced from one another making muscle work easier, and lessening the force placed on ligaments. In a study by McGill (2014), known for his expertise on the back, the outcome is that exercises on a moving surface result in higher torso activation, which parallels paddling motion in dynamic waters.

Sitting in a kayak may lead to an unnatural disposition of the back "by the nature of the activity it is difficult to maintain a neutral lumbar spine in the seated posture in kayaking" (McKean & Burkett, 2010, p.538). A common recommendation is to constantly distribute force

across the trunk is by building core stability "improved core stability has been suggested to increase efficiency of movement, prevent injury and improve performance" (McKean & Burkett, 2010, p.538). Adams and Huttons (as cited in Oxland, 2015), reinforce this by showing that the load bearing ratio through the back is posture dependent. From this, a kayaker should use better posture in kayaks and consider the influences of the kayak seat.

#### **Stroke Biomechanics**

Every kayaker who has ever used strokes to get places, commonly known as paddling, has been sore. Without the stroke there is no power or propulsion within the environment, which leaves a paddler vulnerable to the dangers of moving water. Without the stroke a kayaker cannot be a kayaker and the kayak loses meaning. Also, without the stroke there is little mechanical stress placed on the thoracic and scapula regions and therefore very small chances of strain. It is worth examining how the shoulder and back come into play as well as an overview of visual criteria by coaches.

The stroke appears visually simple at first. To apply stroke force effectively it is necessary to have firm contact with the seat, back brace, foot brace, and a thigh brace to transmit stroke force. With fortified practice and instruction, the stroke becomes coordinated and graceful looking. The evidence for stroke efficiency is huge; someone who can paddle an extra eight inches per stroke will be a significant distance ahead before half a day is over. In the stroke, the humeral head rotates inward of the glenoid cavity during the early draw and then the joint shifts to outside rotation as the draw phase finishes. This is good to know how the articulating surface positions, are changed by muscles activation.

Reaching for the toes during the stroke, scapular and thoracic muscles would be the greatest extended or most exposed. The torque (force x distance) is much higher because the

force distance begins further from the body, also the highest force occurs as the initial speed of the kayak increases; "the greatest potential for injury during the forward stroke may be at the thrust paddle shaft vertical when the humerus is maximally elevated in internal rotation and adduction as subacromial structures may be mechanically impinged [negative impact]" (Wassinger et al 2011, p.106). Yet, paddlers are encouraged to reach as far forward as they can "theoretically, greatest forward reach should occur at the catch for maximum mechanical efficiency" (McDonnell 2013 p.39). These statements coming from different arenas, are worth a paddler reflecting on for biomechanical performance and injury prevention.

To maintain performance, paddlers may employ a strategy that involves switching intensity of muscle use. Repetition, elevated arm postures, and periods of sustained muscle activity act in combination as risk factors for developing shoulder pain and disorders (McDonald, Tse, & Keir, 2016). Variations in paddling technique can be used to change muscle activity while, though repetition and elevated arm postures are unavoidable in all paddling.

Smaller paddlers, in both height and muscle mass often have to make maximum use of technique because of lower mechanical advantage in paddling (Osberg, personal communication, February 2015). In a study done on elite paddlers race time it was recorded that larger paddlers speed averaged faster 57s over 1000m (McKean, & Burkett, 2010).

Little written information exists on the Greenland paddle though it has a proven history of 3,900-years (Morrison 1994). With that many trial runs of a paddle blade in both towing and distance it is likely that the style of blade was kept for a reason. With stress versus strain, a higher stroke cadence matched to lower blade force in the water places less stress on the body (Yu, personal communication, September 2007). One has seen many senior sea kayak guides switch to the Greenland blade, as an example of this. That being said, many guides have also moved towards wider blades for more power with each stroke.

