The Role and Importance of Biomechanics in Orthopedic Surgery:

How It's Shaped the Field into What it is Today.

Senior Project

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Madison Graybar
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Madison Graybar Honors College Scholar	Date: May 1, 2020
Conner Sandefur Faculty Mentor	Date: May 1, 2020
Joshua Kalin Busman, Ph.D. Senior Project Coordinator	Date: May 1, 2020

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Abstract

Within this paper a multitude of topics are discussed to provide overall understanding of orthopedics and biomechanics. However, to provide further information, case studies and surgical procedures are discussed. The goal was to see how biomechanics has improved patient quality of life, by restoring them to some sort of normalcy. Orthopedic surgery does not just restore the patient's abilities to resume normal daily activities. It also can provide a better life for the patient than they had previously. This is a common goal within the elderly patients doctors care for, but it is not limited to them. Due to the role of biomechanics within the orthopedic medical field, doctors are able to help the patients at hand. By reviewing the procedures and case studies, one may see the raw data for themselves and understand this important fact.

The Role and Importance of Biomechanics in Orthopedic Surgery: How It's Shaped the Field into What it is Today.

Orthopedics plays an important role within health care and provides patients with the necessary treatments to help them improve their quality of care. Within this specific field of healthcare, the main focus is the skeletal system and muscular system. These two systems work together and if one fails it impacts the other. So, it is important to make sure both of well and working properly with no issues. However, if an issue occurs and inhibits you day to day life it is important to visit your health care provider. These include your orthopedic doctors, physician assistants, and surgeons if it's an emergency. Furthermore, orthopedics is dependent on biomechanics and is an important focus within this field. Biomechanics allows them to help diagnose and treat you properly. It focuses on how the body moves and functions within the skeletal system and muscular system. Therefore, motion and stability are crucial within biomechanics and orthopedics. This allows the health professionals to diagnose you and when treating you provide the correct and best treatment there is. With technology becoming widely used within medicine patients are now getting the highest quality treatment. Quality of life is improving within this field due to biomechanics and technology. Constantly new devices and techniques are being developed to further increase the quality of life. However, patients need to be aware of the benefits and consequences of these techniques and procedures that they are about to receive. Therefore, research and background information are necessary in order to understand the treatments and the recovery. This research paper allows everyone of orthopedics and its importance. However, in order to get the most beneficial

understanding you also need to be aware of biomechanics and how it plays a crucial role in this health care field.

Orthopedics and Orthopedic Surgery

Overview of Orthopedics

Within the medical field there are many subspecialties', orthopedics, being one of these specialties. It plays a vital role within the healthcare system since it deals with the skeletal and muscular system. These two-play hand-in-hand with each other and are important for one to complete their daily tasks and activities. Bending, squatting, running, sports, and even simple tasks like lifting an arm require both of these systems. If one system fails and doesn't work properly it limits one's ability to complete these tasks as simple as possible. Orthopedics helps to diagnose and treat a multitude of issues that prevent one from being able to do so. Furthermore, if the injury is significant you require surgery to fix the problem. With orthopedic surgery it can range from minimally invasive to critical. One may require a simple procedure, for example a shoulder arthroscopy and examine the anatomy inside and remove scar tissue. However, severe shoulder arthroscopies can require repairing a torn tendon and muscles and require a longer recovery time. To understand orthopedics further it is best to understand it origins and how much it has transformed over time.

The History of Orthopedics

Orthopedics or also known as "*orthopedia*" means straight child, as the focus began with physical deformities in children. This practice started back in the primitive times, however very little evidence has been found for this time era. The New Stone Age is where it really began with procedures like trepanation and amputations were performed.

