Pros+Tithenai
// In Addition to Place

By
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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Architecture

Waterloo, Ontario, Canada, 2013

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

The human being may no longer be reduced to the bounds of organic matter. An organism – a life form constructed from interdependent components that maintain various vital processes – may now reach beyond the limits of biological materials. Beyond the skin, thumbs, eyes, and organs of the average human being, we may notice the mutually dependent system of parts, functioning simultaneously as autonomous and interconnected components. These organic systems are now capable of fusing with foreign systems that help maintain the vitality of the macroscopic system – the human. Between human and machine, recent advancements in technology and prosthetic designs have enabled humans to graft with mechanized and computerized systems, challenging the preconception of what it is to be human.

The advanced prosthesis has become an integrated extension of the human body. This realization begs the question: how intimate can architecture become? *Pros+Tithenai* analyzes the body's imposition on space – transforming, manipulating, conforming to the void – and the equivalent imposition of space on the body. *Pros+Tithenai* examines how the human body unfolds in the creases between architecture, biology, engineering, cybernetics, psychology, and emerges reassembled.

ACKNOWLEDGEMENTS

To Donald, Rick & Wayne,
Thank you for graciously accepting my oddness. This thesis would not have been possible without your understanding, patience, and appreciation for interdisciplinary projects and collaborations.

To Eisa, Marta, Julie, Simon, Giles, & Michael,
Simply put, I wouldn't be sane without each of you. I also would be very, very hungry - thanks for all the food dates.

To Jesse,
Thank you for the wildly entertaining vocals while taking me on a handful of material runs. Both were greatly appreciated.

To my family,
Thanks for your assistance and never questioning my methods, even though telling from your awkward nods, you often thought I'd lost it.

And finally,
Thank you to the generous amount of individuals who shared their skills, passion, advice and kindness when discussing the many adventures of my thesis. Your encouragement helped me to continue pushing my work forward as I met several layers of resistance.

DEDICATION

I dedicate *Pros+Tithenai* to my Aunt Wendy.

I could have used you on this one. I'm sure it would have been hillarious.

Love & miss you always,
Kristal

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PREFACE

I don't know how to do this. I don't know how to spend every day with a smile on my face knowing that my sister could die. The only time that I am not entirely consumed by my private, overwhelming thoughts is when I build. My hands, thankfully, have thoughts of their own. They create comfort for my mind, my heart, by sculpting the smooth curves of the human body, by building plywood stands for designs not yet conceived, or by heat forming plastics to test their material properties. The inherent problem solving skills required to build any original project, no matter how simple, entices me, motivates me – and this is what will get me through this experience.

During my attempt to remain present and positive while completing *Pros+Tithenai*, my sister attempts to do the same as she battles Ewing's sarcoma for the second time. While this thesis is a necessary component to my master's degree, it is also a welcomed conceptual exploration that is inevitably influenced by what I cannot control. Despite the realization that I medically cannot comfort or cure my sister, as a student of architecture, I have the capacity to create a prosthetic architecture suited to any individual – and personally, this presently developing field of architecture fascinates me.

It's ironic that I wrote a substantial portion of this thesis in a cramped hallway of a hospital, starved of any architectural inspiration: the sound of the frequently flushing water pipes, the flood of artificial light, and the impersonal décor. The only architecturally "stimulating" element is the diagonal mullion aside an entrance to the communal chemotherapy treatment area, but it's completely misplaced and extremely ugly.

My train of thought is continuously derailed by ranting medical professionals, a resentful internal mail deliverer, a lost family with misguided anger, and the lady riding a miniature Zamboni designed to clean the floor – twice. There's one man in particular however who holds my attention. He keeps doing laps around the hallway, presumably unable to sit still – his body remains in motion in order to give his mind a rest. He's tall, hair turning white, *“Hope is the only thing stronger than fear.”*

Suzanne Collins, *The Hunger Games* (2010)

and pale with a solemn face. I constantly try to make him smile, to no avail. During every lap I offer him an extra coffee I have but he politely refuses every lap. (Although, in hindsight, I may just appear to be some creepy stranger who keeps offering people coffee – I've already offered it to four other nurses at this point). His voice is gentle, kind, but he still can't force a smile.

During his fourth lap a nurse has joined him. I overhear him mention how he and his wife watched the television show, *Dancing with the Stars*, the previous evening. I try very hard not to laugh and just keep thinking, "Keep your head down, Kristal," but I'm still grinning. He sees me, and finally starts laughing – both at himself and me. Then quickly includes, "But I didn't like it!" At this point my mother is now with me – aware of my mission to make him smile – and lets a laugh escape as well. Hope, laughter, it's contagious, and it cures what chemotherapy can't: the will to survive.

I have been where this gentleman has been before. Pacing, unsure of what to expect next. Afraid to sit still, afraid to absorb reality. Crammed in a room of pale faces, filled with false smiles and overly repeated joyful stories. It's a peculiar moment to experience. Everyone, at some point, stares at the floor; suddenly excusing themselves to complete a mundane task, only to cry in the hallway.

Two years ago my sister, was diagnosed with cancer for the first time. As a result, she had a right internal hemipelvectomy, including sacrum and surrounding cancerous tissue, at twenty-six years old.

I still remember watching her subtly overwhelmed, pale, blood-drained face as she hesitantly, with quiet determination on her face, entered her basement apartment for the first time after the surgery. She had to recalculate, re-navigate and renegotiate her agreements with a space she had already lived in for over a year. The stairway entrance was no longer viewed as a convenient architectural transition, but a physical and architectural obstacle, the couch crowded a pathway for her crutches, and a small floor mat became a hazard. She had to redefine the familiar, not only for her body but for space itself.

What I learned from this is the indefinite value of laughter and of nurturing hope in others. It's always important to believe that a rich future still exists; hope is medicinal in itself. If enabling my sister to walk again gives any individual a single ounce of hope, then it makes this process entirely worth while.

// PART ONE
INTRODUCTION

INTRODUCTION

The human being may no longer be reduced to the bounds of organic matter. An organism – a life form constructed from interdependent components that maintain various vital processes – may now exist beyond the limits of biological materials. Beyond the skin, thumbs, eyes, and organs of the average human being, we may notice the mutually dependent system of parts, functioning simultaneously as autonomous and interconnected components. These organic systems are now capable of fusing with foreign systems that help maintain the vitality of the macroscopic system – the human. Recent advancements in technology and prosthetic designs has enabled humans to graft with mechanized and computerized systems, challenging the preconception of what it is to be human.

The advanced prosthesis has become an integrated extension of the human body itself. This realization begs the question: how intimate can architecture become? *Pros+Tithenai* analyzes the body's imposition on space – transforming, manipulating, as well as conforming to the void – and the equivalent imposition of space on the body. *Pros+Tithenai* examines how the human body unfolds in the creases between architecture, biology, engineering, cybernetics, psychology, and more, and emerges reassembled.

This essay contains:

- PROSTHETIC ARCHITECTURE
- WAR + PROSTHETIC DEVELOPMENTS | Mark Wigley, CRS
- THE FRAGMENTED BODY | Antonin Artaud, Gilles Deleuze, Felix Guatarri
- BODY WITHOUT ORGANS | Antonin Artaud, Gilles Deleuze, Felix Guatarri
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- CYBERNETICS | Gregory Bateson

- AVATARS | Ann Lasko, Jaron Lanier
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- HUMAN COGNITION | Oliver Sacks, *The New York Times*
- HUMAN + MACHINE | *Game of Thrones*
- CYBORG IDENTITY | N. Katherine Hayles, *The New York Times*
- CONCLUSION

PROSTHETIC ARCHITECTURE

Prosthetics has been theoretically fascinating in architecture for several decades. Architecture derives from the human body. Whether human anatomy inspires form, or architecture pre-determines human spatial interactions, this tradition has prevailed in Vitruvianism, mechanicism (17th century), sensualism (18th century), organicism (19th century), and 'celibate machines' and 'dwelling machines' (20th century).[1] While the final design of *Pros+Tithenai* may not propose an architectural building, it does propose how to alter an individual's mobility, thus changing how one experiences space entirely. The architectural promenade has always been vital to architecture; without it, without movement, the experience of space deteriorates.

WAR + PROSTHETIC DEVELOPMENTS

WWI was the catalyst for the mass production of prosthetic extensions for the human body. Two types of prosthetics were developed during this time, each an anti-thesis of the other. "Arms" were created to harm bodies while prosthetic limbs were created to rehabilitate the body. The later was a direct result of the former; "Prosthetic technology alternated between producing substitutes for the body parts that military weapons had destroyed and producing these very weapons."[2] What once empowered an augmented soldier inevitably left many of their bodies wanting and dependent after being injured by a similarly augmented being.

The New York Times frequently published reports on prosthetic limb applications and developments during the 1940s and 1960s. Reports were encouraged by the combined estimation of 16859 United States American soldier amputees from WWI, WWII, Korea War and Vietnam War; WWI resulted in 2610 amputations, WWII totaled 7489, Korea War with 1477, and the Vietnam War resulted in a total of 5283 amputations.[3] 1 in 29 American casualties endured an amputation while enlisted in the Vietnam War.[4] As a consequence of combat, numerous soldiers' physical interactions with their environments became compromised, limited by their remaining limbs and altered functionality. War amputees excited public and intellectual interest for integrating mechanized prosthesis with desiring human bodies.

THE FRAGMENTED BODY

No mouth
No tongue
No teeth
No larynx
No esophagus
No stomach
No belly
No anus
I will rebuild the man that I am.[5]
- Antonin Artaud, 1948

French playwright, poet, actor and theatre director Antonin Artaud's (1806-1948) description of himself (above) is invaluable to the theoretical development of human augmentation. It has inspired many notable authors concerned with prosthetic architecture, including philosopher Gilles Deleuze (1925-1995) and co-author psychoanalyst Felix Guattari (1930-1992), theoretical architect Georges Teyssot

(b. 1946), and interdisciplinary design studio Diller Scofidio + Renfro (established 1979). This passage is found alluring because it depicts the body as an amalgam of autonomous parts. Furthermore, all of these authors are preoccupied with the function of the fragmented body. They examine the human body's interior relations – organs without body – compared to its exterior relations – body without organs – to both itself and other bodies.

BODY WITHOUT ORGANS

A human body must acknowledge its virtual possibilities in order to achieve augmentation. In *Capitalism and Schizophrenia: Anti-Oedipus* (1972), authors Deleuze and Guattari develop the concept of a 'body without organs', a term first introduced by Atonin Artaud during a radio play in 1947.[6] A 'body without organs' is comprised of a human body that acknowledges and activates its virtual possibilities: traits, connections, affects, movements, etc. This allows it to function without relying on the integrity of the entire system. The human is no longer reliant on one single organ for survival, but instead functions as an interdependent systematic organism.

When a prosthetic is combined with the human body it must successfully mediate the transmissions between the body and physical environment. The conjunction with another 'body without organs' – referred to by Deleuze and Guattari as a 'becoming' – increases the potential for the human body's virtual possibilities to be actualized. The 'body without organs' is a human body interconnected with its exterior environment, to "other bodies, perceived through relations of surfaces, differences, affects, desires, functioning like 'a virtual and smooth space, connected with fluxes that transverse it and get intercepted in it.'"[7] If one accepts the human body as a 'body without organs', then one must also accept the prosthesis as a 'becoming' as well. A properly functioning prosthetic transverses the human as much as the human transverses it; therefore, prosthetic must be capable of activating its own virtual possibilities in order for the body to reach a greater level of augmentation.

ORGANS WITHOUT BODY

In opposition to the 'body without organs' is the 'organs without body.' The 'organs without body' focus on the interiority of the body, "in its regime of internal distribution, where autonomous organs (de)compose the whole in multiple parts, breaking its integrity."[8] The organ is removed from one body, only to be grafted to another, whether the organ is mechanical, biological, or computational; It is believed that the organ will remain in a constant state of alterity because it will always be considered as an 'other' to the body.[9] However, *Pros+Tithenai* argues that this is simply not true. If successful grafting should occur, the organ is absorbed into the identity of the human and the body reprograms, rather than remaining in opposition. If the graft has successfully been "absorbed" into the identity of the human, an interdependent system comprised of human and graft – a cyborg – has been created.

PHANTOM LIMBS

One's virtual possibilities, or rather prosthetic cybernetic potential, may be understood when considering phantom limb phenomenon. Phantom pain occurs when an amputee feels sensations in his or her removed limb(s) or, during rare episodes, amputated organ(s). Sensations include an awareness of posture, length, volume, telescoping, movement, touch, temperature, pressure, itchiness, tingling and pain.[10] Phantom pain occurs naturally, however sensations can be induced by stimulating specific areas of the remaining body. This can be achieved by simple means or advanced technological applications.

Neurologist Dr. Vilayanur S. Ramachandran at the University of California in San Diego has been able to prove the former by use of simple tools: a cotton swab, warm and cold water. By touching different areas of the body with his tools he is able to stimulate phantom sensations. Dr. Ramachandran explains how this is possible after he evokes sensations in a man's amputated left hand and arm by rubbing a cotton swab on the man's left cheek and nostril:

It seems that the brain does not have fixed circuits. Rather, in ways that are still unknown the adult brain appears to be capable of reorganizing and rewiring itself over incredibly large distances -- so that brain cells receiving inputs from the face and shoulder can trigger brain cells no longer receiving inputs from an arm.[11]

This is possible due to the sensory remapping that occurs in the body after an amputation has taken place. This naturally occurring process is also referred to as "filling in".

Phantom limb sensations do not occur because of irritated nerves near the incision as previously believed, nor do the brain cells once connected to the amputated limb die. The sensations occur because of a cognitive misinterpretation in the rewired sensory brain map.[12] Filling in demonstrates the cybernetic reality of the 'natural' human body. Although parts may be missing, human bodies are capable of adapting far better than a machine in order to retain its functional integrity and wholeness; the neurological system is able to "rescript" itself.

CYBERNETICS

In addition to neurology and other related disciplines, an advanced understanding of cybernetics could assist scientists with predicting and controlling the sensory remapping within the human body after an amputation has occurred. Furthermore, it could eventually assist scientists with remapping the nerves onto a prosthetic graft. Cybernetics – the study of messages between biological, mechanical and electronic systems – promotes seamless transmissions between humans and machines. In order to "absorb" the machine, however, first an understanding of the body's own transmissions is needed.

While it is common to think that the external, physical environment is divided from the human internally, mentally, this assumption would be incorrect – "information processing is not limited by the skin."[13] In *Steps to an Ecology of Mind* (1972), Gregory Bateson proposes that information processing: communication, organization, etcetera, is measured in an abstract matter by the body, which he calls 'difference'. He explains:

> *There is... an important contrast between most of the pathways of information inside the body and most of the pathways outside it. (For example), the differences between... paper and... wood are first transformed into differences in the propagation of light or sound, and travel in this form to my sensory end organs. The first part of their journey is energized in the ordinary hard-science way (i.e. concrete conditions or events), from "behind." But when the differences enter my body by triggering an end organ, this type of travel is replaced by travel which is energized at every step by the metabolic energy latent in the protoplasm which receives the difference, recreates or transforms it, and passes it on... Be that as it may, this contrast between internal and external pathways is not absolute.*[14]

Thus, it is important to understand how one's prosthetic will be received by the body. While the body's physical, exterior acceptance of a prosthetic – already containing its own pre-existing codes – is slightly more predictable, the rewiring, and how the mind will receive messages from that rewiring, is not.

AVATARS

Learning how to control and program non-humanoid or extra-limbed avatars can become a valuable study for prosthetic designers. Ann Lasko's lobster avatar has enabled scientists to discover that humans are capable of adapting to and controlling extra limbs. Computer scientist Jaron Lanier – notorious for his contribution to virtual realities – explains:

> *It turns out by pulling bits of data from different parts of your body and combining them – like just a little bit of wrist, a little bit of ankle, a little bit of hip, to say, control the middle arm joints on the left side (of a lobster) – you [can] suddenly learn to control extra limbs.*[15]

By adapting an advanced version of avatar technology, it is plausible that a prosthetic can be controlled in the same manner as an avatar lobster's extra legs. The human body is capable of creating and adapting new movements and functions in order to perform effectively. As discussed previously, we evolve alongside our ever changing environment, enabling possibilities and human potential not quite yet conceived.

BIONIC PROSTHETICS

Not surprisingly, the advancement in biomechanical technology has realized the cyborgs only once imagined in science-fiction literature and film. An example of this technology is the biomechanical hand. The LifeHand Project in Italy (2009) and Touch Bionics further developed I-Limb Ultra (2011) share similar technologies. Both biomechanical hands are connected to the nervous system and controlled through cognitive information processing. In order to stimulate Pierpaolo Petruzziello's nerves of the LifeHand Project, scientists' implanted small electrodes in the remainder of his amputated arm. The electrode stimulation enabled Petruzziello to recognize the prosthesis with his body – as if it were a phantom. Petruzziello quickly learned to localize the electrical sensations into what he perceived as his phantom limb and apply them to the biomechanical hand.[16] The increasing popularity of interdisciplinary prosthesis studies – that integrate human and machine – has enabled prosthetic designers to achieve the previously unimaginable. By further introducing research regarding avatars and phantom limbs into the pre-established study of cybernetics, mechanics, prosthetics, and biology, we can speculate that even further advancements in prosthetic technology could be made.