A study by Croft and Ribeiro found a "stroke rate of 24 resulted in decreased stress on the lumbar spine when compared to stroke rate of 18, 20, 22. Therefore, one injury control is to control load and stroke rate" (2013, p.17). This is not a surprise, since building higher forces leads to aggravating bones, tendons, and ligaments. It was also found by Croft and Ribeiro "lower cadences needed a longer stroke length to maintain the same speed" (2013, p.17). The blade force needed to displace the system of: water, friction, kayaker, kayak weight, and kayak gear, need a strong stroke to counteract this system as can be seen by elite kayakers "elite kayakers are reported to produce average peak forces of up to 400N (90 lbs) and impulses of over 1000 meters (Helmer, Farouil, Baker & Blanchonette, 2011, p.502). Peak forces during starts can reach 800N (180 lbs) for a single stroke" (Helmer, Farouil, Baker & Blanchonette, 2011, p. 502). For reasons such as these some kayak instructors advise starting paddling slow until your kayak picks up speed (Foster, personal communication, February 2016). One way traveling kayakers naturally do this is to keep traveling at a steady pace instead of stop and start.

Previous literature reports stroke rates of  $118 \pm 4$  (Mann & Kearney, 1980) and  $96 \pm 5$ per minute (Sanders & Kendal, 1992) during high intensity kayaking. Shoulder relationship to the stroke should be understood and kept in mind while paddling, such as muscles discussed in the Shoulder Literature section, "as the blade passes the hip of the kayaker, the opposite shoulder adducts with internal rotation and the corresponding arm is actively pushed forward... likelihood of mechanical irritation within the shoulder complex is increased" (Hagemann 2004, p.413).

The most comprehensive listing for the forward stroke in Canada are given by Canoe Kayak Canada's list, which is written for coaches to reference. There is no genuine anatomical breakdown, however a list for visual description is given. It should be noted this stroke criteria is optimized for speed. Canoe Kayak Canada trains people for competitive and recreational

kayaking and until the coaching title is reached, little written information is given on the forward

stroke. No written information is given at the Instructor level and Leader level. Below are the

components of the Kayak-Tech check for the forwards stroke from the Canoe Kayak Manual

(2014).

# **Kayak-Tech Check**

Set up

Pull

Hand positions approximately eye level Athlete is relaxed in shoulders and arms Rotation from end of pull phase is held – avoid overstretching / reaching. Avoid front arm crossing body to create an angle in elbow of less than 90 degrees Boat is level Catch Both hands are directing / placing paddle in water Blade is completely in the water before any rotation is initiated Sequencing of movements is evident Boat is level Hip rotation – athlete rotates in cup of seat Bottom hand stays at catch area Leg works with hip to create a strong connection to the footrest, boat and water Torso rotation follows hip rotation All movements are directing boat forwards Sequencing of movements is evident Pressure with top hand is down versus forward Movement of top hand is straight versus looping as torso rotates through phase Hip movements are power for moving boat Bottom hand - palm open Top hand – fingers are relaxed Wrists are neutral Elbow bends in latter part of stroke to allow for proper hand and paddle moves. Blade exits at hip – accelerates through exit Athlete finishes it off – connection throughout the stroke Paddle always in front of chest Hands always in front of hips

Boat is level

## **Muscle Physiology**

The anatomy or the architectural structure surrounding the scapula and thoracic column have been covered. Knowing the location of the muscle is important but knowing *how* the muscle works is important too. Some knowledge provides background to muscle adaption and the makeup of injury. Internal actions of muscle physiology gives paddlers a grasp deeper than 'muscles contract' and 'that creates motion' which 'makes the kayak go forward.' Muscle physiology established by scientists forms a basis for the overlay necessary for those working with athletes. Paddling loads applied are usually well within a muscle's physiological range, but repeated frequency through paddling and multiple sessions shortens recovery time, tissue healing cannot occur, and the structure fatigues (Ball & Herrington 1998).

All skeletal muscles depend on the same principles. Skeletal muscles work on sensory output carried from the brain and spinal cord, which stimulates muscle actions (Greig & Jones, 2016). "Optimal function is achieved when normal anatomy interacts with normal physiology to create normal biomechanics" (Kibler, 1998, p.325). Adenosine triphosphate (ATP) is a necessity for the energy for cross bridge cycling, commonly known as contraction (Greig & Jones, 2016). Large motor units are only used when forceful contractions are required, such as paddling quickly through a surf launch, rapid set, or a competitive race.