It was even stated that “the union of fractures in fair alignment has also been observed, which emphasizes the efficacy of nonoperative orthopedics and suggests the early use of splints and rehabilitation practices.” (Swarup, et al. e434). Throughout ancient times Egyptians, Greeks, and Romans all engaged in orthopedic practices. In Egypt they found a significant document that has been proven to be the earliest and most important document to date for orthopedics. This document is called the Edwin Smith papyrus and it was written by Imhotep, who was a physician. “Many scholars recognize this medical document as the oldest surgical textbook. With regards to orthopedic conditions…” (Swarup et al. e435). Together the Greeks and Romans helped to further extend the knowledge of orthopedics with Hippocrates. They created the Corpus Hippocrates and it is known for the exclusivity of information on just orthopedic medicine. During this time as well, Galen was an important surgical figure and he to date is known as “the father of sports medicine” (Swarup et al. e435). New devices and techniques were emerging at this time, to list the prothesis was early emerging during these times. Unfortunately, during the Middle ages (476 A.D – 1453) medicine took a hit and progressed was completely slowed down. The churches became important in the day to day life of individuals, however the theories of medicine and church conflicted each other. Nevertheless, medicine started to grow and evolve rapidly in the Renaissance era. Artists like Leonardo Di Vinci started to created illustrations of the human body, which proved to extend knowledge of anatomy. Modern orthopedics was founded based on the knowledge found during this time and shaped it into what it is today. Technology has played an important role as well for the orthopedic field today. The X-ray was created in 1895 by Wilhelm Röntgen and at this time it helped improve the “ability to diagnose and manage

orthopedic conditions" (Swarup et al. e437). In 1942 the first metal hip replacement was done by Austin Moore and from there on orthopedics began to develop into the modern field of orthopedics. Today, technology plays a huge role in orthopedics and orthopedic surgery. Surgeries are being performed by scopes, which are minimally invasive and use a camera to look within the body cavity, from there the procedure is completed. There are many orthopedic surgeries that are based on multiple technological devices that show the surgeon the surgical field and allow them to perform the surgery. There are still technological advancement occurring within this field and it is constantly changing.

Biomechanics within Orthopedics

Overview of Biomechanics

Orthopedics revolves around the understanding of biomechanics since it is largely used to determine the diagnosis and proper treatment for the patient. Biomechanics is based on mechanics and the principles of human motion (Innocenti 2018). Within orthopedics they learn about biomechanics because it educates them on the proper motion of each joint and the interaction of the bone and muscle with movement. Knowing this allows the medical professional to treat patients correctly and provide them with the best treatment to restore them to the quality of life they had previously. With prosthetics being used for replacements or to replace a limb they require biotechnicians to create the best version of the device using their knowledge on biomechanics. A lot of orthopedic devices that are used are made to replicate human motion exactly or as close as possible. Therefore, when one gets a total knee replacement they expect the prosthetic to replace their knee and give them back their motion, so they can resume to normal activities and tasks. Biomechanics allows them to successfully do that and fulfil patient needs.

History of Biomechanics

Initial knowledge on this study was first seen with Aristotle with the *De Motu Animalium,* which was a text that showed the actions and mechanics of muscles found in animals (Innocenti 2018). In the renaissance period biomechanics alongside medicine became widely studied. Leonardo Di Vinci was also important due to his illustrations of anatomy and the mechanics of human motion. Di Vince also studied biomechanics alongside anatomy and "analyzed muscle forces as acting along lines connecting origins and insertions and studied joints function." (Innocenti 2018. P.491). More scholars helped to shape biomechanics into what it is today. Galileo looked at the strength of the bone and the change in shape due to external factors (e.g. weight). Newton published works on laws of motion and this proved beneficial to understanding human motion. Borelli contributed by finding the "human joint force in equilibrium conditions and … the position of the human center of gravity". (Innocenti 2018. P.491). In the 1960s Al Burstein introduced biomechanics and how much it contributes to orthopedics, providing the foundation of orthopedic biomechanics. Presently, biomechanics plays a critical role within orthopedics. Bioengineers create orthopedic implants for joint replacements and it is critical for them to get the precise measurements to create the highest quality product. They also are collaborating with orthopedic surgeons and applying biomechanical principles to current clinical issues that have arose. (Innocenti 2018). This study is helping to improve patient outcomes and provide new products that will replace the older models.