Now that neurologists are capable of predicting sensory remapping, we can speculate that it is quite possible that they will soon be able to control sensory remapping. However, augmentative sensory remapping already occurs naturally without medical intervention:

> *Many deaf people are being fitted with cochlear implants, artificial hearing devices in which electrical sensors replace the ear's sensory cells. At first they report hearing speech that sounds mechanical and impersonal... But after a few months, they begin saying that the speech sounds natural as well as distinctive. Filling in has occurred.*[17]

Once medical scientists are capable of controlling sensory remapping, the augmentative possibilities to the human body will become boundless.

HUMAN COGNITION

Research regarding the entire brain and its combined processes is lacking; studies regarding the right hemisphere are considered limited in comparison to the left. Neurologist Oliver Sacks (b. 1933, England) explains in *The Man Who Mistook his Wife For a Hat and Other Clinical Tales* (1998):

> *The entire history of neurology and neuropsychology can be seen as a history of the investigation of the left hemisphere... [The right hemisphere] was presumed, usually contemptuously, to be more 'primitive' than the left, the latter being seen as the unique flower of human evolution... (However), it is the right hemisphere which controls the crucial powers of recognizing reality which every living creature must have in order to survive.*[18]

The left hemisphere is a highly developed contribution to human evolution. It is responsible for logic – the human computer – while the right hemisphere is known to be intuitive and creative. However, while prosthetic designers and scientists develop cognitive prosthetics, it is simultaneously important for humans to understand, learn from, and develop the capabilities of their own right and left hemispheres and recognize the interrelated attributes of both. The development of both the cognitive prosthetic and the cognitive human should occur simultaneously. If the body can augment itself prior to prosthetic application, we can speculate that cognitive prosthetics would transform into unimaginable extensions of the human body.

Cognitive science is not only limited to the brain, however. Within the fields of philosophy of mind and cognitive science a division has recently been created referred to as 'embodied cognition' and 'the extended mind.' The research is not limited to the right hemisphere, but instead focuses on the study of perceived wholeness and reality of the human body. It accepts that the "mind" or "brain" goes beyond the limits of its tissues. *The New York Times* columnist Andy Clark explains in his article, "Out of Our Brains" (2010):

> *The fact that there is a stable biological core that we do not "remove and throw down" blinds us to the fact that minds, like bodies, are collections of parts whose deepest unity consists not in contingent matters of undetachability but in the way [the parts] function together as effective wholes. When information flows, some of the most important unities may emerge in integrated processing regimes that weave together activity in brain, body, and world.*[19]

The body, through its movements and gestures, can create an extended cognitive process in addition to the brain. Scientists returning to the body itself – using technological advancements only to study the body not improve on the body – to discover the full cognitive potential of the human would make cognitive prosthetics ever more responsive to what the human body demands.

> *The individual mind is immanent but not only in the body. It is immanent also in pathways and messages outside the body; and there is a larger Mind of which the individual mind in only a sub-system. The larger Mind is comparable to God and is perhaps what some people mean by "God," but it is still immanent in the total interconnected social system and planetary ecology.*[20]
>
> \- Gregory Bateson

HUMAN + MACHINE

While developing seemingly endless technological possibilities – progressing far beyond our anthropological understandings – the exponential advancement in technology has led many to neglect our metaphysical considerations – cybernetics: the mutual exchange of messages between all things. Cybernetics originated as part of a human/machine speculation, however, the exciting advancement of robotics left it to be forgotten; technology advanced without cybernetic theory, without a philosophy. Now, the observer has changed; thus, the phenomenon has changed. From adapted television series *Game of Thrones* (2011):

Syrio Forel - *"Now the grip let me see." (Extends his hands outward, grabbing both the wooden sword edge and handle)*

Syrio Forel - *"Yes." (While adjusting Arya's fingers)*

Syrio Forel - *"The grip must be delicate." (Makes a delicate gesture with hands)*

Arya Stark - *"What if I drop it?"*

Syrio Forel - *"The steel must be part of your arm. Can you drop part of your arm? No! ...You must listen to me boy."*

Arya Stark - *"I'm a girl." (Annoyed)*

Syrio Forel - *"Boy, girl. You are a sword. That is all." (Points at her with his wooden sword)* [21]

Although the applied prosthesis is an extension of the human body, the inverse is also true; the body is an extension of the prosthetic. A machine, a prosthetic, plays into you, shapes you. A prosthetic will influence a human, as much as the human influences the prosthetic. It is crucial when designing a prosthetic to consider the necessary customization, interchangeability, and flexibility for the prosthesis to mould with the human body.

CYBORG IDENTITY

In order for a body to seamlessly receive a prosthetic – which exists with its own set of codes and transmissions – it is necessary for an individual to accept the prosthetic into their personal identity. Inspired by N. Katherine Hayles theories on "humans" and "post humans," Christina Hubert explains, "If the prosthetic is incorporated into the subject's identity, he becomes a cyborg. If it is kept outside, it cannot be used with 'natural' dexterity."[22] When a person is described as a cyborg – a person whose physical abilities become augmented by mechanical or robotic interventions grafted to the body – it implies that the augmentation has become successfully enmeshed with the human body entirely. This is succeeded when the human and machine become mutually dependent without conscious effort. This succeeds the prosthetic user to enhance their mobility improving the quality of life – as a "whole" human, as expressed by Cameron Clapp in *The New York Times* article, "Getting a Leg Up, Thanks to Robotic Limbs" (2005):

"I do have a lot of motivation and self-esteem," Clapp said, "but I might look at myself differently if technology was not on my side." [23]

While technology may advance enough for the human body to physically accept the prosthesis, it is equally important for the user to accept the prosthetic into their identity as well. Without question, a prosthetic should always be an expression of an individual's character.

CONCLUSION

So how intimate can architecture become? The Exoskeletal Pelvic Replacement presented here is influenced by such disciplines as architecture, cybernetics, prosthetics, bionics, biomechanical engineering, aircraft fabrication, physiotherapy, psychology, and fashion. All disciplines are involved in order to develop the best prosthesis prototype possible. It is crucial to understand the human body and how it interacts with space in order to develop an architecture that is capable of moulding with the individualized human body.

"The authenticity of architectural experience is grounded in the tectonic language of building and the comprehensibility of the act of construction to the senses. We behold, touch, listen and measure the world with our entire bodily existence, and the experiential world becomes organized and articulated around the centre of the body. Our domicile is the refuge of our body, memory and identity. We are in constant dialogue and interaction with the environment, to the degree that it is impossible to detach the image of the Self from its spatial and situational existence. 'I am the body,' Gabriel Marcel claims, but 'I am the space, where I am,' establishes the poet Noel Arnaud."[24]

- Juhani Pallasmaa

END NOTES

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“When you will have made him a body without organs,
then you will have delivered him from all his automatic reactions
and restored him to his true freedom.”

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// PART TWO
PRECEDENTS

INTRODUCTION

Collected here are 3 external interviews and 15 photographic images of 17 mannequins.

During the preliminary research phase of *Pros+Tithenai* – even prior to committing to any final design – it became evident that *Pros+Tithenai* would become an interdisciplinary project in order to meet the demands of prosthetic spatial environments. Four current inspiring individuals from varying disciplines dominate the prosthetic related discourse: Olympian Oscar Pistorius, designer Scott Summit and partner Dr. Kenneth Traunder of Bespoke Innovations, and notable pioneer of virtual reality, Jaron Lanier.

In addition, I created several human forms in order to site physical manifestations of both the ideas presented and the ideas that they inspired.

HOST | pg. 53

The initial purpose of the human forms was to function as tools for conceptual design: a medium to sketch and build on; however they evolved into an intimate lesson of the complex forms of the human body – a warning for future constructions.

The forms were created using three different methods: a layer application process (in order: polyethylene, utility tape, newspaper, plaster), a wax mould/plaster cast method, and a plaster cloth mold/plaster cast method. A fourth method included 3D digital image photo stitching, but was discontinued because it was inaccurate.

Similar to a prosthetic, the human forms allow me to go outside myself – all made from my own body – to remain whole while simultaneously becoming an 'other' to myself. The limitation of mannequins, however, is that, at most, they are anthropomorphic forms that exhibit no life of their own. When a prosthetic is applied to a form, neither the form nor the prosthetic benefit; neither becomes dynamic or living. The vitality of a prosthetic is dependent on the same viscera as its host.

INSPIRATION | pg. 27

Oscar Pistorius' prosthetic legs become activated as they are absorbed into his identity. The worldwide interest surrounding Pistorius' identity – pre-2013 – is the issue of legality. Pistorius, a double amputee, competed in the 2012 Summer Olympics in London, United Kingdom, after having been banned from the previous 2004 Summer Olympics by the I.A.A.F. While Pistorius had to prove that his non-neurological prosthetic legs were in fact not an unfair advantage prior to competing, he additionally challenged the definition of what it means to be a human athlete – or rather just a human.

DESIGNER + ORTHOPEDIC SURGEON | pg. 31

Industrial designer Scott Summit and orthopedic surgeon Kenneth Trauner founded Bespoke Innovations in 2009. The company takes advantage of new technologies by 3D printing mirrored images of existing body parts to match the non-existing "missing" parts. Currently Bespoke Innovations does not create prosthetics, but rather prosthetic coverings (named fairings) for prosthetic users seeking self-expression.

AVATAR TECHNOLOGIST | pg. 41

Jaron Lanier is an inventor of virtual realities. While the average avatar reduces humans to 2D data representations of themselves used for social mediation, it is important to see beyond this popular culture to more advanced avatar technologies. Near the end of his presentation, Lanier speaks of unknown but possible capabilities of the homunculus in the brain. As this current research advances, it is quite possible that it will venture more and more into prosthetic disciplines, fully augmenting the human body – the avatar becoming intertwined with the body itself in real time.

INSPIRATION

[mass noun]
The process of being mentally stimulated to do or feel something, especially to do something creative.

(HE SMIRKS SLIGHTLY, THEN LETS A QUEIT CHUCKLE ESCAPE)

(GRINS)

PISTORIUS: My mother said to us in the morning...

"Cole, you put on your shoes and Oscar,

So I grew up not really thinking that I had a disability,

(SMILE INCREASES AS HE RECALLS HIS MEMORY)

(HE BEGINS TO EXCITEDLY SHIFT HIS BODY FREQUENTLY IN THE CHAIR, PULLING HIS TORSO UPWARD AS IF LIMPING)

(HIS SMILE DISAPPEARS, EYES MOVE UP AND TO THE LEFT)

(HIS BODY RELAXES, APPEARS THANKFUL, RELIEVED)

OSCAR PISTORIUS,

"HOW HE BECAME THE BLADE-RUNNER"

REPORT BY SAM DATTA-PAULIN | TRANSCRIBED BY KRISTAL O'SHEA

DURATION 00:02:45

INTERVIEWER: *(Question eliminated from video.)*

PISTORIUS: *When I was eleven months old I had my legs amputated. My brother's a year and a half older than I am and my sister's about two years younger than I am so we're all very close. We just grew up and lived a very normal life. My mother said to us in the morning, "Cole," – whose my brother – she said, you know, "Cole, you put on your shoes and Oscar, you put on your prosthetic legs, and that's the last I want to hear about it!" So I grew up not really thinking that I had a disability, I grew up thinking that I had different shoes. It was just kind of a very normal kind of life for me. [I] just played sports and I was never really an academic from a young age so sports was the one thing that I loved.*

INTERVIEWER: *(Question eliminated from video.)*

you put on your prosthetic legs, and that's the last I want to hear about it!"

I grew up thinking that I had different shoes.

PISTORIUS: *In 2003 I was playing a high school rugby game and I was playing on the wing and I had kind of a late pass and the ball came very high and as I caught the ball I got tackled and I hurt my knee. It was fairly late in the afternoon and the big school fixtures have beer tents and all the fathers had had a couple of beers and they were kind of shouting, "Oh walk it off!" You know, "Don't be so soft!" So I got up and I was limping on my knee and I was thinking, "K, usually when something looked amiss on my ankle – it looked like it was twisted – it was a matter of filling out the medical aid card and I'd get my leg back two days later. But this I could feel really wasn't going to be two days," and what happened was [that] I went through a couple months of sports rehabilitation.*

(SMILES BRIEFLY, AS HE APPEARS TO BE SOMEWHAT LAUGHING AT HIMSELF)

PISTORIUS: *Usually when something looked amiss on my ankle*
the medical aid card and I'd
But this I could feel really wasn't going to be two days," and what
rehabilitation.

INTERVIEWER: *(Question eliminated from video.)*

PISTORIUS: *Then, in January 2004, I met up with a gentlemen called Ampie Louw – Abraham Louw – and he's been my coach ever since. He's coached some several top Paralympic sprinters in the past and South African hurdle champions and I've learned a lot from him and I'm still learning quite a bit. So I started running and three weeks after I started up I broke my first Paralympic hundred-metre record. Then, seven months later, I was in Athens for the Paralympic games and I got my first gold in the two-hundred there with the world record. I started running from the beginning on the prosthetic leg – which I'm still using today –and it has been used since 1996 by some of the worlds top Paralympic athletes. I really just enjoyed running, and at that stage it was just fun and it was my way of getting fit for the rugby the following year. It was really never meant to be anything that I was going to get stuck into.*

– it looked like it was twisted – it was a matter of filling out
get my leg back two days later.
happened was [that] I went through a couple months of sports

INTERVIEWER: *(Question eliminated from video.)*

PISTORIUS: *I've grown up competing against kids in my neighbourhood at schools. I never saw a difference between disability and ability – I just kinda, you know, played sports. And then in 2007 my times were gradually improving every year to the point that I was able to run on my first international able-bodied event. So, I just kind of progressed. It wasn't that I started in 2007 – I've been running pretty much against the able-bodied guys in my town or my region since 2004.*

DESIGNER + ORTHOPEDIC SURGEON

SUMMIT: ***The*** *(three-dimensional scanning & printing)* ***technology***
back - which is a fairly sacred, fairly
but we can also do it with a

(PERKS UP, SMILES)

SCOTT SUMMIT, CO-FOUNDER & CTO OF BESPOKE INNOVATIONS,

"CUSTOMIZED CASINGS FOR PROSTHETIC LIMBS"

INTERVIEW BY KRYSTLE HUNT | TRANSCRIBED BY KRISTAL O'SHEA

DURATION 00:09:07

HUNT: *The loss of a limb brings tremendous psychological and emotional costs for an amputee. People can go through the same stages of grief as when they've lost a loved one. Even after overcoming the physical trauma of an amputation, the person often has to deal with the emotional pain or depression afterwards. We're now beginning to understand that the acceptance of what has happened is a key element in a person's physical and mental recovery.*

Today we meet a company who is trying to help. Welcome Scott Summit, the founder of Bespoke Innovations. Hi Scott, thanks for joining us today.

means that we cannot only recreate somebody's shape fundamental part of our humanity - sense of style and a sense of design.

SUMMIT: *Hi Krystle, thanks for having me.*

HUNT: *So at Bespoke you make a custom fairing that fits the individuality of each patient. Can you expand on that a little bit for us?*

SUMMIT: *Certainly. The idea of a fairing is that it's a way to give a person their shape back after they've lost it to trauma or birth defect or a number of things. It's a way to create their shape by three-dimensionally scanning their surviving leg, mirroring it, and then three-dimensionally printing something that will represent a fairly accurate facsimile of what was lost. As simple as that sounds, it really wasn't possible before the technologies that we're using, so we're exploring that to see how far we can push that.*

HUNT: *What does that technology mean to people who have lost limbs?*

SUMMIT: *We start with a three-dimensional scan of the body…*

We then talk to the person and design that fairing part, requirements and their design intent.