To recognize fatigue from muscle weakness or damage, it is important to note that the loss of power with fatigue is changeable by rest, meaning fatigue is temporary. For example, factors which cause fatigue during high-intensity exercise differ from those that induce fatigue in endurance activity: "force, velocity, and power are ultimately determined by... the number and force of the strongly bound cross bridges, and the rate of cross-bridge cycling" (Fitts, 2008 p.556).

Type I muscle fibres are less powerful than type II fibres but are more resistant to fatigue (Greig & Jones, 2016). Type I would be more developed in a sea kayaker, who is more prone to paddling all day at an even pace. Type II fibers are recruited for bursts of high intensity energy and short duration and would be more developed in a white-water kayaker or short distance racer, who paddles all out for five minutes, rests, then paddles hard again. The force production in endurance is generally about 30% of the maximum muscle generation (Baldwin, & Haddad, 2002). For type II fibres, force production is high and in general 80% of maximum power output (Baldwin & Haddad, 2002).



Fig. 3. Ultrastructural differences between type I and type II fibers related to exercise-induced damage. Type II fibers are more susceptible to injury due to smaller Z-disk, titin, nebulin and dystrophin as well as higher strain on the sarcolemma.

# Figure 19 Microview of Muscle Structure (Qaisar, Bhaskaran, & Van, 2016)

A damage ratio of 3:1 in fast-twitch type II fibres is reported in *Muscle fiber type diversification during exercise and regeneration* (Qaisar, Bhaskara, & Van, 2016). The anatomy makeup of a type II differs from a type I muscle fibre. This may help to explain a higher degree of damage found in white water kayaking. Type II fibers have narrow Z-disks which mean fewer attachments to sarcomeric threads. The sarcolemma is responsible for sarcomere contraction and muscle fiber structural integrity and exists twice as much in type I compared to type II fibers.

The muscle changes follow disruption of muscle cell components, especially desmin. Desmin integrates or stabilizes key features: the sarcolemma, Z-disk and nuclear membrane. Desmin's quantity increases through repeated eccentric contractions (Qaisar, Bhaskaran, & Van, 2016 p.60). Fibers without desmin, for example muscular dystrophy, lose membrane integrity and that essentially impair contractions resulting in reduced force generation.

In mild forms of injury, key structural sections of the muscle, Z-disks (figure 19) appear wavy and this causes less stability in transmitting muscle force across the fiber. In worse injury cases, Z-disks thicken and stagger into the next sarcomere unit (Qaisar, Bhaskaran, & Van, 2016).

## Training

The forward stroke does not necessarily use the shoulder in a perfect manner, requiring some extra training effort, "the kayaker will naturally develop agonist muscles through kayaking... strength training may be appropriately used to maintain stability of the shoulder and offer some protection against potential muscle imbalance" (McKean & Burkett, 2010, p.540). Despite the wide range of paddling movement, the bones need to be kept solidly in place while moving. "Maintaining proper shoulder function and general strength by training the antagonists and shoulder stabilisers... maintaining proportionate strength of shoulder stabilisers are important" (McKean & Burkett, 2010, p.540). Understanding proportional strength of movement requires thought of the muscle volume as well as distance from the joint.

Slow muscle training may be more effective than explosive training for initial acceleration through the paddle stroke (Liow, 2003). However, the crossover of explosive weight

training shows similar patterns of paddle force development: force is produced rapidly at the start of explosive movement, then steadily declines until the blade exits the water.

More strength is gained with explosive training, yet in the initial acceleration of the stroke phase overall improvement came from slow training (Liow, 2003). Force maintenance opposed to rate of force development during strokes is more important (Liow 2003). As the kayak reaches full speed, force-time of the paddle stroke shows force peaks quickly after paddle entry then steadily declines until paddle exit.