Orthopedic Procedures and Benefits

Overview

As a health professional one of the most important goals that you want to achieve is giving a patient a better quality of life. Whether it is by eliminating pain or replacing their knee so they have better mobility and now can complete tasks they couldn't before. Therefore, in orthopedic surgery the main goals on people with existing problems that are inhibiting their daily life is to eliminate or improve it overall. With the older generation, ages ranging above 50 years old, they are at higher risks to having orthopedic problems. It is "essential to improve the management and outcomes of individuals living with chronic medical conditions and disorders" (Kulig p.3). They are at risk for osteoporosis, diabetes, and many other medical conditions that can expose them to orthopedic issues. If a patient has osteoporosis, which is a condition that weakens the bones, they can be subjected to hip fractures, knee issues, arm fractures, and many more issues. However, we are going to focus on the most commons orthopedic procedures the elderly receives and are the most successful in enhancing their quality of life. These procedures are: total hip replacement (THR), total ankle replacement (TAR), and total knee replacement (TKR). The following have been shown to help these patients live a higher-quality life and lets them resume their normal activities.

Total Hip Replacement

Due to health complications that arise in the elderly population, elderly people are at a higher risk of obtaining injuries that need surgical interference. Usually it is common for those 65 years or older to obtain a hip fracture and females are at a higher risk. Currently there are 340,000 cases a year from falling, which keeps increasing.

(*Orthoguidelines*). Health complications that increase the risk consists of loss or impairment of vision, osteoporosis (weakening of the bones), loss of balance, and diabetes. If an elderly person falls and suffers a hip fracture most times the only way of treatment is surgery. There are three treatments that can help treat a hip fracture: preoperative traction, partial hip replacement, or total hip replacement. (Orthoguidelines). However, it does depend on the severity of the fracture and where on the hip bone it is located. In this case, if an elderly person falls and receives a severe break in their hip bone and they are diagnosed with osteoporosis, they would receive a total hip replacement. Total hip replacements are one of the top most successful orthopedic surgeries. This is beneficial to the elderly population, since the goal of these types of surgeries is to restore normal function which helps them perform normal activities. However, in order to have a successful surgery there are three factors that are looked at to determine the patient's success rate. These include surgical factors, prosthetic factors, and patient factors. (Alvarado et al. 2003) Within the surgical factors the skills and experience of the doctor cannot harm you however, the more knowledge and skill can benefit patients in the long-run. Prosthetics are important, since they are what is being used to replace the hip and will act and function like the hip. Therefore, the orthopedic surgeon and bioengineer collaborate to make sure the implants will fit and cause no further issues. Lastly, the health of the patient is critical, since you want them to be healthy enough to recover from the surgery without any complications.

With total hip replacements it is important that you use the correct materials for the procedure. They used to complete these surgeries with metal-on-metal prosthesis however complication arose. These complications were as followed high loosening rate,

disappointing lab results, and wear and creep of the polyethylene component (Christel et al. 1988). However, today alumina-alumina or cobalt chrome/stainless steel is used for hip replacements. In order to stabilize the implants and high-density polyethylene in place, bone cement or polymethylmethacrylate is used (Alvarado et al. 2003). After surgery to increase recovery time and lower the risks of blood clots mobility is encouraged. The sooner the patient is up and walking, the sooner they will recover and produce the best results. However, in some cases after ten years of getting the hip replacement a revision is needed because the materials are wearing down and the patient is having symptoms. This procedure is known to help elderly patients recover fast and resume to their normal life after physical therapy.