SUMMIT: *The technology means that we cannot only recreate somebody's shape back – which is a fairly sacred, fairly fundamental part of our humanity – but we can also do it with a sense of style and a sense of design. We actually don't try to ever mimic a person's body or try to trick anybody into thinking we're creating flesh and blood – we're certainly not – we create something that's designed. So, we might use chrome and leather and patterns and all kinds of different things; the idea being to turn it into something that is more art. It becomes a sports car that you wear.*

HUNT: *Absolutely. That's really important to be able to wear what you want and be able to express how you dress and things like that. You had kind of mentioned a little bit on your 3D modeling process. Can you walk us through the steps of how that works?*

SUMMIT: *We're using a range of very new technologies,*

and once the body is in our computer it's a digital form.

based on a combination of their body and the mechanical

and that is the heart of the process. Like I was saying, this would have been impossible five years ago – at least at the kind of price and the [unclear word] that we do. So we start with a three-dimensional scan of the body – and we use a number of different scanning techniques, some of them we created – and once the body is in our computer it's a digital form. We then talk to the person and design that fairing part, based on a combination of their body and the mechanical requirements and their design intent. So their individual personality and their personal style really adds flavor to the design. The final step is that we three-dimensionally print the parts. And again, that's a technology that's been around twenty years, but it's really come to a state of maturity in the last few years. And it's something that allows you to then take that digital form

(VOICE RISES IN PITCH, AS IF GENUINELY CURIOUS)

(DEVISES THE NUMER IN HIS HEAD, OUT LOUD, AS IF QUESTIONING) *and turn it into something physical that you can hold. It's durable and they can wear it and it completes the whole picture.*

HUNT: *You mention that five years ago this wasn't possible. What was your main reason for starting this company? What was the driving force behind it?*

SUMMIT: *I actually started this company five years ago after doing some research into three-dimensional printing and prosthetics, and thinking that there's probably a way to go into, for example, Cambodia, with nothing more than a camera, and three-dimensionally scan somebody with that camera, do some work on it with a computer, what's called a parametric model, build a template that is adjustable on a per person basis, and then three-dimensionally print for that person a very high quality, low cost prosthetic limb. I did a number of experiments with that for a couple years and it worked very well. Right now the cost is prohibitively high, it's about four-thousand dollars, so as low as that is for a prosthetic leg – which is typically fifty to a hundred-plus thousand – it's still too high for developing countries. So, that's a continuing project, but we're waiting for the technology to become that much more affordable.*

...

HUNT: *Do you have any patents on the technology that you're using?*

SUMMIT: *We are kind of a patenting machine here because the three-dimensional printing of something for the body is actually a fairly untapped area in the intellectual property world, so we're patenting things up and down with the prosthetic legs, but then also a wide range of exoskeletal applications where three-dimensionally scanning the body and three-dimensionally printing something that will then address a muscular-skeletal need. We've been covering that in every possible way with intellectual property. I think twenty-seven in play right now and maybe three or four issued. That's the bulk of our*

(DOESN'T EVEN SMILE - MUST HAVE A DRY SENSE OF HUMOUR)

SUMMIT: *We... three-dimensionally scanned [Chad's] surviving limb and*
He was able to play soccer again because his brain

(HE LAUGHS)

funding, where it's going, we have some very happy patent attorneys right down the street. So that's very much part of our business model.

...

HUNT: *When I was looking on your website there were a lot of touching stories. One of the testimonials is about a gentleman named Chad who is an athlete that lost part of his leg to cancer. Can you tell us about Chad's journey and how that's affected you?*

SUMMIT: *Chad is an especially cool character. He lost his leg – like you were saying – to cancer, I think what, nine or ten years ago, and he was an active soccer player. So what we did is we, again, three-dimensionally scanned his surviving limb and mirrored it over, and then created what we call (a) "soccer fairing." A fairing that recreated his shape and it was especially durable. So it was intended for soccer playing. What's kind of cool about that is that*

mirrored it over and then created what we call [a] "soccer fairing"... remembered the shape of the leg that was lost.

he was able to play soccer again because his brain remembered the shape of the leg that was lost. So he was able to feel the ball again like he used to to some degree. But also, it took the distraction away from him.

HUNT: *Well that's great that you're doing that. Where do you see this company going in the future? What's in store for you guys?*

SUMMIT: *We have quite a lot of things in store. It's actually kind of painful to do interviews right now because ninety percent of what we do is what's happening behind the wall behind me. And it's all the top secret stuff, the intellectual property that we're working on that we just can't tell the world. Thematically it's a broad range of areas where we three-dimensionally scan the body and three-dimensionally print something to fix the body, and that might be a muscle-*

SUMMIT: *There are just so many areas where the body can use* *skeletal issue it might be trauma, it might be birth defect, any number of things. There are just so many areas where the body can use some type of corrective fixing in a very custom way, and so we're seeing how many of those we can tackle.*

HUNT: *Well it sounds like you're doing a lot of great work over there; we wish you the best of luck. Thanks for taking the time to talk to us today.*

SUMMIT: *My pleasure Krystle, thank you.*

some type of corrective fixing in a very custom way.

AVATAR TECHNOLOGIST

[noun]
an incarnation,
embodiment, or
manifestation of a
person or idea

[mass noun]
the application of
scientific knowledge
for practical
purposes, especially
in industry

(PLAYS A WIND INSTRUMENT: KHENE, FROM LAOS)

LANIER: ***The science of avatars and the cultural potential almost nobody's***

JARON LANIER,

“YOU ARE NOT A GADGET”

TEDxSF BY COMPUTER SCIENTIST JARON LANIER | TRANSCRIBED BY KRISTAL O’SHEA

DURATION 00:20:27

...

LANIER: *Now I’m going to tell a story about a different related technology, which is the history of avatars that actually is bound up with instruments. As it happened, my little team in the early ninety-eighties invented avatars. We made the first virtual reality machines – which is people embedded in simulations [that] could see each other in a social setting, and in order to see each other we have to turn into something – and thus was born the avatar. Ever since, of course, avatars have become a cliché of pop-culture – and there’s that movie about the blue aliens and all that – so the idea of the avatar has become extremely*

of them is amazingly obscure still because experienced being one.

well known. Yet the science of avatars and the cultural potential of them is amazingly obscure still because almost nobody’s experienced being one. Now I know you’ve experienced maybe making your avatar in Second Life or something like that, or an online gaming world, but actually being in a [three-dimensional] one where you see other people in real space and time you’re in this other creature, that’s a whole other thing. It’s more of a different thing that you can know until you try it. It’s been deeply frustrating to me that the sort of slow motion way in which some of these technologies open up. I’ve been waiting for thirty years now to get virtual reality as I understand it out to people. Back in those days I used to predict that 2020 or 2025 was when virtual reality would really hit for people and I still think that’s about right. So we’re not there yet.

(ABSOLUTELY QUIET, NO RESPONSE)
(HE KINDLY BUT ABRUPTLY LAUGHS OUT LOUD)

(GESTURES TOWARDS DIFFERENT AREAS OF HIS BODY)

(STRETCHES HIS ARMS OUTWARD)

(HOLDS RIGHT HAND OVER MOUTH, MOMENTARILY LOOKS DOWN AT FLOOR)

But let me talk to you a little bit about the avatar experience. In the early days – in fact, these early days continued until precisely last week, because something happened about a week ago that's extraordinary that's changed everything. How many of you know what I'm talking about?

AUDIENCE:

LANIER: *Okay well you'll figure it out. I'll get there.*

But the problem 'til last week was in order to measure your physical body to turn you into an avatar in real time required that you get into this special suit. In the early days these suits were incredibly inconvenient; it would take like twenty minutes to put it on and then an hour to calibrate it. Then after you used it you'd end up with these gashes and marks all over your body – sort of like tribal markings. These things eventually evolved into better suits, which are these days known as Mocap (motion capture) suits, and they're used in computer special effects all the time – for like the Gollum and Middle Earth you'd have an actor wear one of these things. But they were originally used for real time avatar control.

What changed a week ago or so is a, there's a thing called Kinect, a consumer gadget for measuring somebody's full body pose, and it goes with X-box. And I should disclose I'm doing my research in Microsoft research now which made that thing so, there might be some bias here but I've been working on this from before MSR (Microsoft Research) existed so I'm not really swayed by it. But the Kinect camera is this $150 thing that you can buy and it instantly will measure your full body pose so now you can actually measure everything your body is doing without wearing one of these suits. That's never been true before, so suddenly, the avatar experience can open up. Now, why is that a big deal. In order to begin to explain that I will tell you about a bug that occurred in our – well, I could call it our lab but it was really a garage in Paulo Alto

(WITH HIS BODY HE PRETENDS TO BE SWALLOWED BY THE FINGERTIP)

(EXCITED)

LANIER: *Something very interesting happened: people in the garage started*

extraordinary, which is that you can be a really weirdly

You can instantly adapt to weird body shapes.

(POINTS TO THE SIDES OF HIS TORSO

(EXTENDS ARMS OUTWARD)

(POINTS AT EACH BODY PART)

as it always is – almost thirty years ago.

I was an avatar, I think just something humanoid, something boring – and accidentally my hand was a mile long. You know it was one of these typical bugs; it was probably one extra zero. I curled my finger and suddenly this gigantic finger swooped in and swallowed me and I was inside my fingertip. So the first thing was, "This will be a good story but let's fix it and move on." But, something very interesting happened: people in the garage started playing with the distorted avatars and discovered something extraordinary, which is that you can be a really weirdly shaped avatar and still control your avatar body quite well. You can instantly adapt to weird body shapes. So then we got interested in this question of, "Well how weird can they get?", and we started turning into all kinds of different animals and aliens and weird fantasy creatures and some of them didn't work and some of them did.

playing with the distorted avatars and discovered something shaped avatar and still control your avatar quite well.

A famous early [avatar] was designed by a woman named Ann Lasko that was a lobster. The thing about lobsters is if you've ever taken a close look at them they have extra arms, there are three little arms on the side, and there's this question of how you would control them with just your physical body; that's all you have to start with to control an avatar. It turns out by pulling bits of data from different parts of your body and combining them – like just a little bit of wrist, a little bit of ankle, a little bit of hip, to say, control the middle arm joints on the left side – you could suddenly learn to control extra limbs, which is really pretty strange! Not something you'd expect.

So a friend of mine, biologist Jim Bower, saw this phenomenon [and] said, "This actually makes perfect sense because the nervous system has evolved through all of

(DRAGS HAND OVER SCALP, INDICATING WHERE THE HOMUNCULUS IS LOCATED)

LANIER: Everything in biology is preadaptive for
when we make weird avatars we're putting the brain in a time travel
[This] phenomenon is called

(WIGGLES FINGERS AS IF HE IS PLAYING A PIANO) these different body shapes through deep time, through deep biogenetic time." The same nervous system we have had evolved to swim, to crawl, and in fact everything in biology is preadaptive for evolutionary designs that don't exist yet. In a sense when we make weird avatars we're putting the brain in a time travel machine for species that might evolve to be able to control in the future. Everything in biology is always preadaptive. So this is time travel for the brain, across tens of millions of years, hundreds of millions of years.

The phenomenon is called homuncular flexibility. The homunculus is the mapping of your motor cortex onto your body. It's usually visualized as this weird obscene impish thing stretched across under your scalp – under where a mohawk would be more or less. It's got an extra big tongue and extra big thumbs – it looks really sort of bizarre. There's this Avant-garde or conceptual art project

evolutionary designs that don't exist yet. In a sense machine for species that might evolve to be able to control in the future... homuncular flexibility.

of making an avatar that exactly is a homunculus that nobody's done yet - I really want to do that one. Now, what might be important about this? In order to explain why I think this might be important I want to go back to musical instruments.

I play piano and I improvise at the piano and anyone who studies improvising at the piano will notice that there is a certain special point in your studies where all of a sudden you notice, "Wow, my hands just seem to solve this complicated harmony and voice leading thing that my brain can't even follow. What just happened?" I've seen the same thing in great athletes: basketball players; I've seen it in great pilots; I've seen it in great surgeons. What's going on there? It's not that your hands are smarter than

LANIER: *"Wow, my hands just seem to solve this complicated*
...It's not that your hands are smarter than your brain precisely, it's that the
problem solving, and it's doing it in a different channel than the sort of

your brain precisely, it's that the part of [the] brain that's running your hands is actually capable of complex problem solving, and it's doing it in a different channel than the sort of verbal, symbolic temporal lobe stuff that we're mostly used to. And it happens a little less consciously, but it's a real phenomenon.

So then the interesting question is, "How far could that go?" That's the kind of question that really excites me because when I look at progress in technology I'm really interested in opening up new continents in human potential. I'm really interested in how we can wake up aspects of human character that might actually be functional that we've never even noticed before. That's what really gets me going. So there's this enormous part of the brain, the motor cortex, [which] usually we think of as being this thing that just gets us around, but if we can apply it to complex problem solving, could it do things that we

...thing that my brain can't even follow."

part of [the] brain that's running your hands is actually capable of complex verbal, symbolic temporal lobe stuff that we're mostly used to.

can't do in the sort of verbal symbolic way [that] we're used to? Or could it augment the usual way we do things? Or something? We don't know what.

...

LANIER: *I think that the perspective of imagining technology as an autonomous force or as something that's its own centre is entirely plausible. We do it all the time, and yet, I don't think it's that functional. I think it's important to always reframe the discussions about technology for its own sake, as technology for human sake. Or even for Guya's sake or for all sorts of other centres that one can come up with. It's not so much that I don't think technology has a life of its own, but we're so able to confuse ourselves, we're so able to reduce ourselves to fit whatever our most*

(LAUGHS)

(CLAPS)

LANIER: *It's not so much that I don't think technology has a life so able to reduce ourselves to fit whatever*

Technology design is our most defective way of self-confusion ever.

recent idea about technology is. Technology design is our most defective way of self-confusion ever. Thus, I tend to not be too supportive of a lot of the recent media designs – even though in many cases my friends designed them – social networking, tweeting and all this stuff. The reason why is I'm concerned that we're all fitting more and more into database representations of ourselves. I'm concerned that we're letting algorithms recommend friends and music and movies to us, in a way that's separating us from each other.

...

LANIER: *Anyway, I am so grateful for your attention, and I hope that you all have a chance to experience the joy of becoming an avatar. It's truly one of the greatest gifts you can give your brain, and I bet you'll be able to do it within a few years. Alright, take good care.*

AUDIENCE:

of it's own, but we're so able to confuse ourselves, we're our most recent idea about technology is.

...I'm concerned that we're all fitting more and more into database representations of ourselves.

HOST

[noun]
An animal or plant on or in which a parasite or commensal organism lives.

A person or animal that has received transplanted tissue or a transplanted organ.


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LAYER APPLICATION
This method was used for the legs & body form. While excellent for covering large areas in a time efficient and affordable manor, the final form increased in size w/ no detail.

WAX MOULD & PLASTER CAST
This method was used for the hands, fingers & feet. It was extremely accurate in form w/ excellent detail, but limited to small areas.

PLASTER MOULD & CAST
This process was used for the midsection, above. While the form was fairly accurate, it stretched out due to the weight of the wet plaster.

// PART THREE

EXOSKELETAL PELVIC REPLACEMENT

INTRODUCTION

Part 3 is comprised of nine sub-sections that include research, design, and structural analysis. The primary function of the Exoskeletal Pelvic Replacement is to transfer forces to/from the skeleton through the prosthetic in lieu of the amputated pelvic area. Since exoskeletal prosthetics - ones that momentarily transfer forces from, and then back to, the human skeleton - currently do not exist, and since this a new and rare procedure, discourse specific to this topic is currently non-existent. Therefore, this project became an interdisciplinary study with first-hand influences from architecture, biomechanical engineering, aircraft fabricaton, physiotheraphy and sports medicine, and previous internal hemipelvectomy patients.

BODY ANALYSIS | pg. 60

Typical of any architectural investigation, a "site" analysis was first completed. In order to design for the human body, its proportions, postures, dimensions, individualized characterisitics, and story must first be documented.

PATIENT INTERVIEWS | pg. 73

Patient interviews and questionnaires were used as the primary source for information regarding mobile and spatial impairments caused from internal hemipelvectomies. They offered information regarding their impairment, prosthetics, rehabilitation, culture, architecture, the Exoskeletal Pelvic Replacement, and their design preferences.

IDENTITY | pg. 113

In addition to my understanding of the body, ergonomics, cyborgs, prosthetics, fashion, and architecture, design preferences received from the former patients were also considered. Identity contains a collection of images that inspire personalization of future customized prosthetic devices.

PRELIMINARY DESIGNS | pg. 115

During the preliminary design process, several architectural prosthetic designs were proposed that resolved or heightened one's mobile, tactile, and spatial awareness. Afterwards the Exoskeletal Pelvic Replacement was explored in greater detail.

INTERLUDE: DOLL PROTOTYPE | pg. 119

A doll protoype was created prior to any human-scaled prototypes. This was done in order to test and develop the construction process prior to human involvement.

DESIGN | pg. 123

The design drawings focus on the function and necessary components needed in order for the Exoskeletal Pelvic Replacement to successfully mediate transmissions between the users body and the surrounding spatial environment.

STRUCTURAL ANALYSIS | pg. 131

Structural Analysis explains the essential behaviours of the Exoskeletal Pelvic Replacement through a series of anatomical diagrams, force diagrams, and structural calculations.

PHYSICAL ANALYSIS | pg. 147

Questionnaires were given to physiotherapists who specialized in sports medicine and mobile impairments. These professionals also had first hand experience with the mobile rehabilitation of internal hemipelvectomy patients. They offered information regarding their professional experience, culture, prosthetics, architecture, and medical concerns regarding the Exoskeletal Pelvic Support.

PROTOTYPE CONSTRUCTION | pg. 171

Prototype construction offers process documention on how the Exoskeletal Pelvic Replacement was constructed, including explanations, reflections, and future revisions.

COMPLETED PROTOTYPE | pg. 189

Completed Prototype offers photographic images of the final Exoskeletal Pelvic Replacement prototype on both the mannequin it was constructed on and a human model.