There are many exercises physical therapists and gym trainers have developed over the years. Fisher provides excellent primary research for exercises particular to kayaking in her doctorate thesis *Revealing complexities within flat-water kayaking: injury prevention and biomechanical analysis* (2015). An interesting find is that humans have shoulder blades not optimally positioned for the best paddling movement (Fisher 2015). Through another study, attempting to shift scapula placement, was unsuccessful. This is possibly related to different methodology criteria for muscle training.

Not every paddler uses the same muscle activation sequences, suggesting individualized kayaking technique, as is seen on the water. In a study by Fisher, sprint paddlers used their latissimus dorsi as the main mover during the same side propulsion but marathon paddlers used their latissimus dorsi most during the opposite stroke propulsion.

Bearing similarity to internal rotators and external rotators differences can be seen in flexion and extension as well. Shoulder knowledge shows extensor area exceed flexors area in a study by Cook (1987) "flexion and extension imbalance may also be explained by comparison of the cross-sectional area of muscle mass responsible for shoulder extension and shoulder flexion" (p.5). Thus, the shoulder extensors create greater force capabilities than the shoulder flexors. For a strong-willed kayaker, lifting weights will not be mentally challenging, as this is sometimes a deterrent for the public. Balance is more intricate by training one muscle in relation to another; "the selection of appropriate exercises in the rehabilitation of scapular muscles performance depends on the actual strength of muscles but also on the relative strength of one muscle in relation to another" (Cools et al., 2007, p.1745).

Rocky Snyder's book, *Fit to Paddle* (2003), is unique because it covers kayak training from a weightlifter's perspective instead of a paddler who weightlifts. The book uses the word paddling, instead of strength, but does not explain kayaking mechanics. *Fit to Paddle* is a useful resource for those unfamiliar with proper weight lifting form at the gym, by listing different exercises in bullet point form. *Fit to Paddle* is sponsored by kayak champions Dave Johnston and Eli Helbert. Rocky Snyder could, but does not build a philosophy of movement and deepen the anatomical knowledge allowing kayakers, losing some effectiveness as a result.

A similar book written by John Chase, *Power to the Paddle* (2013) covers many exercises that will strengthen the body. By strengthening the body, one is presumably likely to have higher resistance to acute or micro-traumatic injury. Chase himself is a high-level paddler; however, Chase's audience is the general person who would like to take up paddling.

In literature, muscle balance often surfaces, but is not fully understood. Imbalance is modification in functional length and muscle recruitment resulting in abnormal over and underpull around a joint (Mischiati et al., 2015). A muscle's functional resting length generates peak tension. Movement dysfunction can be found at one or multiple joints. Fatigue decreases proprioceptive accurate repositioning at the shoulder, visibly evident in tired paddlers. Muscles that are a single joint stabilizer should first activate, followed by a multi joint mobilizer, then load supporting trunk or girdle muscles as the load is transferred (Mischiati et al., 2015). For example, when one pulls a paddle blade, the rotator cuff muscles should pre-tense, then your latissimus dorsi should tense.

Stiff muscles leave little room or energy for further movement. While training to keep muscles flexible, kayakers should know of massage. Unassisted massage is possible through foam rollers or lacrosse balls, particularly lacrosse balls which are much more packable. Foam rolling a younger method of recovery for athletes, is currently recommended by many physiotherapists though does not have a wide array of literature studies. Foam rolling improves mobility (Griefahn, Oehlmann, Zalpour & Von Piekartz, 2015). The rolling action under body weight pressure lengthens muscle fibres to their normal resting length, fascia and lets fluid flow more freely which means increased blood flow and oxygen (Beardsley & Karabot, 2015). Selfmyofascial release shows consistent evidence in increasing flexibility and reducing muscle soreness. It likely leads to improved arterial function and improved endothelial vascular function (Beardsley & Karabot, 2015).

Recommendations from the literature point to the following: control of full rotation of the shoulders (both external and internal rotation range), coordination of glenohumeral movements, strength of scapula stabilizers, thoracic strength and range of motion.