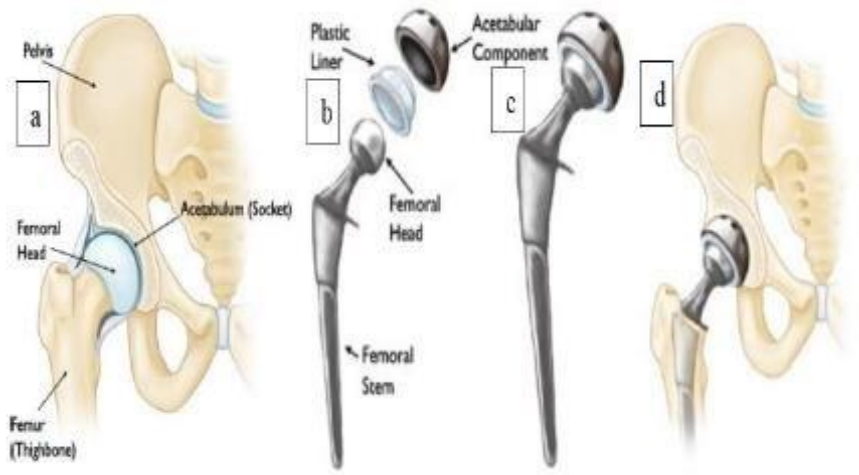

Figure 1. Components of a Total Hip Replacement (Aliyu 2017)

Total Ankle Replacement

When an elderly patient presents with ankle issues it is important to establish the severity of the issue. With a patient who is older they are at most risk during surgery do to their current health. Therefore, orthopedic doctors want to treat the patient first without

listing surgery as an option. If a patient is diagnosed with tendon degeneration or tendinopathy, which is weakness within the Achilles tendon found in the back of the ankle, it impacts the patient because they have “significantly lower ankle joint and higher hip joint contribution to support movement” (Kulig p.8.). The treatment plan is to tendon load, which is exercising the tendon, to increase mobility within the ankle joint and tendon. (Kulig 2008). This technique has been shown to be successful and improve their mobility and gait (walk). However, there are instances where the ankle has to be stabilized via surgery because the damage cannot be reversed any other way. This is commonly seen with osteoporosis or arthritis within the joint of the ankle. There are two types of ankle revision surgeries: ankle arthrodesis (ankle fusion) or total ankle replacement. The main difference between these two is that TAR involves removing the impacted joints and replacing them with an implant. With ankle arthrodesis the orthopedic surgeon will fuse the ankle together to help stabilize the joint. However, there are many disadvantages to this surgery and it can have complications as well. The recovery period is long (12-20 weeks) which can lead to leg muscle atrophy and they also are at risk for Acute/chronic infection, delayed union, decreased functional ability. (Hintermann et al. 2012). Due to this surgery not providing the best results, Total ankle replacement is always an option for the patient. Although, total ankle replacement is recommended for elderly patients at end-of-stage osteoporosis of the ankle. This procedure allows patients to have a normal walk, a quicker recovery time, and better stability/mobility. Within the recovery period patients are allowed to weight bear immediately and the cast id removed and placed into a boot after six weeks (Hintermann et al. 2012). After a total of twelve weeks patients are allowed to start physical therapy,

which is around the time ankle fusion starts to heal. When comparing both procedures and the success rate TAR has a "3.5% decrease in the hazard of failure" (Hintermann et al. p.5), meaning that it has a higher success rate then ankle fusion.

Case Studies for Ankle Arthrodesis

Case Study 1: There was 38 patients that in 2008 each had an ankle arthrodesis performed to resolve their ankle issues. However, a while each of these patients started to complain about pain in the surgical site. When they went back to their main orthopedic care provider, each one was told that they had a non-union of their ankle, which means that ultimately it wasn't successful. Thirty-one out of thirty-eight patients were informed post-surgery that it was successful and they would heal properly and regain normal function. However, this is not the case in this study and shows that this procedure doesn't provide proper results. (Hintermann et al. 2012)

Case Study 2: A 71-year-old male patient presented with ankle pain five years after his ankle fusion and the orthopedic surgeon said he needed a revision. After the revision surgery was completed the patient presented with no pain at the year post-op follow up. (Hintermann et al. 2012)

Case Study 3: A 60-year-old female patient presented with rheumatoid arthritis, which was causing her pain and limited mobility of her ankle. She was set to have a total ankle replacement due to the severity of the issue. After one-year post-op she presented with no pain and mobility of her ankle. Which allowed her to resume to her daily schedule and be able to perform tasks again pain-free. (Hintermann et al. 2012)

These case studies show that even though ankle arthrodesis is a recommended surgery for patients who do not meet the qualifications for TAR, it has a lower success

rate. This leads to higher complications and revisions that have to be made later to help the patient restore ankle mobility. Orthopedic surgeons do want to give the best treatments to patients, however they do not meet qualifications for that specific surgery. Complications do arise sometimes do to this as seen previously within the case studies. Therefore, surgeons and orthopedic doctors are striving to come up with better ways to improve these complications and create better treatments that are not as severe as a total ankle replacement since it is the last resort.