INTERNAL HEMIPELVECTOMY

BODY ANALYSIS

Typical of any architectural investigation, a “site” analysis was first completed. In order to encourage greater understanding of an internal hemipelvectomy patient’s body, measurements, x-rays, and photographic documentation are offered here.

BODY DIMENSIONS + PHOTOGRAPHIC DOCUMENTATION | pg. 61

These dimensions were used for all prototypes, casts, and equations. They are derived from my own body out of basic convenience, time efficiency, and availability.

SPINE DETAILS | pg. 67

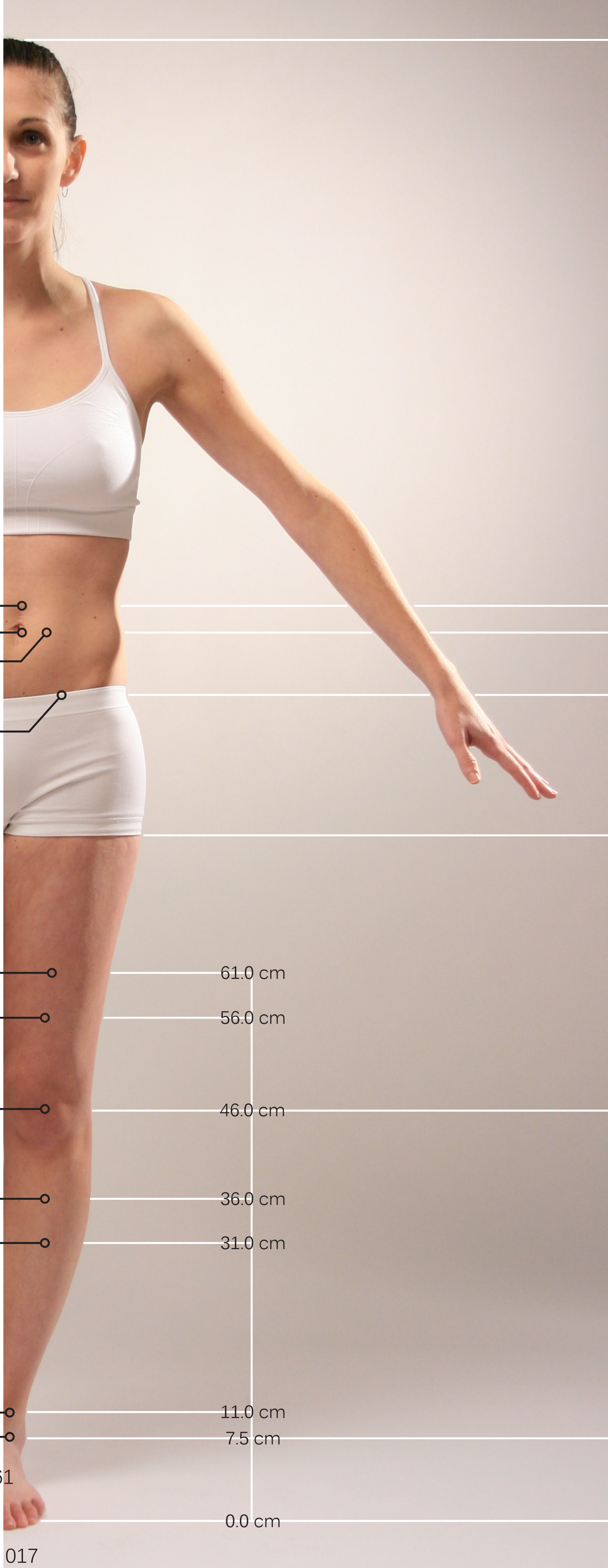
The spine has adjusted its centre of gravity accordingly. This can be seen when comparing the x-rays of an individual who has received an internal hemipelvectomy to the hand rendered details of a typical spine.

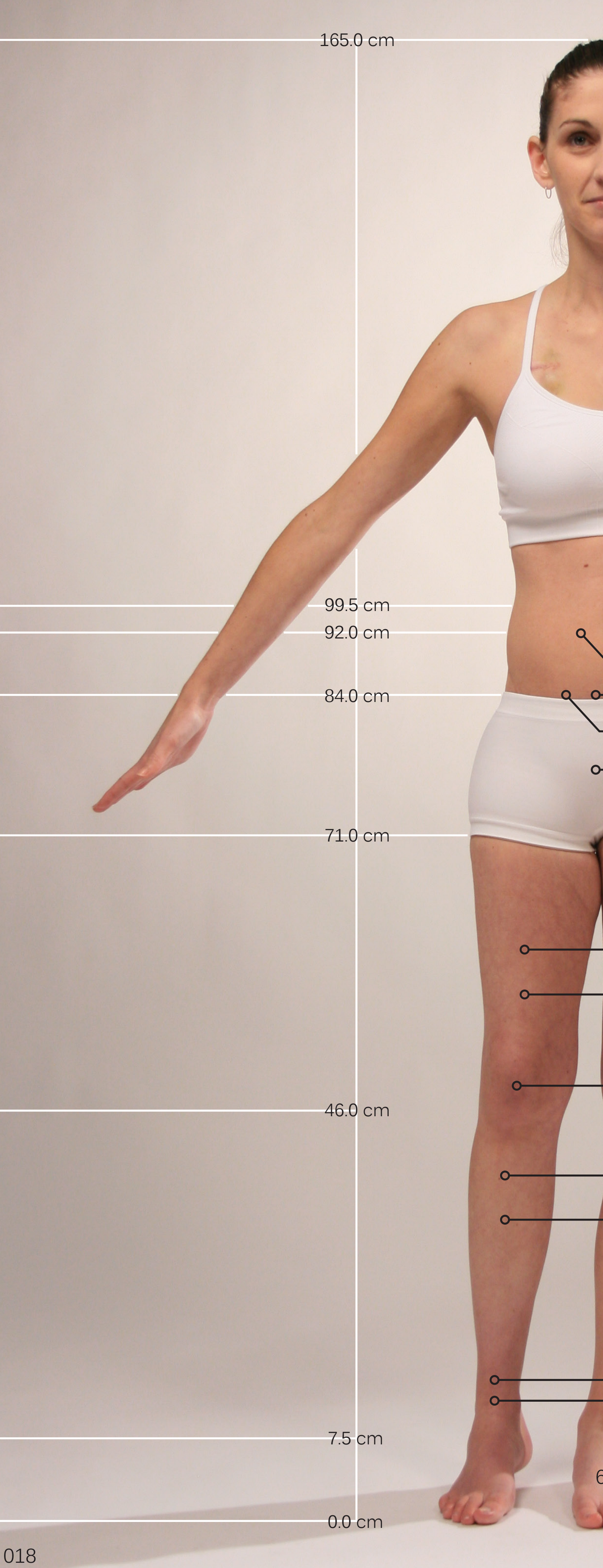
PELVIC AREA DETAILS | pg. 71

Due to the asymetry of the pelvis, the surrounding skeletal componenets have realigned. Since the spherical femoral head typically rests in the acetabulum, the affected femur is now free to move upward into the abdominal cavity, as can be seen in the details.

LEFT SIDE

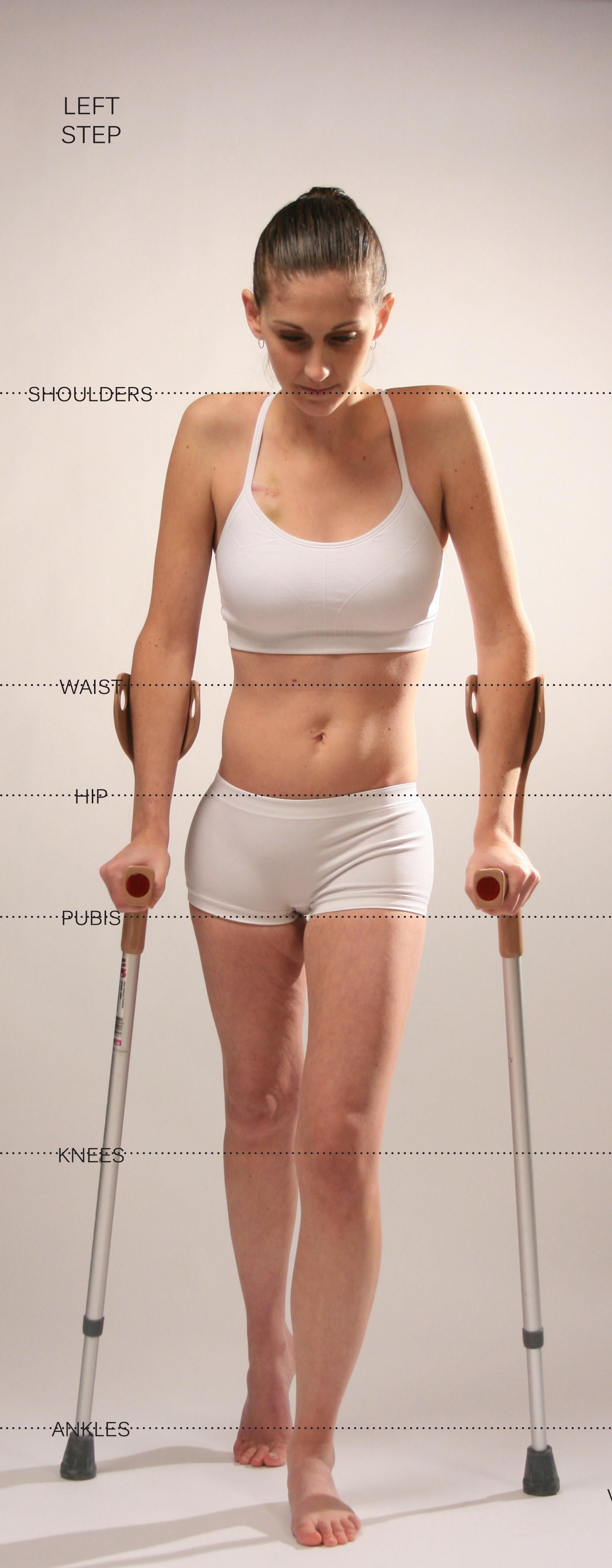
C 61.0 cm	W 22 cm	D 15.5 cm
---	W 24 cm	---
---	---	D 16.5 cm
---	---	D 17.5 cm
C 39.5 cm	---	---
C 35.0 cm	---	---
C 30.5 cm	---	---
C 31.0 cm	---	---
C 30.0 cm	---	---
C 17.0 cm	---	---
C 21.0 cm	---	---
Stirrup dim: 18.5 cm	---	---



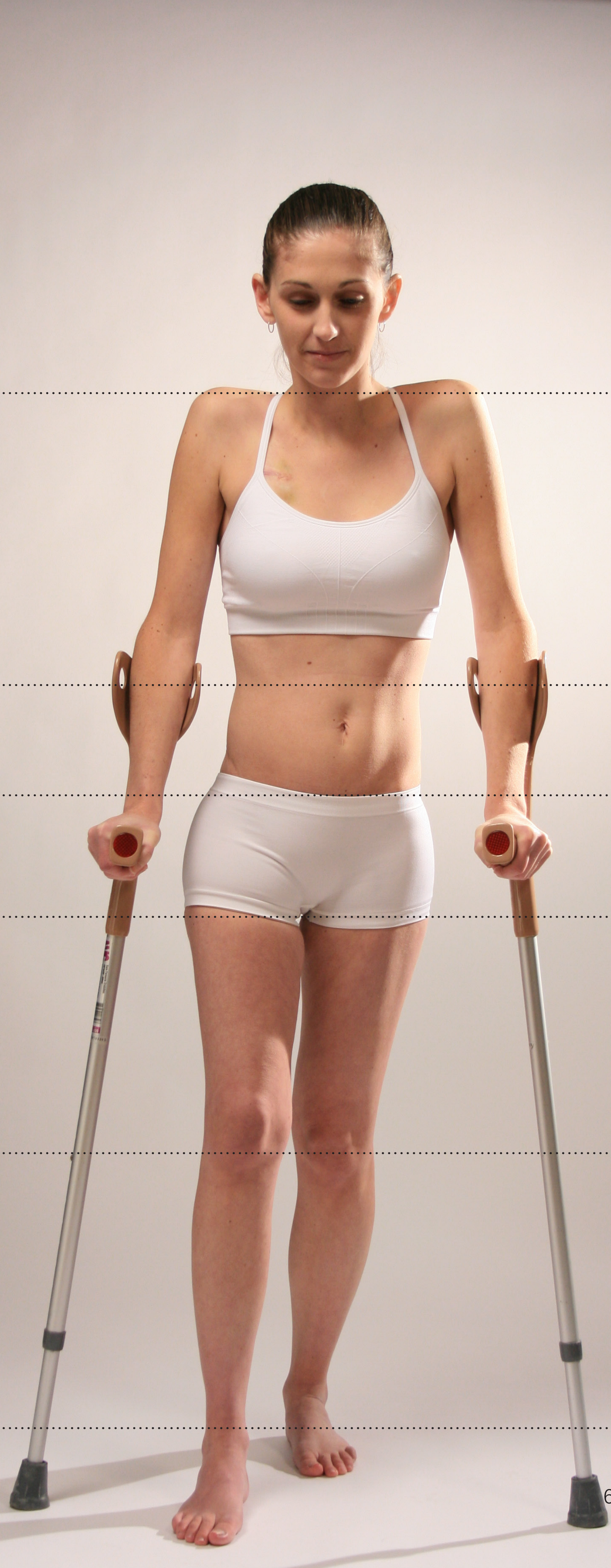


RIGHT SIDE

---	---	D 17.0 cm
C 65.5 cm	W 25 cm	---
---	---	D 18.0 cm
C 78.5 cm	---	---
C 38.0 cm	W 12.0 cm	D 13.0 cm
C 34.0 cm	W 11.0 cm	D 11.5 cm
C 30.5 cm	W 10.0 cm	D 10.5 cm
C 28.0 cm	---	---
C 26.0 cm	---	---
C 17.0 cm	---	---
C 21.0 cm	---	---
Stirrup dim: 18.5 cm	---	---