## Discussion

This paper can provide further anatomical knowledge for better recognition of muscle distress for kayakers, while potentially providing an understanding of the kayak sport and movement for health professionals. In the case of paddling, the body is a machine, yet much more difficult to fix because the scapular and thoracic cannot be repaired the same as a damaged hull. In order for there to be more prevention of paddling injury, instructors, guides and avid recreationalists should be able to articulate a simple muscle break down of the shoulder for the stroke. For higher levels of certification process I recommend instructors spend half a day on scapular and thoracic placement care, and those who are trained for multi-day guiding or longer recreational touring spend a full half day on thoracic and scapular placement care. Formal course training rubrics usually adapt to increase their effectiveness and also mitigate potential problems. This paper has tried to bring attention to the overlook of stroke biomechanics up to this point.

Different viewpoints are necessary to understand the scope of the problem of kayak injury and form preventative measures. Each literature subsection; Adventure, Shoulder, Thoracic Column, Stroke Biomechanics, Muscle Physiology, and Training; link to one another to give perspective to the problem of injury stemmed from the kayak forward stroke. Looking at the formalized environment of kayaking, anatomical sites, how the anatomy unfolds in real life, as well as the potential problems and solutions encompassing muscle injury form the ground work for the serious kayaker in searching for solutions.

Self-reliance is a huge aspect of kayaking. Most paddlers do not have coaches or people who understand anatomy and physiology, and it is often not part of a paddler's background. Further knowledge of injury may play a part in future prevention and care of self. Injuries take on graver levels of seriousness at a higher performance levels, in remote places or in split second decision making in rough water. A sea kayaker is not expected to have the depth of training as a weather man, navigate like a sea captain, or perform as a paramedic yet they're training gives them knowledge in each area. Perhaps it is now time to increase this capacity to include shoulder biomechanical issues in a more articulate way in rubric.

Kayaking originated in an era of no reading nor writing. There might have been discussions about preventing kayak injury because of Inuit culture's attention to detail and their second-hand nature of dissecting animal bodies. Most men paddled regularly since their teenage years and were able to figure out many complex maneuvers that are not currently practiced in contemporary kayaking. There would have also been a concentration of thought on the topic of paddling but now it is very difficult to access those information resources, unless in an area with elders who recall and discern knowledge around kayaking.

To the modern-day researcher, there is a vast array of online material available. The biological discourse or specific wording usually intimidates paddlers or may be shrugged off as not truly relatable. However, a general search gives general answers, much of the time without giving sources or critical thinking. One can find recommendations online that are simple but bare in information and very difficult to connect the subject matter together, especially as it relates to kayaking. A problem with these sources is they do not explain how they came to these conclusions.

Kayaking is a growing sport in popularity and demands high use of shoulder and upper back. Indeed, the two move together in synchronization to propel a paddle blade. The paddle stroke is a combination of human anatomical parts and the shoulder is a complex mechanism, having different muscle groups that pull it in different directions and activate in specific sequences. Key muscles include latissimus dorsi, deltoid, infraspinatus, supraspinatus, rhomboids, trapezius and teres minor. It is these practiced specific sequences that allow trained kayakers to paddle faster than untrained, strong paddlers.

A shortage was noted on direct connections made between kayaking and scapula. Through a study of shoulder, thoracic and kayaking, one would learn about each, though forming the relationships could be unclear. Physiologically, the parts that bare the most strain are the shoulder and back in the forward stroke. It is often the conditioning of the shoulder and back that can determine the difficulty of the waters and distances a person can paddle in. For example, while weather is a huge influence, skilled paddlers have been known to handle 30 foot swells.

Guides and recreational kayakers paddle in dynamic and dangerous environments. Still, the number of guiding years can give a false sense of security, since many tourists are novices. This could be another reason why it would be useful to make detailed recorded paddling knowledge available to the serious paddling community. They already have special technical skills under positions of authority for calculating tides, currents, interpreting weather and performing rapid rescues under pressure. In addition to these skills guides are highly dependent on their bodies. It is not uncommon to find guides towing clients which makes their stroke twice as forceful. Micro trauma also occurs through guides usually works many days without the choice of taking breaks.