Total Knee Replacement

Lastly, another joint replacement the elderly populations are at a higher risk of getting is a total knee replacement. This procedure can either be done on one knee or two knee (bilateral), which helps to eliminate any existing knee problems that they currently have. Usually, a bilateral knee replacement is rarely done since it is better to have one functioning knee and a recovering one to speed up recovery. However, in rare cases if severe enough or the patient wants both done at the same time, will the orthopedic surgeon do both. This surgery is extensive since it requires the shaping/molding of the knee itself in order to fit the implants. Both bones, the femur and tibia, are measured using certain tools that then determine the build of the implant. During surgery the orthopedic surgeon will cut the bone into the desired shape and measurement and then place the implants in the knee to see if it fits. If it does they then continue to use bone cement to secure the implants into their desired spot. Orthopedic bone cement is a mixture of both liquid and powder that when mixed turns into a paste and can be squeezed out into a hard mass (Lu 2016). This cement is known for stabilizing the knee and the prosthetic used during surgery, so later on there are no further issues with the implant and reduces risk of revision. Currently there are studies being done to see if there

are any procedures that are better than a total knee replacement. They are trying to find ones that produce better results and a quicker recovery time.

Case Study for Knee Joint Distraction

In this case study a trial was done to see which treatment plan is better in patients with knee osteoporosis, since it can harm younger patients. Even though "total knee arthroplasty (TKA) is a widely accepted intervention for end-stage knee OA, it poses a major healthcare burden when placed in younger patients, since they have a higher risk of needing a costly and less effective revision surgery later in life." (Jansen et al. 2020). Due to this purpose they decided to run a trial in which they will regularly care for those with osteoporosis (OA) versus those who get the knee joint distraction. The 62 clinical trial patients had the procedure and an in-patient stay for two to three days. After this the frame that supported the knee was left in place for another six weeks. When they returned to have the frame removed, the surgeons also performed knee manipulation, flexion and extension of the knee. They collected data and found that there was an increase in joint space, but none in widening (Figure 2.). A year after surgery they collected their final results from each of the patients. The results were as followed: the clinical care patients had better results than the regular care patients. They had an increase in mobility, stability, a higher ROM (range of motion), and less stiffness than the regular care patients. (Jansen et al. 2020)

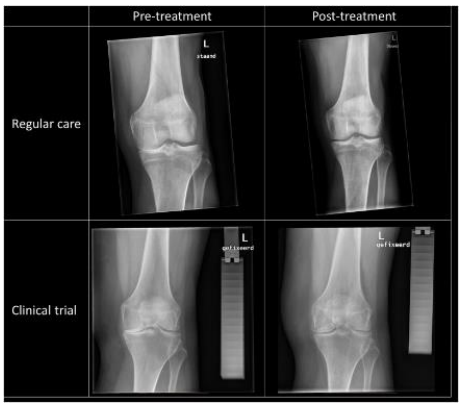

Figure 2. Results of the Clinical Trial Patient A Year After Knee Joint Distraction.

To date a new device, “KneeReviver’, is being created to perform joint distraction has been made and is in the trial period to determine its effectiveness. (Jansen et al. 2020).

Overall Effectiveness Following TKR

The purpose of a total knee replacement is to help the patient have a higher quality of life, eliminate pain, and resume to normal daily activities. One thing to note however is does it actual provide that for you afterwards? Data was collected from orthopedic surgeons and patients to show how effective it is to both in getting this procedure done.