LEFT
STEP
SHOULDERS
WAIST
HIP
PUBIS
KNEES
ANKLES

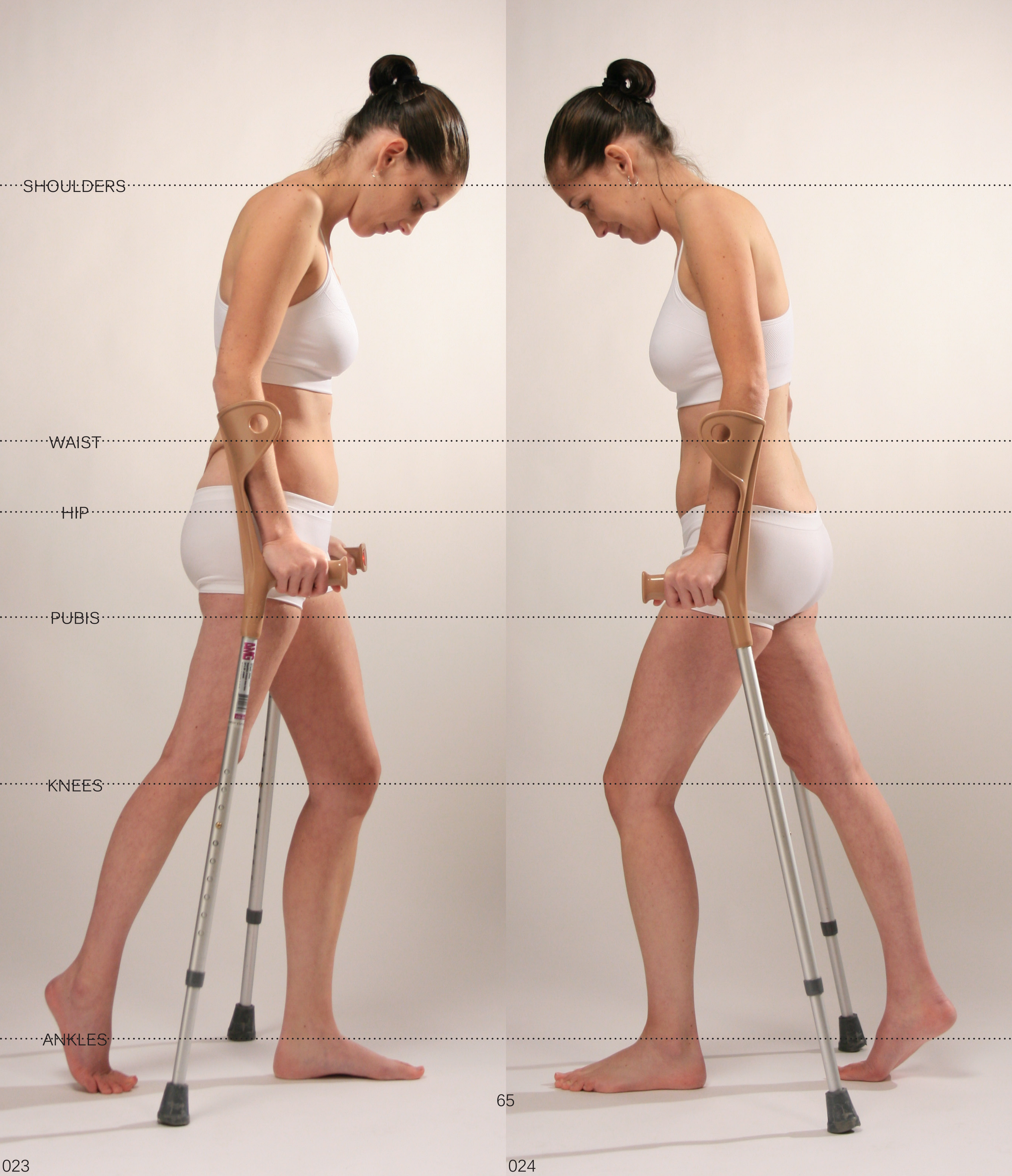
RIGHT
STEP



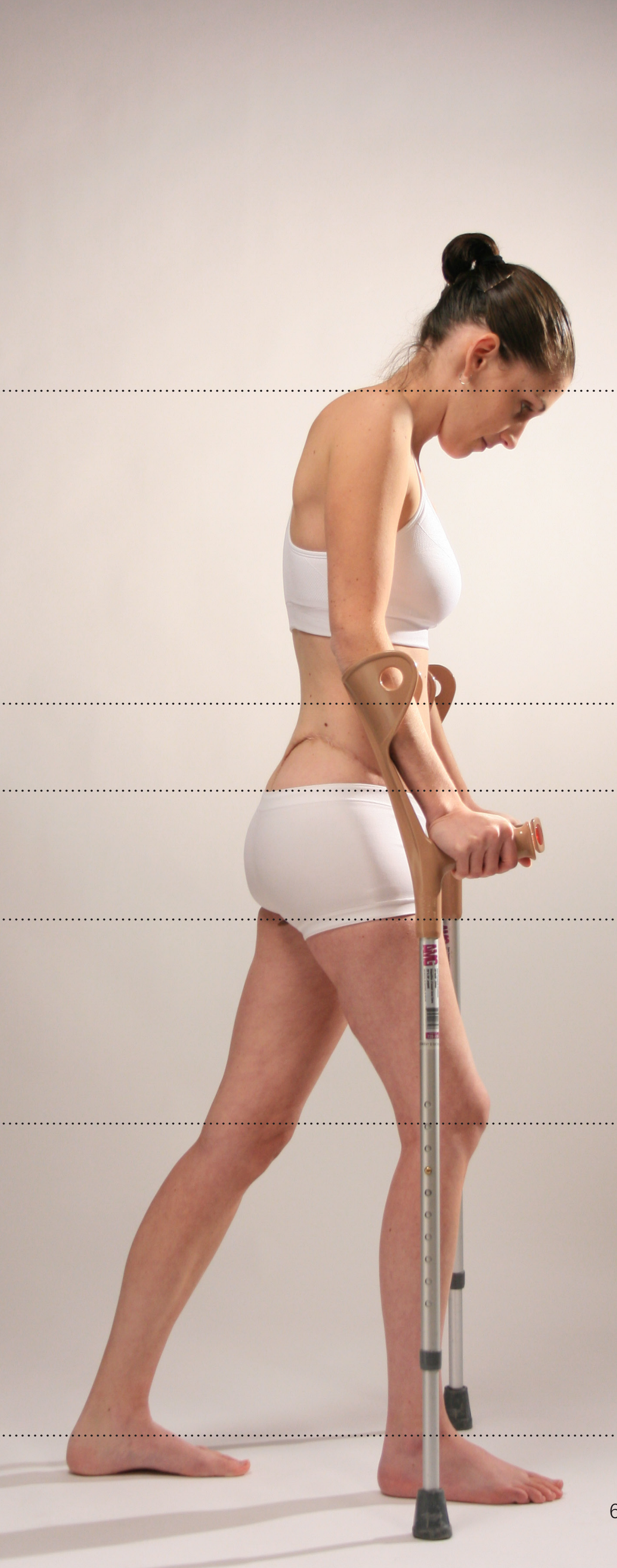
021

022

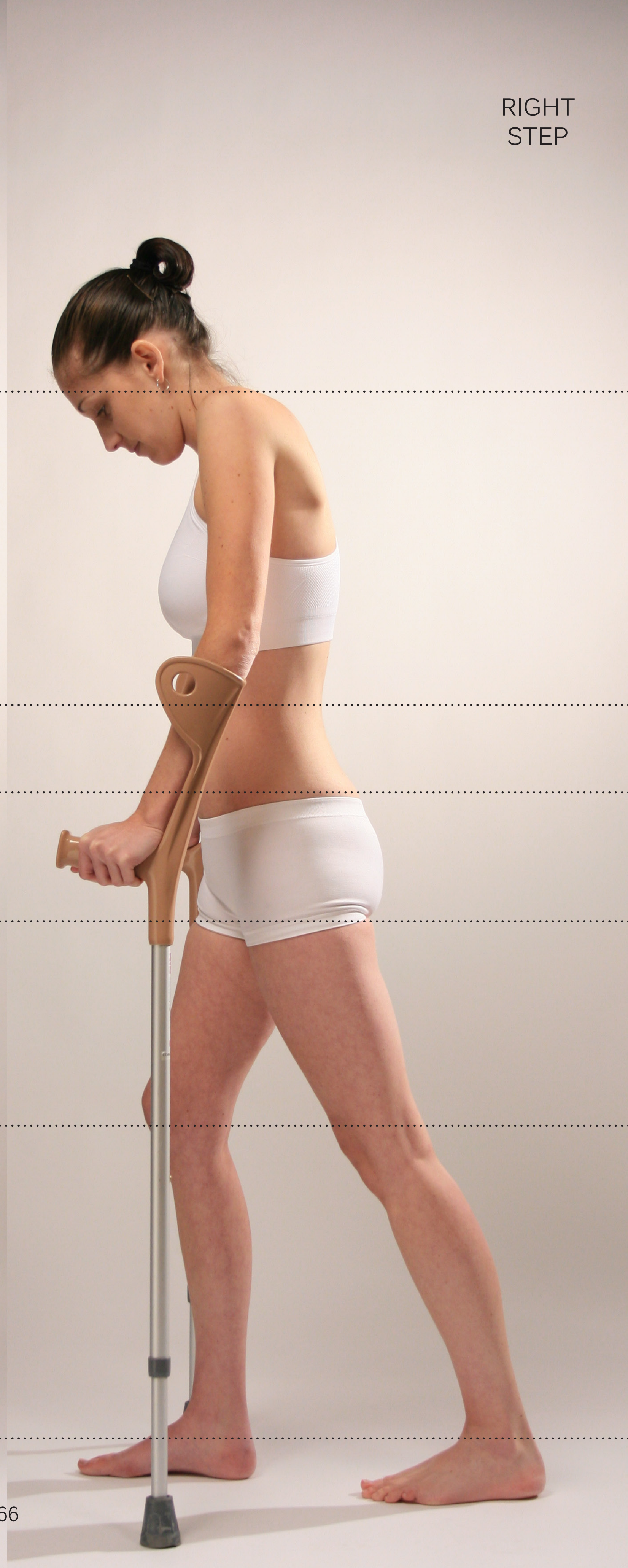
LEFT STEP



RIGHT
STEP



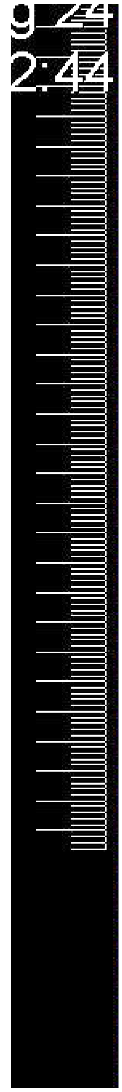
025



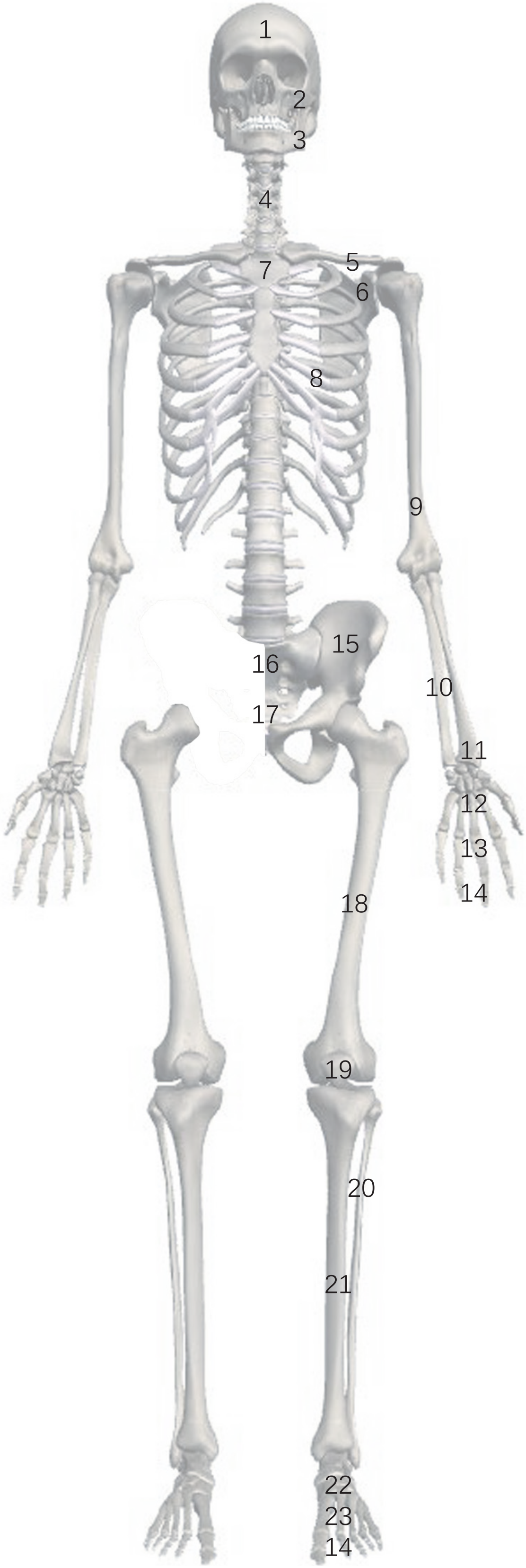
026

FRONT ELEVATION
[ANTERIOR VIEW]
027

BACK ELEVATION
[POSTERIOR VIEW]
028



INTERNAL HEMIPELVECTOMY PATIENT'S SKELETON



FRONT ELEVATION [ANTERIOR VIEW]

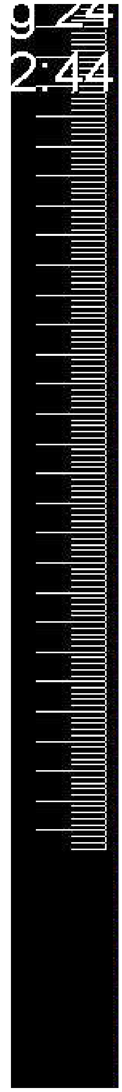
029

LEGEND

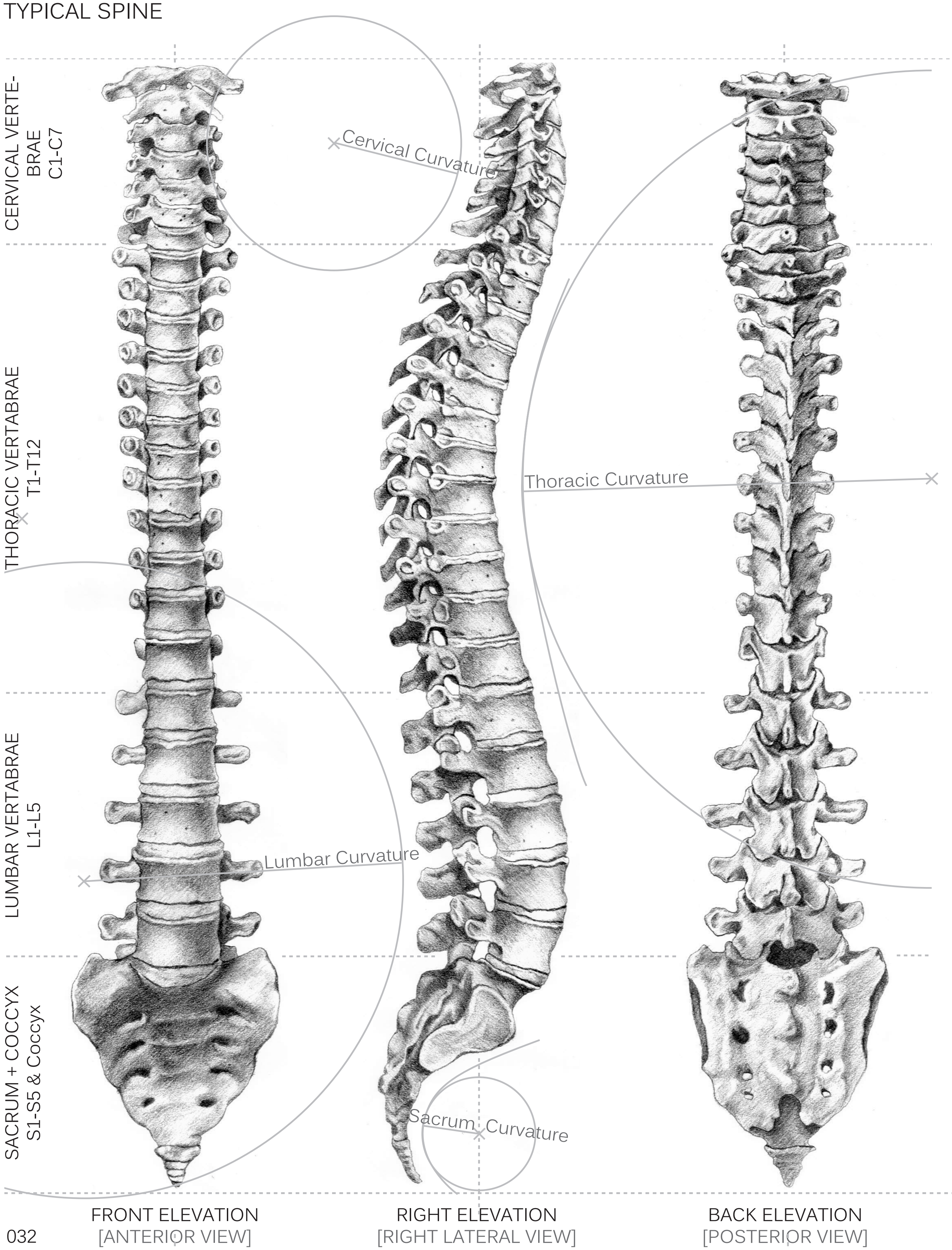
1 CRANIUM
2 MAXILLA
3 MANDIBLE
4 VERTEBRAE
5 CLAVICLE
6 SCAPULA
7 STERNUM
8 RIBS
9 HUMERUS
10 ULNA
11 RADIUS
12 CARPALS
13 METACARPALS
14 PHALANGES
15 PELVIS
16 SACRUM
17 COCCYX
18 FEMUR
19 PATELLA
20 FIBULA
21 TIBIA
22 TARSALS
23 METATARSALS