However, serious recreational kayakers almost always go into harder and more technical terrain than commercial guides. Serious recreationalists do not hold the same positions of responsibility for the group, however, they usually double the paddling distance and pass through more technical water which again leaves them very dependent on the forward stroke.

All paddling muscles discussed were skeletal, which means they work off the same principles. That is why it is worth covering some physiology and forming an understanding as to how muscles operate as well as their anatomical placement. Sea kayakers, unless they are racing, or practicing in heavy ocean current will build type I fibers and white water kayakers will build type II fibers. While details surrounding stroke biomechanics is probably not what kayakers want to discuss around the fire at night time it provides a means of understanding of what could be wrong. If one considers the amount of time spent in an injured or dispositioned state, it seems easier to educate a paddler before hand. It may be difficult to convince kayakers who have been paddling for many years, additional thoughts on the forward stroke. Yet truly committed kayakers are always looking for ways to improve their stroke. Many of the combined sources for this paper came from analysis of viewing Olympic flatwater stroke, athletes who are always striving to improve their peak performance. Also, people from all kayak sub-disciplines can learn from each other.

If one were to consider the beginnings of a course outline it may start with the following. The shoulder is the widest ranging joint of the body. It needs many muscles to make is the widest ranging joint and have slightly different paddle strokes. The shoulder muscles correspond to a study of Table 1. Supraspinatus, infraspinatus, teres minor, and subscapularis are the key muscles that protect the arm so it can perform the forward stroke. Paddlers in a class setting should partner and tactilely feel the muscles contract while performing a dry land forward stroke. Serious paddlers can learn to identify the rough borders of these muscles. In the pull phase of a stroke, supraspinatus, upper trapezius, and latissimus dorsi all engage. The exit phase uses latissimus dorsi, rhomboid major and serratus anterior muscles. The recovery phase uses supraspinatus and upper trapezius.

Though balance is a key concept it is not defined, especially from a paddling perspective. However, if muscles are used in the same fashion than they are likely to become stronger than other parts of the shoulder and upper back. Consciously ensuring that all the muscles attached to the scapula and thoracic column remain active is a sensible way to ensure continually balanced strength.

This in turn relates to range of motion. Through proper balance, paddling range of motion is more easily achieved. Fatigue, weakness, and injury set the make-up of a muscle differently from each other. Fatigue can be easily recovered through short-term rest, weakness can be changed via exercise but injury disrupts the muscle unit and will take longer to recover. Stabilizers are essentially muscles that form anchors for the three key bones (scapula, humerus, thoracic vertebrae). By keeping these muscles trained they can withstand abrupt or consistent stroke mechanical forces.

# Conclusion

The information garnished for this paper come from scholarly research articles, normally written by teams with PhD or Medical Doctorate, which have strong methodology, results and discussion. If a state of conflict had been noticed, comparisons of the methodology used in the scholarly papers would have been checked for a better possible outcome.

In kayaking emphasis is placed on equipment, experience and certification. Indeed, in a professional office setting there are steps to make more ergonomic offices. Paddlers can often tell the pros and cons of equipment, yet, being able to give more insightful advice on stroke mechanics, scapular and thoracic column, is desirable in the kayak community. It would be helpful to have scapular and thoracic placement experimental studies for guides and expedition travelers to build more research around the topic.

Kayakers pride themselves on their boat, the distances they have paddled, and the certifications that show the level of achievements they have maintained. All of these are important. However, what needs to be done in addition to this, is for kayakers to critical look at the musculature that makes that all possible beyond "if you try hard you'll make it way." Multiple tests have diagnosed the forward stroke show upper trapezius, supraspinatus, latissimus dorsi, serratus anterior, and rhomboid major being key movers in the complex motion of a paddle stroke.