After surveying 234 orthopedic doctors 90.2% of them replied saying that it is extremely beneficial for the patient (Wright et al. 1995). With patients showing pain, discomfort, and limited mobility surgeon identified this as the main correction that needed to be fixed with TKR. however, some of these indications changed in between the surgeons. This disagreement allows for future research and studies to be conducted to find a census of agreement for all orthopedic surgeons. They stated, “the development of practice guidelines and the implementation of strategies will change surgeons' behavior”

(Wright et al. p.696). They also found that the surgeons who had more favorable impressions of the outcome were the ones who had more experience and skills, since they had been doing it longer. (Wright et al. 1995).

Another patient survey was conducted and 257 questionnaires were sent out and returned. Within this they had about an equal number of males (46%) and females (54%) complete the questionnaire. Most of the patients who had a total knee replacement stated that they did have experience doing activities that place greater strength on their knees. However, they could perform normal day-to-day activities with no pain or limited mobility (Noble et al. 2005). With more weight bearing on the knee the patients recorded symptoms and said that they had to stop the activity. Other factors beyond the knee replacement can impact this, however it is known that this procedure doesn't restore proper knee function. With that being said, patients are allowed to perform day-to-day activities that do not exert the knee and allow them to live without pain. Beyond this specific study, patients have said that they felt it did not benefit them. Of the people who reported back on their satisfaction, 20% of these patients reported dissatisfaction after having the surgery (Gunaratne et al. 2017). There are many reasons they could have reaction after and not be satisfied with the results. However, the remaining shows that 80 % of patients were satisfied with their results.

Other orthopedic procedures

Beyond extensive procedures that help the elderly populations, there are also other procedures that benefit others. These two procedures deal with fracture healing and then cranial sutures. Starting off fracture healing is important since everyone is subjected to obtaining a broken bone. The purpose of this is to find a way that fixes the problem

and allows the patients to have full mobility. With biomechanics they are able to determine which plates are better for the patient and help reach that goal. Firstly, locked plates are known to be successful and provide significant results. Locked plated improve fixation in osteoporotic bones and avoids early deleterious instability (Hak et al. 2012). Orthopedic surgeon can also use conventional plates since they are minimally invasive. However, the downfall to these are that they can produce stiffness of the bone and limit mobility. Whenever determining plate length and screw position, it is essential that you determine which one will best help the patient. They have found that "increased length and less screws reduce stiffness and increase motion (Hak et al. p.755). This has been shown to produce better results for the patient and doesn't limit their motion or day-to-day life.

Next, craniofacial orthopedics plays a big role in patient care and patient outcome. With craniofacial orthopedics the main goal is to apply enough mechanical force to the cranial sutures to enhance cell growth at these sites. (Mao et al. 2003) It is common to see infants with headgear on to help stabilize their sutures and enhance the growth in these sites so they can connect and heal into their proper place. An experiment was conducted and the patient spent 10 every 12 day in headgear to see if it was enough mechanical strain to produce desired results. At the end of the twelve days they saw that there was indeed enough mechanical strain to induce sutural growth. (Mao et al. 2003)

All orthopedic procedures are beneficial to the patients and help provide a better quality of life for them. Even though some procedures and minimal, they still help to fix the problems the patient presents with. Orthopedics is essential for everyone ranging from infants to elders and helps to improve all quality of life. Therefore, many different

procedures and treatments are available to those who need it and have been shown to correct and fix their problem.

Conclusion

Throughout this paper a multitude of topics were covered to help others understand the purpose of orthopedics and biomechanics and their effectiveness. Many orthopedic procedures are done and rely on biomechanics to help provide the patient with the best outcome possible. However, even though a small portion of patients report dissatisfaction with their surgery. Most of the orthopedic surgeries are successful and restore a better-quality function of the joint for the patient. Many new procedures, techniques, devices are being created to help fix this gap of dissatisfaction and failure rates. Even though the success rate isn't 100% does not mean that it isn't beneficial for the patient to get. It will help the patient long-term by restoring their function to the best of the ability and eliminate pain. Orthopedics plays a huge role in the heath field and will continue to play a huge role, since it targets a large group of individuals. The field is always evolving and changing due to the technological advancements of this era. Which will allow those gaps of knowledge to be filled and new techniques that reduce risks following treatments for patients.

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