FRONT ELEVATION
[ANTERIOR VIEW]
030

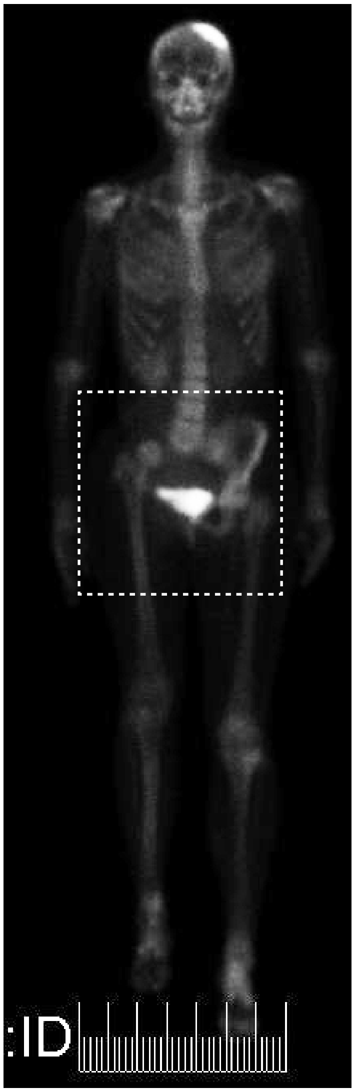
BACK ELEVATION
[POSTERIOR VIEW]
031



TYPICAL SPINE

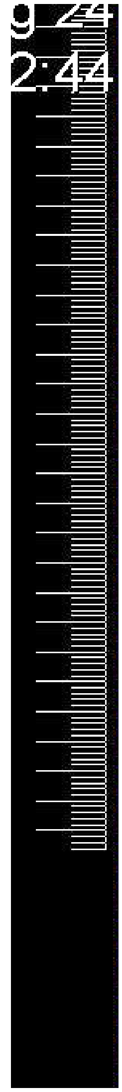


032

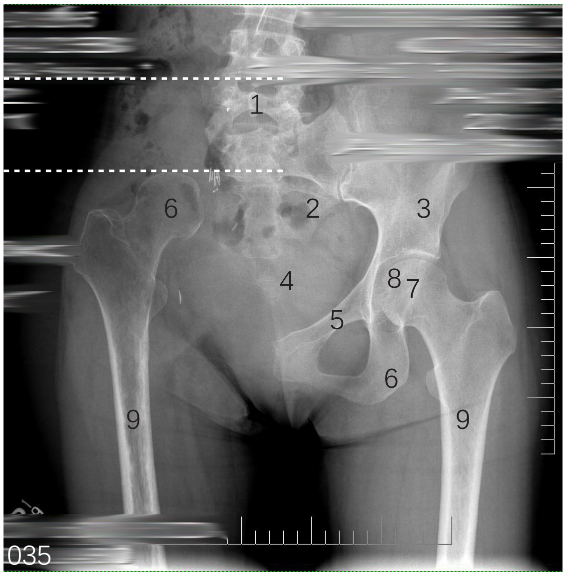


FRONT ELEVATION
[ANTERIOR VIEW]
033

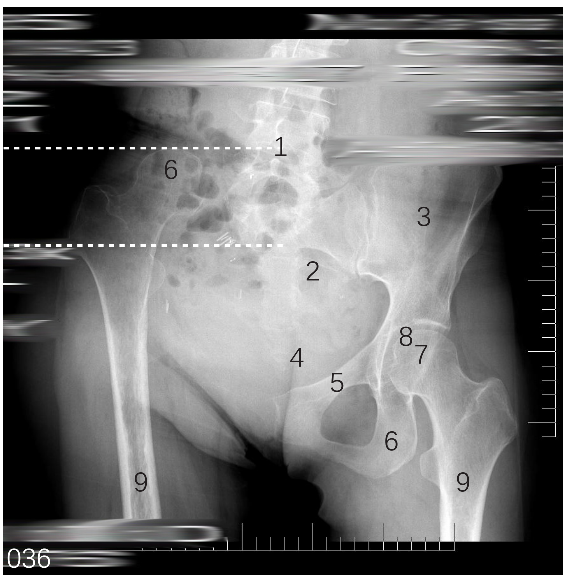
BACK ELEVATION
[POSTERIOR VIEW]
034



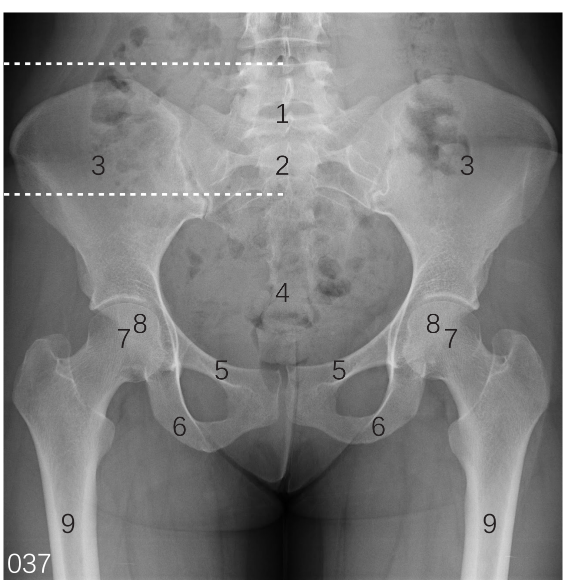
PELVIC DETAILS



STANDING ON STABLE LEG
Shown here is the affected femur located in its new “natural” position in an internal hemipelvectomy patient.



STANDING OF AFFECTED LEG
Due to the absense of the acetabulum, when weight is applied to the affected leg, the femur moves upward into the abdominal cavity in an internal hemipelvectomy patient.



TYPICAL PELVIS

LEGEND

1 L5 LUMBAR VERTABRAE
2 SACRUM
3 ILIUM
4 COCCYX
5 PUBIS
6 ISCHIUM
7 ACETABULUM
8 FEMORAL HEAD
9 FEMUR

PATIENT INTERVIEWS

IMPAIRMENT ▸

“JUNE,”

INDEPENDENCE ∝ MOTION

INTERVIEW BY KRISTAL O’SHEA | TRANSCRIBED BY KRISTAL O’SHEA

DURATION 00:25:09

SEX: Female

AGE: 27

KRISTAL: *What is the name of the surgery that you received that caused your mobile impairment?*

JUNE: *A right internal hemipelvectomy.*

KRISTAL: *What was the cause of this surgery?*

JUNE: *Ewing’s sarcoma of the the right pelvis.*

KRISTAL: *What year did your surgery take place?*

JUNE: *2011.*

KRISTAL: *Can you describe your mobile impairment?*

JUNE: *I do not have the right half of my pelvis, which means my femur/right leg is not attached to my skeleton. Therefore when I step on my right leg, I can’t put weight directly into it without compression.*

KRISTAL: *What does it feel like when you take a step?*

JUNE: *When I take a step… How it used to feel or how it feels now?.. When I first started to take steps, it felt like when you step on a balloon, and the balloon squishes out. That’s what my butt felt like. The very first time I took a step, it felt like my foot was going through the floor, like quick sand. Because my leg was already straight, and my leg just kept going into the floor.*

KRISTAL: *Interesting.*

JUNE: *And now it just seems – I have a new normal. So, it still feels pressure.*

KRISTAL: *Do you still feel like you have a balloon in your butt?*

JUNE: *No. But I’m pretty sure it probably still does it’s just normal now.*

KRISTAL: *Interesting.*

PROSTHETICS ▸

JUNE: *The very first time I took a step (post-surgery), it felt*

CULTURE ▸

KRISTAL: *Sometimes people feel sensations in their amputated body parts, such as your pelvis. This is called phantom pain. Have you ever experienced this sensation?*
JUNE: *I don't think so, because I don't know how to feel a pelvis.*
KRISTAL: *It's pretty unlikely that you would say yes.*
JUNE: *So I'm going to say "no."*

KRISTAL: *What prosthetics do you currently use to overcome your mobility?*
JUNE: *Forearm crutches and a shoe lift.*

KRISTAL: *Do you consider your prosthetics an extension of your body?*
JUNE: *Yes, because without them I don't move very well.*

KRISTAL: *Are there any prosthetics that you wish existed but currently do not, for either yourself or others?*

like my foot was going through the floor, like quick sand.

JUNE: *Well, if there was like, this awesome thing that made my leg not compress and then I could walk without my crutches – then yes.*
KRISTAL: *So you would prefer if there was a prosthetic that freed your hands up?*
JUNE: *Yeah, hands are good. I like them.*
KRISTAL: *I like hands too.*

KRISTAL: *Have people treated you differently since your mobile impairment? How so?*
JUNE: *Yes. They assume you can't do things, and want to do them for you, without checking to see if you want to do them yourself first.*
KRISTAL: *Is that just within your family or other people as well?*

JUNE: *Oscar Pistorius is going above and beyond what other thinking, "You can't do this." He's showing that people because they have a disability.*

JUNE: *Other people as well.*

KRISTAL: *Such as?*

JUNE: *At work, people assume that you can't partake in something or will accommodate for you without checking to see if you would like those accommodations made. (For example), [My place of employment] built a new building and I wasn't allowed in my new office because people thought I wouldn't want to wear construction boots... because I couldn't wear my special shoe (lift). But nobody asked me if I could just use construction boots.*

KRISTAL: *Oh, so no one bothered to ask they just assumed that if you put them on it'd pull your leg out?*

JUNE: *They just said, "Well, we can't [put] a lift... on construction boots so you don't get to [visit] the new building." (However,) there are a lot of things that could have been done. I could have just worn the boots.*

KRISTAL: *Do you feel the need to prove any of these [misconceptions] wrong?*

people think he can do, because he probably has people can't assume that someone can't do something just

JUNE: *People think I can't do things, (so it) motivates me to do things - just so they're wrong. But that's me. ...It's why I walk down the CN Tower.*

KRISTAL: *In spite of others?*

JUNE: *A little bit. I want to do it for myself because it's a goal, you know, new sports new challenges. But at the same time, people think I can't do things. (For example,) I wanted to go bowling – because I want to go bowling – but also because people think I can't.*

KRISTAL: *In my opinion, Oscar Pistorius' participation in the Olympics was monumental to the cultural acceptance of handi-capable people and their prosthetics. Would you agree?*

JUNE: I *would agree.*

KRISTAL: *Okay, so you're just going into old*

JUNE: *Yeah I should stay away from those buildings now...*

KRISTAL: *So you actually feel frightened when you go into certain spaces?*

JUNE: *Oh yeah!*

Sometimes it can be nerve wracking... to go out into the world.

KRISTAL: *Why?*

JUNE: *I don't know. He's going above and beyond what other people think he can do, because he probably has people thinking, "You can't do this." He's showing that people can't assume that someone can't do [something] just because they have a disability.*

KRISTAL: *In your opinion what are the most difficult architectural elements for the mobility impaired?*

JUNE: *Stairs, doors...*

KRISTAL: *Is there a specific type of door?*

JUNE: *Funny enough handicapped doors, when the button doesn't work, because they're heavy, because they have so much mechanics in them. So if you push the button and it doesn't open, those doors are the hardest to open because you have to pull against all the mechanics that aren't functioning. It's like going against power steering.*

KRISTAL: *Yeah I don't think I could really open a door*

buildings, ones that didn't have to conform to recent building codes. [new ones] don't scare me.

like that either. Also, it's a code and safety violation so it shouldn't ever be like that.

JUNE: *Sometimes they'll have accessible handicapped bathroom stalls, but they don't have an accessible door into the washroom in general. Once you're in there you're like, "Oh, there's a handicapped stall, but there was no button to get in or easy door to push on.*

KRISTAL: *That's interesting. I would hope that that's also against code.*

JUNE: *And just... stairs I guess.*

KRISTAL: *What about carpets or ramps or railings or chairs even?*

JUNE: *If you combine a stair and a door. It makes things really hard because I can't get onto a step and open a door.*

KRISTAL: *A door should always be at least a stair width*

KRISTAL: *Why is improving your mobility so important to you?*

JUNE: *Because it makes everyday life easier and you can be*

REHABILITATION ▸

away from the door... Okay, so you're just going into old buildings, ones that didn't have to conform to recent building codes.
JUNE: *Yeah I should stay away from those buildings now...*
JUNE: *Oh! One that is bad still, is slippery floors. When floor surfaces are wet it's bad for my crutches.*
KRISTAL: *Can you give examples of this?*
JUNE: *Like TTC floor, its tile.*

KRISTAL: *Are there certain architectural elements that improve your interaction with space?*
JUNE: *Floors that aren't wet – there are new buildings that have almost a rubbery matted type floor. I like them because they don't scare me. It's also nice when there are ramps or buttons.*
KRISTAL: *So you actually feel frightened when you go into certain spaces?*
JUNE: *Oh yeah!*

more independent. Mobility is a big part of independence.

KRISTAL: *Well that sucks.*
JUNE: *I sometimes will take the street car instead of the subway when it's raining (to avoid TTC's slippery floor). I would rather stand in the rain and wait for the street car then walk down the stairs and on the (subway) platform, even though the streetcar takes me longer.*
KRISTAL: *So put rubber on prosthetic...*

JUNE: *Sometimes it can be nerve wracking if you don't have energy to go out in the world...*

KRISTAL: *How often do you attend physiotherapy?*
JUNE: *Four to five times a week.*
KRISTAL: *Why is it important for you to go this often?*
JUNE: *Because I would like to learn to walk.*

KRISTAL: *Would you find [the Exoskeletal*

JUNE: *Yes, because then it'd help me*

KRISTAL: *Why is improving your mobility so important to you?*

JUNE: *Because it makes everyday life easier and you can be more independent. Mobility is a big part of independence.*

...

JUNE: *I had to learn to lift my leg using different muscles, because I don't have that muscle anymore. And I had to relearn a way to do it.*

KRISTAL: *Could you explain?*

JUNE: *I lay on my left side, and I can lift my right leg up, but it's using a different muscle that's not normal.*

KRISTAL: *What muscle is it using?*

JUNE: *I don't know, I found a new one.*

KRISTAL: *Describe how it feels, this new one.*

JUNE: *Well I would have to do it, but I'm tired.*

KRISTAL: *So you lay on your left side and you lift your leg*

Pevlic Replacement] to be practical for everyday use?

walk and I would regain my independence.

with a magical muscle?

JUNE: *Well it's because my quads and my abs are joined together, they're not joined to the pelvis; I have no pivot point. It's because I have no pivot point that my leg just wants to lift vertically instead of pivoting, so I had to learn to do it differently.*

KRISTAL: *Do you think that the Exoskeletal Pelvic Replacement could be useful during your physiotherapy appointments?*

JUNE: *Yes.*

KRISTAL: *Would you find something like this to be practical for everyday use?*

JUNE: *Yes, because then it'd help me walk and I would regain my independence.*

The following questions refer to the affected leg

KRISTAL: *Do you want there to be a lift in the*

JUNE: *No. I thought I wouldn’t need a lift for these?*

KRISTAL: *Can you move your toes?*

JUNE: *Yup, look they're moving.*

KRISTAL: *Can you move your ankle?*

JUNE: *Yup, it's moving.*

KRISTAL: *Can you move your knee without difficulty?*

JUNE: *No. Well how so? Like bend my knee or move my knee? They are very different things.*

KRISTAL: *Explain both.*

JUNE: *I can bend my knee in any direction, but I can't sit in a chair and lift my knee up off of the chair.*

KRISTAL: *When you are walking can you move your knee?*

JUNE: *Um, backwards more than I can forwards. Like when I take a step forwards, like if this is my knee, I step, I can't lift my thigh upward.*

KRISTAL: *So with this prosthetic would you need something to help move your leg forward?*

JUNE: *No.*

prosthetic to take the place of the lift on your shoe?

I thought that was the whole point, for me to look normal?

KRISTAL: *Okay, can you move your leg as if you had a hip? Like if you're walking, can you do the motion of walking?*

JUNE: *I can pretend and look like I'm walking, yes.*

KRISTAL: *You just can't put weight on it right?*

JUNE: *Yes.*

KRISTAL: *So that's the only thing that this prosthetic needs to aid in.*

JUNE: *Yes, it doesn't need to move. I can move it.*

KRISTAL: *Okay. You only need the compression to stop. Yes. Okay.*

KRISTAL: *Do you want there to be a lift in the prosthetic to take the place of the lift on your shoe?*

JUNE: *No. I thought that I wouldn't need a lift for these? I thought that was the whole point, for me to look normal?*

IDENTITY ▸

KRISTAL: *Do you have any concerns with trying out this specific prosthetic?*

JUNE: *If it's ugly!... I don't want to wear some*

AESTHETIC PREFERENCE ▸

KRISTAL: *I was just concerned that pulling your leg down may stretch the muscles out that you have been trying so hard to build.*
JUNE: *Well when I don't wear the lift, my leg drops an inch above the floor.*
KRISTAL: *Can I try pulling on it? Try to keep your hip square to the floor... Is your heal touching the floor now?*
JUNE: *Yes.*
KRISTAL: *Is there any discomfort?*
JUNE: *No.*
KRISTAL: *Okay, well I can design it without the lift then, and then it's always something we can revisit later if needed.*

KRISTAL: *Do you have any concerns with trying out this specific prosthetic?*
JUNE: *If it's ugly! No I'm just kidding.*
KRISTAL: *Well it will be designed to your specifications,*

hideous thing that attracts more attention than crutches.

including aesthetics.
JUNE: *No like, you know, I don't want to wear some hideous thing that attracts more attention than crutches, would actually be a concern.*
KRISTAL: *So you are more concerned about how it looks rather than gaining your independence?*
JUNE: *I'm just saying, it could be -*
KRISTAL: *No I'm not offended or insulting – I'm just asking for clarification.*
JUNE: *Well no, I want my independence but, it'd be more of an aesthetic thing rather than... I'm not worried to try it. If it works then I'll try it.*

KRISTAL: *Would you like it to be under your clothes or over?*

KRISTAL: *Would you like to personalize the prosthetic so that it*

JUNE: *Probably just simple so*

PERSONAL EXPRESSION ▸

JUNE: *Probably under if it could be under.*

KRISTAL: *Yeah it definitely could be – well I don't know about skinny jeans but...*

JUNE: *Well I don't wear skinny jeans.*

KRISTAL: *Okay, great!*

KRISTAL: *What material finish(es) would you prefer, such as plastic, chrome, titanium, wood, or any other material that you can think of?*

JUNE: *Whatever would be light...*

KRISTAL: *These are more aesthetic questions, so I could always put a nicer finish, a veneer, on a lighter material.*

JUNE: *I don't know that I have a preference. Probably not wood though.*

KRISTAL: *Maybe black because you said that you don't really want people to notice it?*

JUNE: *Probably.*

becomes an expression of your personality and a part of your identity?

that it doesn't stand out.