If people are moving forward and the boat is going forward why rethink the forward

stroke? For paddlers under pressure, ranging from seasonal to year length guides, higher-end athletes with sponsorship, reliance on the forward stroke is extremely important. When the sum of a machine goes wrong, the individual parts must be looked at to see the cause of the fault. By not being educated, and not being able to determine the site of fault, the kayaker is likely to develop unnecessary pain.

Paddlers owe this to themselves to educate themselves as many kayakers do not have the benefit of being in the Olympics and having a personal coach. Possibilities for future directions for research include investigating the effects of training problems and more primary research especially by the sea kayak community. Primary research could be expanded into both guiding and expedition sea kayaking fields. One could be testing guides who have shoulder injuries, guides who do not have shoulder injuries at the beginning of the season, middle of the season, and end of the season. Measuring sea kayak expeditions would be significantly harder because of access to health professionals, as well as the same tester.

A more thorough analysis of the forward stroke from an expedition perspective at a Master's level would yield original data that was not possible in this paper. Setting criteria such as a minimum of 700-km a month to establish positive and negative scapular and thoracic effects in kayaking would set a new standard. Future implications include a detailed view of how to optimally grow and balance the muscles for the scapulothoracic joint for the forward stroke.

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Figure 1. Ball-and-Socket Joint

Martini, F. Nath J., Bartholomew, E. (2015). *Fundamentals of Anatomy & Physiology*, 10th Edition. Pearson.

Figure 2 Scapula

Editors of Encyclopædia Britannica. (2007). Scapula. Retrieved from Encyclopaedia website: https://www.britannica.com/science/scapula

Figure 3 Humerus

Martini, F. Nath J., Bartholomew, E. (2015). *Fundamentals of Anatomy & Physiology*, 10th Edition. Pearson.

Figure 4 Deltoid

Muscles Used. (2017). Image of the Deltoid muscle. Retrieved from Muscles Used website: http://www.musclesused.com/biceps/

Figure 5 Trapezius

Muscles Used. (2017). Image of the Trapezius muscle. Retrieved from Muscles Used website: http://www.musclesused.com/trapezius/

Figure 6 Latissimus Dorsi Muscles Used. (2017). Image of the Latissimus Dorsi muscle. Retrieved from Muscles Used website: http://www.musclesused.com/wp-content/uploads/2012/08/Latissimus-Dorsi.jpg

Figure 7 Subscapularis WN. (2017). Image of Subscapularis muscle. Retrieved from WN website: https://wn.com/musculus\_subscapularis

Figure 8 Supraspinatus Kenhub (2017). Image of Supraspinatus muscle. Retrieved from Kenhub: https://www.kenhub.com/en/atlas/musculus-supraspinatus

Figure 9 Infraspinatus Kenhub. (2017). Image of Infraspinatus muscle. Retrieved from Kenhub website: https://www.kenhub.com/en/atlas/infraspinatus-muscle

Figure 10 Rhomboids Kenhub. (2017). Image Rhomboid major muscle. Retrieved from Kenhub website https://www.kenhub.com/en/atlas/musculus-rhomboideus-major

Figure 11 Serratus Anterior Human Motors. (2017). Image of Serratus Anterior. Retrieved from Human Motors: http://www.human-motors.com/en/muscles/m-serratus-anterior/

Figure 12 Biceps Kenhub. (2017). Image Biceps brachii muscle. Retrieved from Kenhub website https://www.kenhub.com/en/library/anatomy/biceps-brachii-muscle Figure 13 Teres Minor

Kenhub. (2017). Image Teres minor muscle. Retrieved from Kenhub website https://www.kenhub.com/en/videos/teres-minor-muscle

Figure 14 Directional terms

Olgakabel. (2014).Why do we get hip pain and what can we do about it? (2014). Image of directional terms. Retrieved from Sequence Wiz website: http://sequencewiz.org/2014/04/23/get-hip-pain-can/

Figure 15 Thoracic Unit

Ignasiak, D., Dendorfer, S., & Ferguson, S. J. (2016). Thoracolumbar spine model with articulated ribcage for the prediction of dynamic spinal loading. *Journal of Biomechanics*, *49*(6), 959–966.