KRISTAL: *Would you prefer the prosthetic to be solid so there is no risk of a pattern showing through something like the spandex pants that you're currently wearing? Or would you like to personalize the prosthetic so that it becomes an expression of your personality and part of your identity?*

JUNE: *I don't know, probably solid.*

KRISTAL: *Even something solid could be etched with polka dots, stripes, harringbone pattern, etc.*

JUNE: *I do like those... Probably just simple so that it doesn't stand out.*

KRISTAL: *Okay. Did you know that some scientists theorize that acceptance of one's prosthetic is extremely important to not only an individual's emotional response, but their functional response to the prosthetic as well?*

JUNE: *I need the prosthetic to have acceptance so get on it.*

KRISTAL: *Have you accepted your crutches?*

JUNE: *Yeah, for the most part. I've accepted my shoe!*

KRISTAL: *Do you feel that your current prosthetics are an expression of your personality though?*

JUNE: *No. They're really ugly and they have reflectors on them.*

KRISTAL: *Well that's the point I'm trying to make.*

JUNE: *And I don't like them.*

KRISTAL: *So wouldn't you prefer if they were part of your style?*

JUNE: *I would, yes.*

KRISTAL: *So do you still want the Exoskeletal Pelvic Replacement to be plain and hidden; to not be an expression of your identity?*

JUNE: *Well if it can be hidden then I would prefer that, but if not then yes, I should have it be expressive.*

KRISTAL: *Well the way I look at it is, is that I choose panties and bras that I like instead of buying ugly ones. So even if it's hidden, you still might want it to be an expression of yourself.*

JUNE: *Oh yeah, I never thought of it like that. That makes sense.*

KRISTAL: *Any preferences?*

JUNE: *No.*

IMPAIRMENT ▸

PROSTHETICS ▸

“JUDE,”

TENACITY

QUESTIONNAIRE BY KRISTAL O’SHEA | TRANSCRIBED BY KRISTAL O’SHEA

SEX: Female

AGE: 21

KRISTAL: *What is the name of the surgery that you received that caused your mobile impairment?*
JUDE: *Internal hemipelvectomy with an extraarticular resection of the hip joint.*
KRISTAL: *What was the cause of this surgery?*
JUDE: *Osteosarcoma of the right pelvis.*
KRISTAL: *When did it take place?*
JUDE: *2009.*
KRISTAL: *Please describe your mobile impairment.*
JUDE: *Difficulty weight bearing on right side while walking.*
KRISTAL: *Why is your mobility important to you?*
JUDE: *Easier to remain physically active (sports, travel, etcetera).*
KRISTAL: *Sometimes people feel sensations in their amputated body part. Have you ever experienced this in your amputated pelvic area?*
JUDE: *No.*

KRISTAL: *What prosthetics do you currently use to overcome your mobile impairment?*
JUDE: *Crutches.*
KRISTAL: *Does your current prosthetic sufficiently aid your impairment?*
JUDE: *Yes.*

KRISTAL: *Is there some sort of prosthetic that you wish existed but currently does not, for your mobile impairment specifically?*

ARCHITECTURE ▸

KRISTAL: *Are there any architectural elements*

JUDE: *For the sake of dignity I tend to avoid these types of more quickly than other students; people move nonstop. Elevators are a last resort.*

REHABILITATION ▸

JUDE: *I'm not so sure there will be one that I'd be comfortable with using.*

KRISTAL: *In your experience, what are the most difficult architectural elements that you encounter because of your mobile impairment?*
JUDE: *Wet floors and narrow hallways.*

KRISTAL: *Are there any architectural elements that aid your mobile impairment? (For example, stairs, floors, doors, knobs, windows, hallways, etcetera.)*
JUDE: *For the sake of dignity I tend to avoid these types of things. Most of the time I move faster and climb stairs more quickly than other students anyway; people move incredibly slow when they're staring down at their phones nonstop. Elevators are a last resort.*

that aid your mobile impairment?
things. Most of the time I move faster and climb stairs incredibly slow when they're staring down at their phones

KRISTAL: *Do you attend physiotherapy to aid your impairment?*
JUDE: *Not anymore. I attended physiotherapy only for about 6 months after surgery, but it was slow going and there was rarely any improvement; it wasn't challenging enough. A gym membership and a personal trainer worked 100x better. Now I visit the gym 3 days a week, with one day dedicated to focusing entirely on my 'flail leg.'*
KRISTAL: *Why is it important for you to attend physiotherapy this often?*
JUDE: *Core strength is crucial for balance.*

KRISTAL: *Are you aware of any reason why a prosthetic for this*

JUDE: *I was told that it would be too 'extruding' from the body cage somehow, which wouldn't*

BODY FUNCTION ▸

The following questions refer to the affected leg

KRISTAL: *Would you prefer to use the Exoskeletal Pelvic Replacement instead of your current prosthetic?*
JUDE: *I would try it, but if crutches are still easier to manage it's not likely I'd make the switch permanent.*

KRISTAL: *Do you think that such a prosthetic would be practical for everyday use?*
JUDE: *Perhaps in and around the house. It would be a problem if I couldn't drive while wearing it.*

KRISTAL: *Are you aware of any reason why a prosthetic for this purpose has not already been designed?*
JUDE: *I was told that it would be too 'extruding' from the body and that the weight would have to be transferred to my rib cage somehow, which wouldn't be good in the long run.*

purpose has not already been designed?

and that the weight would have to be transferred to my rib be good in the long run.

KRISTAL: *Can you move your toes?*
JUDE: *Yes.*
KRISTAL: *Can you move your ankle?*
JUDE: *Yes.*
KRISTAL: *Can you move your knee?*
JUDE: *Yes.*
KRISTAL: *When you are standing on your non-affected leg, are you able to move your affected leg forward?*
JUDE: *Yes.*
KRISTAL: *When you are standing on your non-affected leg, are you able to move your affected leg backward?*
JUDE: *Yes.*

DESIGN PREFERENCES ▸

KRISTAL: *While standing on your non-affected, are you able to move your affected leg to the side?*
JUDE: *Yes.*
KRISTAL: *While using your non-affected leg for balance, are you able to support your body weight on your affected leg?*
JUDE: *Yes.*

KRISTAL: *Would it be your personal preference for the prosthetic to be fastened under and/or over your clothing?*
JUDE: *Over.*
KRISTAL: *Would you prefer the aesthetic components of the prosthetic to be solid, etched or perforated?*
JUDE: *Solid.*
KRISTAL: *What pattern would you prefer?*
JUDE: *Solid.*

KRISTAL: *Can you explain what the phrase, "empowering through*

JANIS: *It means freedom and independence.*

I have come to appreciate these two words more with each passing day

“JANIS,”

AWARENESS

QUESTIONNAIRE BY KRISTAL O’SHEA | TRANSCRIBED BY KRISTAL O’SHEA

SEX: Female

AGE: 37

KRISTAL: *What is the name of the surgery that you received that caused your mobile impairment?*
JANIS: *Right internal hemipelvectomy.*
KRISTAL: *What was the cause of this surgery?*
JANIS: *Right pelvic chondrosarcoma.*
KRISTAL: *What year did your surgery take place?*
JANIS: *2010.*
KRISTAL: *Please describe your mobile impairment.*
JANIS: *I can’t walk, sit or stand for a long period of time. My non-affected leg becomes strained when I walk too much*

movement,” means to you?

ever since I was able to bear weight on my affected right leg again.

because it bears most of my body weight. My lower back also hurts if I move around too much; I believe this is due to the new imbalance in my skeletal structure. In addition, when I sit for too long my tailbone becomes very sore.
KRISTAL: *Why is your mobility important to you?*
JANIS: *I have always been very active. I also have two boys that I provide for that I enjoy chasing, holding, carrying, and playing with.*

KRISTAL: *Can you explain what the phrase, “empowering through movement,” means to you?*
JANIS: *It means freedom and independence. I have come to appreciate these two words more with each passing day ever since I was able to bear weight on my right leg again.*

JANIS: *I fear that I am using my non-affected side so much me completely bound*

KRISTAL: *Sometimes people feel sensations in their amputated body part. Have you ever experienced this in your amputated pelvic area?*
JANIS: *No.*

KRISTAL: *Is there anything else that you would like to add regarding your mobile impairment?*
JANIS: *I fear that I am using my non-affected side so much that I may cause damage to that side, which would make me completely bound to a wheelchair.*

KRISTAL: *What prosthetics do you currently use to overcome your mobile impairment?*
JANIS: *I use a cane and custom shoes; my right shoe has a 4 inch wedge in it.*
KRISTAL: *Does your current prosthetic sufficiently aid your impairment?*

that I may cause damage to that side, which would make to a wheelchair.

JANIS: *The shoes help with the leg length discrepancy between my left and right sides. They enable me to walk better with less strain to my body.*

KRISTAL: *Do you consider prosthetics to be an extension of the human body?*
JANIS: *Not really, because they are an add-on that can easily be taken off or only temporarily used. If the prosthetic were nonexistent than one's body would be helpless, but I consider it an aid and not an extension when it is an outer addition.*

However if the prosthetic is not removable, then I would consider it as an extension of my body. For example, if a replacement bone were permanently inserted inside my body, then I would consider that prosthetic to be an extension of my body.

** Note: Inserting a pelvis, whether donated from another body or 3D printed, is currently not possiblle. This is for structural reasons. An internal prosthetic cannot be inserted because too much of the skeletal system has been removed during an internal hemipelvectmomy surgical procedure, leaving an inadequate amount of bone to fasten the prosthetic to.*

CULTURE ▸

KRISTAL: *Are there any cultural misconceptions that you are aware*

JANIS: *Most people take pity and think people with mobile on others.*

KRISTAL: *Is there some sort of prosthetic that you wish existed but currently does not, for your mobile impairment specifically?*
JANIS: *Yes, a bone that would replace my surgically removed pelvic bones - although I have never heard of an entire pelvic bone being replaced.**
KRISTAL: *Is there anything in regards to prosthetics and mobile impairments that you would like to include?*
JANIS: *I am open to trying anything that may restore my walking to where it was or closer to how I use to walk before the surgery. I suppose this goes without saying.*

KRISTAL: *Are there any cultural misconceptions that you are aware of against people with mobile impairments?*
JANIS: *Most people take great pity and think people with mobile impairments are poor souls that are extremely dependent on others.*

of against people with mobile impairments?
impairments are poor souls that are extremely dependent

KRISTAL: *Personally, I feel that Oscar Pistorius' participation in the Olympics was monumental to the cultural acceptance of handi-capable people and their prosthetic aids. Would you agree?*
JANIS: *Oscar's participation was a great addition to the Olympics. I do not believe that attaching an aid to one's body makes them superior or different... it equalizes them.*
KRISTAL: *Do you attribute advocate Aimee Mullins for creating a cultural breakthrough of acceptance and/or understanding for prosthetic users?*
JANIS: *Definitely. She is one of my role models. We are a culture of visual acceptance and judgements. Ms. Mullins makes many rational and concrete examples as to how we heavily rely on our visual perception to make poor judgement calls. One good example was her comment*

JANIS: *Being differently abled since the surgery,*

ARCHITECTURE ▸

about Pamala Anderson having more prosthetics in her body than Aimee herself, yet only Ms. Mullins is considered disabled.

KRISTAL: *Is there anything in regards to culture and mobile impairments that you would like to include?*
JANIS: *Being differently abled since the surgery, I have become much more aware of my body and much more aware of the sensitivities of people living with mobility issues. I have never disrespected or looked at someone who is differently abled as someone less than myself. However, since I have become part of that "disabled" (using word lightly) populace, I have become well aware of the differences in how people treat and react to me. I suppose it is human nature to be more conscientious when one is affected first hand.*

I have become much more aware of my body.

KRISTAL: *In your experience, what are the most difficult architectural elements that you encounter because of your mobile impairment and why?*
JANIS: *Inclement weather makes me scared of walking on any floors; for risk of falling because I don't have complete control of my suspended right leg.*
KRISTAL: *Are there any more architectural elements that are perhaps more subtle that individuals without a mobile impairment might not consider?*
JANIS: *I prefer rough but flat ground; if the surface is glossy or slick, any water or grease on it will not allow me to have good grip when I bear my entire weight on my affected right leg.*

REHABILITATION ▸

--------- EXOSKELETAL PELVIC REPLACEMENT ---

BODY FUNCTION ▸

The following questions refer to the affected leg

KRISTAL: *Are there any architectural elements*

JANIS: *Handrails help me a lot, mainly*

KRISTAL: *Are there any architectural elements that aid your mobile impairment?*
JANIS: *Handrails help me a lot, mainly for security and mind assurance.*

KRISTAL: *Do you attend physiotherapy to aid your impairment?*
JANIS: *I find hydrotherapy and yoga to be beneficial. I regularly attend hydrotherapy because it helps my affected right leg remain strong and my whole body aligned. I attend yoga because it helps keep my muscles limber and relaxed.*

KRISTAL: *Can you move your toes?*
JANIS: *Yes.*
KRISTAL: *Can you move your ankle?*
JANIS: *Yes.*

that aid your mobile impairment?
for security and mind assurance.

KRISTAL: *Can you move your knee?*
JANIS: *Yes.*
KRISTAL: *When you are standing on your non-affected leg, are you able to move your affected leg forward?*
JANIS: *Yes.*
KRISTAL: *If moving your leg forward is limited, please explain and provide an example.*
JANIS: *I can swing my affected leg forward by using my hips.*
KRISTAL: *When you are standing on your non-affected leg, are you able to move your affected leg backward?*
JANIS: *Yes.*
KRISTAL: *When you are standing on your non-affected leg, are you able to move your affected leg to the side?*
JANIS: *Yes.*

DESIGN PREFERENCES ▸

KRISTAL: *While using your non-affected leg for balance, are you able to support your body weight on your affected leg?*
JANIS: *Yes.*

KRISTAL: *Would it be your personal preference for the prosthetic to be fastened under and/or over your clothing?*
JANIS: *Under to be discrete.*
KRISTAL: *What material finish(es) would you prefer?*
JANIS: *Any materials that are both breathable and strong.*
KRISTAL: *What pattern would you prefer?*
JANIS: *Solid. The more clean lined and unpatterned for me the better. I do not see a prosthethic as a fashion accessory.*

THE ISSUE OF
IDENTITY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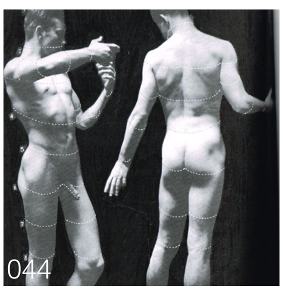
043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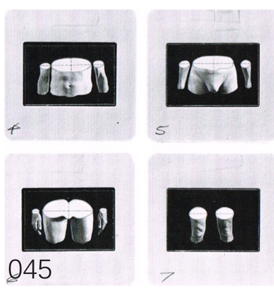
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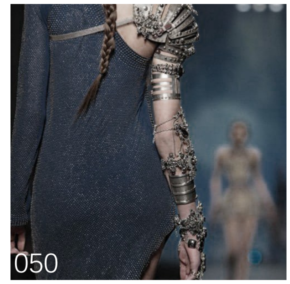
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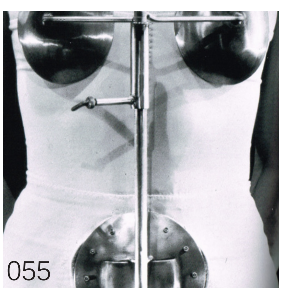
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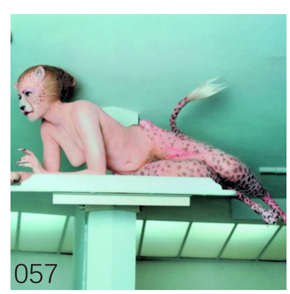
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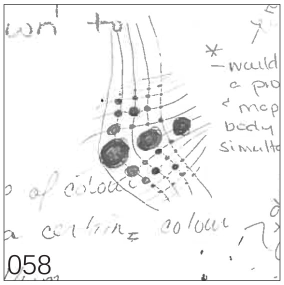
PRELIMINARY DESIGNS

During the preliminary design process, several architectural prosthetic designs were proposed that resolved or heightened one's mobile, tactile, and spatial awareness.

Once the Exoskeletal Pelvic Replacement was selected as the final design for *Pros+Tithenai*, relevant sketches were gathered and the function of the prosthetic was developed in greater detail.