Figure 16 Semispinalis

Kehnhub. (2017). Image Semispinalis thoracic muscle. Retrieved from Kenhub website https://www.kenhub.com/en/atlas/musculus-semispinalis-thoracis

Figure 17 Multifidus

Kenhub. (2017). Image Multifidus muscle. Retrieved from Kenhub website https://www.kenhub.com/en/atlas/multifidus-muscle

Figure 18 Rotatores Breves

Kenhub. (2017). Image Rotatores breves and longi muscles. Retrieved from Kenhub website https://www.kenhub.com/en/atlas/musculi-rotatores-breves-et-longi

Figure 19 Microview muscle structure

Qaisar, R., Bhaskaran, S., & Van Remmen, H. (2016). Muscle fiber type diversification during exercise and regeneration. *Free Radical Biology and Medicine*, *98*, 56–67.

# Appendix

## **Background Anatomy**

Abduction: Movement away from trunk, as in raising arms to the side horizontally or scapula away from the spinal column

Adduction: Movement towards trunk, as in lowering arms to the side.

Extension: Straightening, moving bones apart.

Flexion: Bending, bringing bones together

Internal rotation: rotation with axis of bone toward body, as when humerus is turned inward.

External rotation: rotation with axis of bone away from the body, as when humerus is turned outward.

# Thoracic spine

Twelve bony vertebrae segments compose the thoracic spine. The thoracic spine gets larger and stronger in ascending number, ranging from thoracic 1 to thoracic 12. They are distinguished by applying finger pressure to the spine to feel the pointy bones. Oxland (2015) summarizes the functional spine unit best: two adjacent vertebrae, intervertebral disk, facet joints, and spinal ligaments.

Muscles are used differently throughout the thoracic region between deeper (multifidus) spinal muscles and superficial muscles (semispinalis, rotatores, longissimus) (Lee, 2005). Longissimus is controlled for upright posture but multifidus is more variable and data shows it more used for rotating (Lee 2005). A small amount of frontward movement between vertebrae occurs with flexion. The middle thoracic region (T4– T8) is considered to have the highest range of rotation (Lee, 2005), which makes it more prone to pain.

Due to their small size and medial positioning, the intertransversarii muscles are weak rotators and lateral flexors of the spine (Gilchrist, 2003). Some researchers believe that these muscles serve more of a proprioceptive role for the spine (Nitz & Peck, 1986). The interspinales are small, thin, paired muscles that insert onto the tip of the spinous process. They angle outward in insertion to the process of the lower vertebra and lie beside the interspinous ligament. Their small size limits them contributing to any significant movement (Gilchrist, 2003).

## Muscle Physiology

Skeletal muscles fibers are brought to life by a single branch of axon transmissions arising from a motor neuron. Action potentials, generate enough electrical current to open important calcium channels and which spreads to other cells in the muscle fiber (Greig 2016). Actin and myosin are molecules that act together to form the contractile unit, long intertwining fibers. Myosin has a strong preference to actin and when bound, the myosin pivots, contracting the actin fiber toward the sarcomere center. In this case, the contraction force is transferred to the kayak paddle. There can be a pre-build of calcium before release which there is an expectation of increased muscle force (Greig & Jones, 2016). Changes to calcium pathways play crucial roles in regulating muscle growth and energy efficiency.

# **Training**

Mild pain is a part of kayaking, and is beneficial to growth of skill and muscles but when pain becomes less of a benefit, it is worth knowing how pain is transmitted through the body and then perceived. In an experiment done on a rabbit to mimic what would be done in humans, a high density of pain receptors around the rotator cuff 's humeral insertion was found. The ability to feel pain is transmitted from the spinal cord to the brain through several different pathways. These pathways connect to the thalamus, a control area that balances the body, and also connects to the lower thalamus, which links hormones to the nervous system (Dean, 2013). The primary sensory cortex and motor cortex are a key part of the brain in pain processing (Dean, 2013).