In addition, several material tests were completed in order to determine what the cuffs of the Exoskeletal Pelvic Replacement should be made from. Laminated acrylic plastic sheets with aesthetic fabric layers sandwiched in between, and various 3D printed ABS plastic test strips were made prior to deciding on fibreglass as the final prototype material.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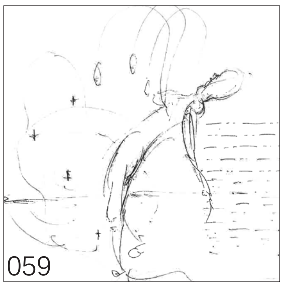
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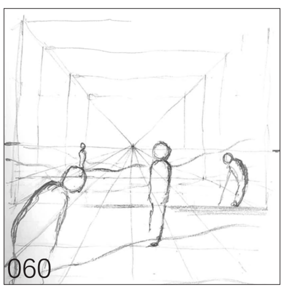
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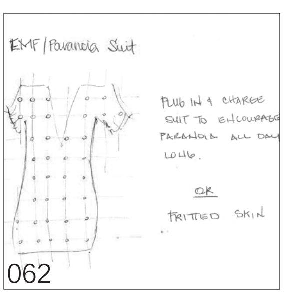

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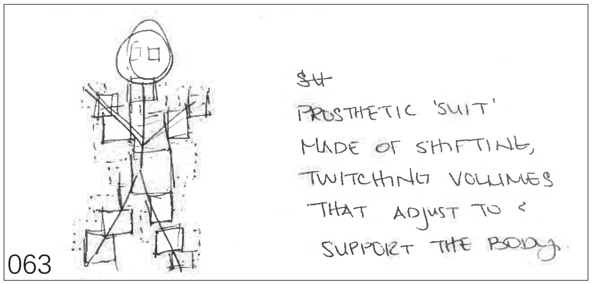

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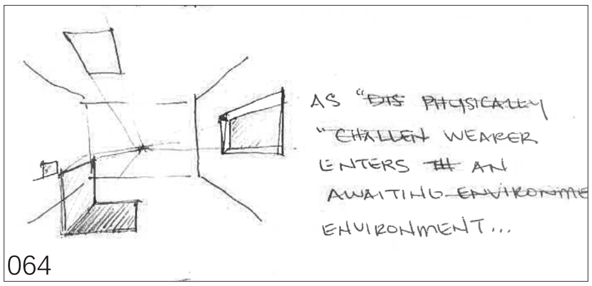

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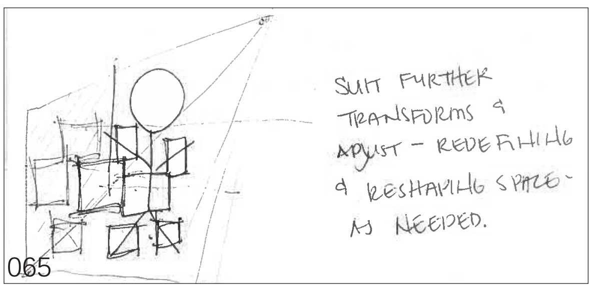

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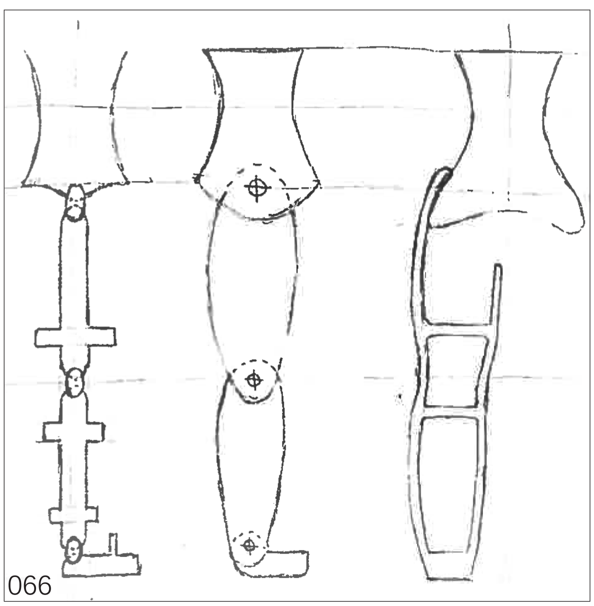
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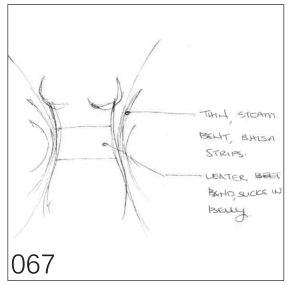

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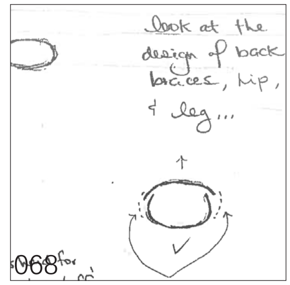

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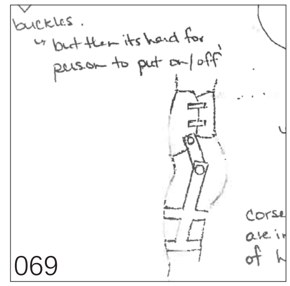

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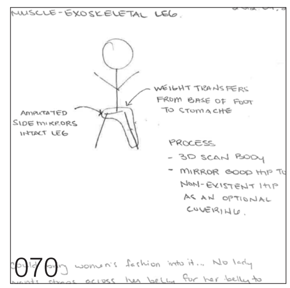

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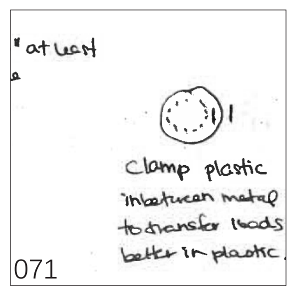

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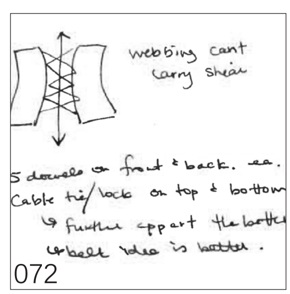

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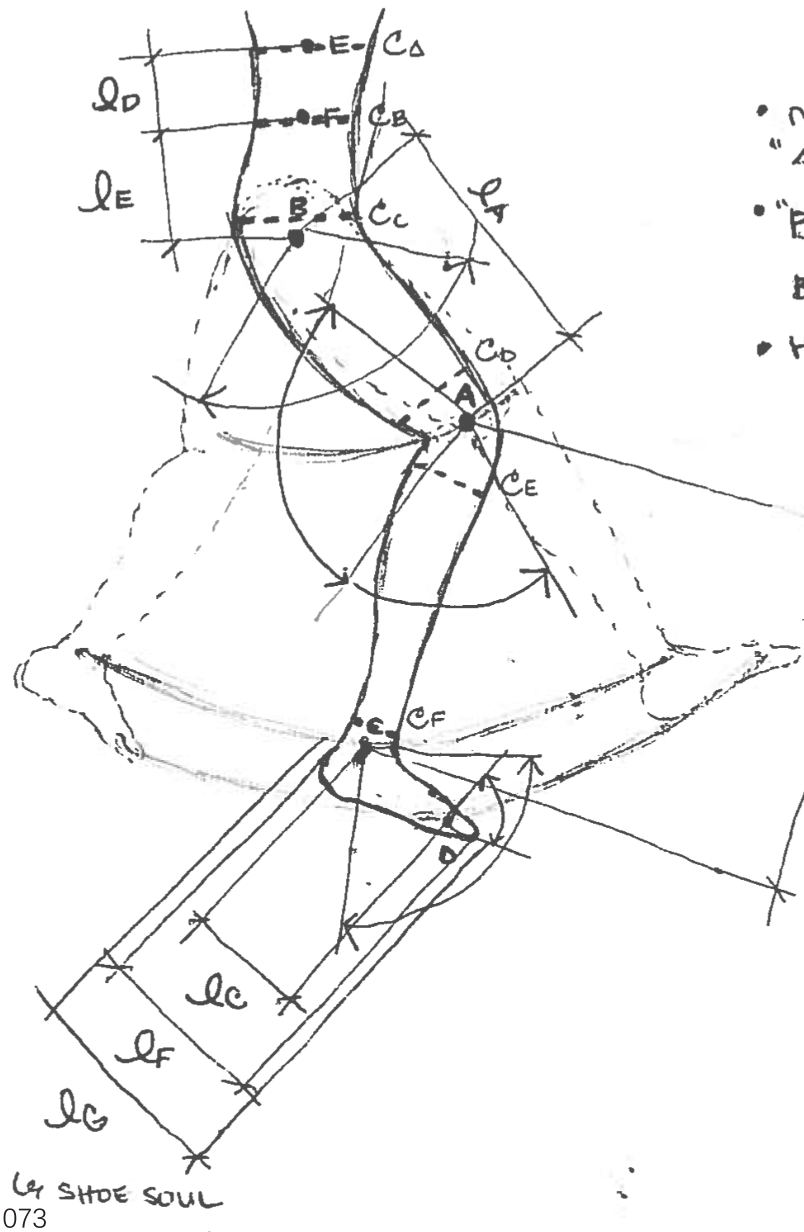
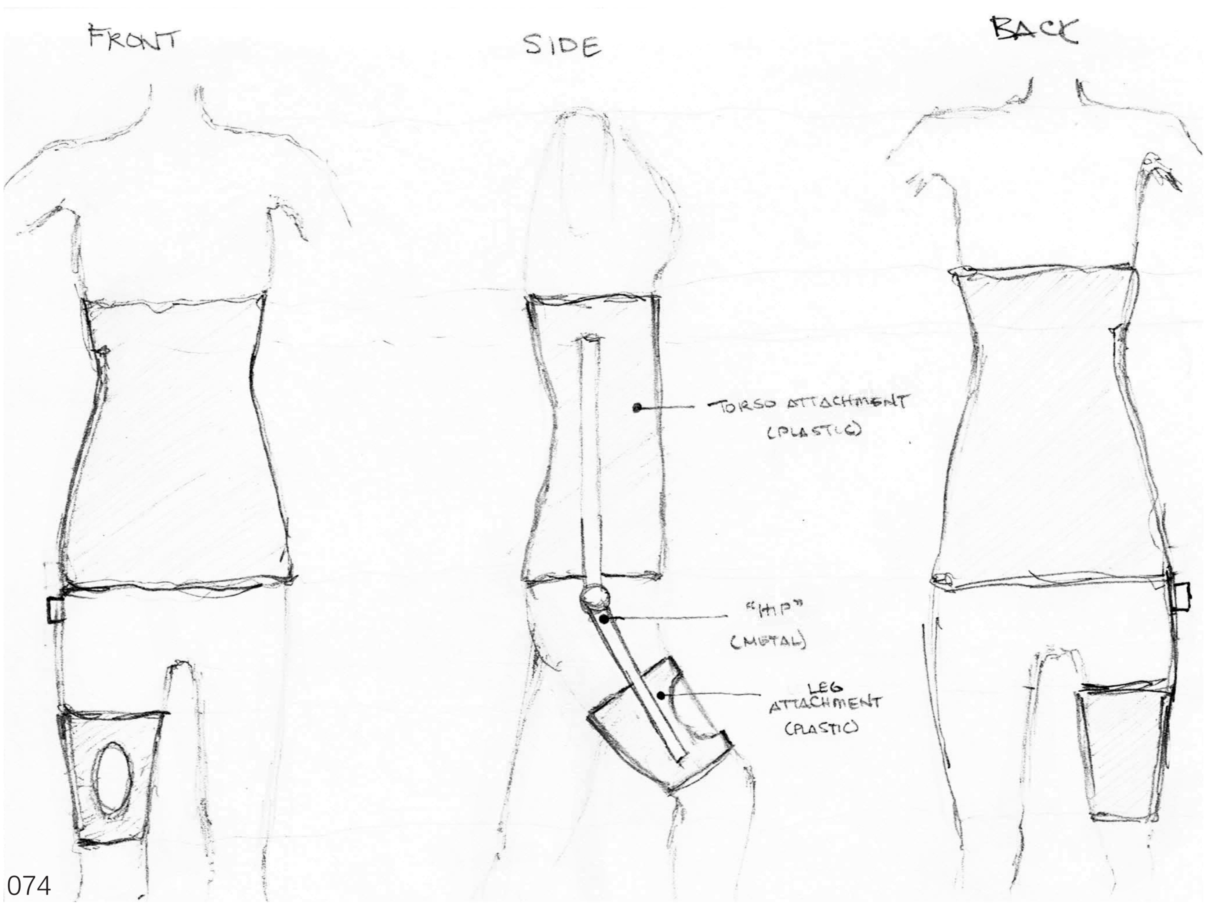


- MIN. ANGLE OF "A" WHILE STANDING
- "B" MIGHT NEED A BLOCK AS WELL
- HER BODY JOINTS IN OTHER LOCATIONS ~~CAN BE~~ ARE STRONG ENOUGH SO PROSTHETIC JOINT CAN BE PASSIVE.

073


FRONT
SIDE
BACK
TORSO ATTACHMENT
(PLASTIC)
"HIP"
(METAL)
LEG
ATTACHMENT
(PLASTIC)

074


075

INTERLUDE:

DOLL PROTOTYPE

After the basic concept and preliminary design sketches were completed, a scaled prototype was constructed. This process consisted of smoothing trace paper onto the body of a doll, sketching the form of the prosthetic onto it's body until the ergonomics suited, and then revising the form in 2D aided computer design and drafting software. The templates were then printed 1:1 and cut from 0.5mm acrylic plastic sheets. The plastic cut-outs were then secured in place onto the doll and heat formed to it's body using an industrial heat gun. Finally, the rotation point of the leg was located underneath the plastic and a hole was made in order to attach the Torso Cuff to the Thigh Cuff with a metal brace.

Torso	Circum.	Width	Depth
Underbust	18	5.8	4.9
Waist	17.5	5.7	5.1
Navel	19	6.5	5.3
Hips	19	7.1	5.4
Drop waist / bum	21	7.6	5.3

Right Leg	Circum.	Width	Depth
Thigh @ 0cm above knee	12.3	3.5	4.1
Thigh @ 2cm above knee	11.7	3.4	4
Knee	10.7	3	3.1

Right Foot	Length	Width
Foot	5.2	2.5

Right Vertical Dimensions	Length
Knee to waist	4.2
Waist to pubic joints	6.2
Knee to point of rotation	4.2
Waist to point of rotation	5.4

076

077

078

SCALE 1:3

: CUT MATERIAL SECURED IN PLACE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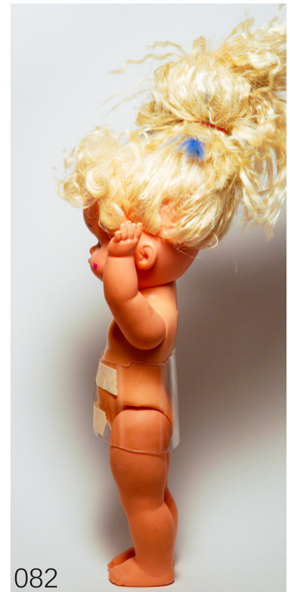
081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: POST-HEAT FORMING


083

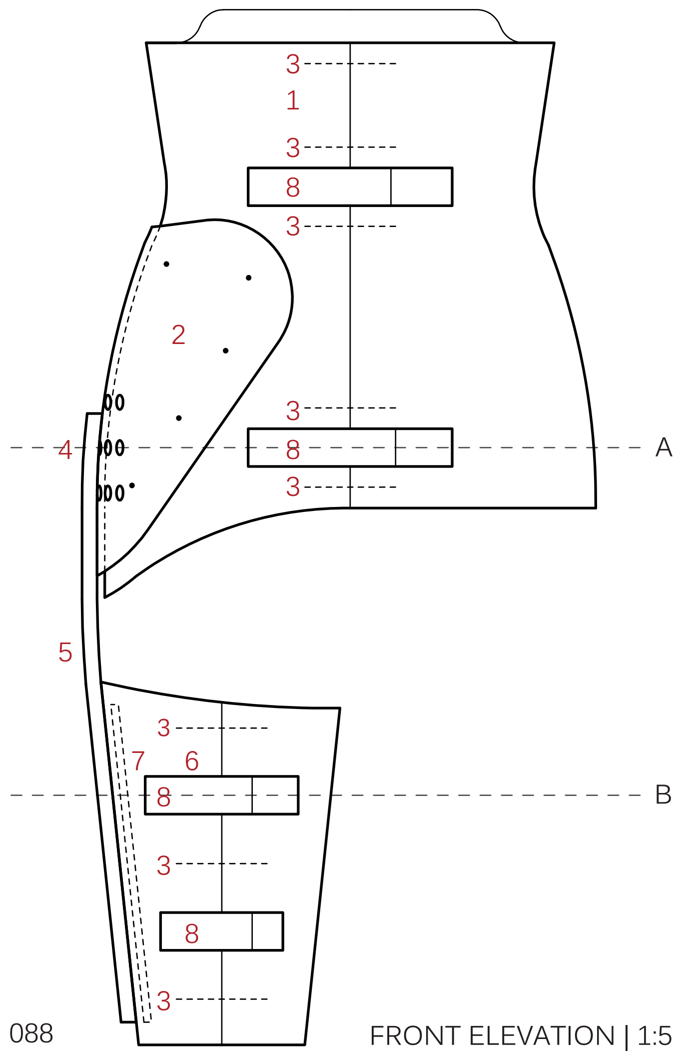

084


085


086

: COMPLETED PROTOTYPE

DESIGN



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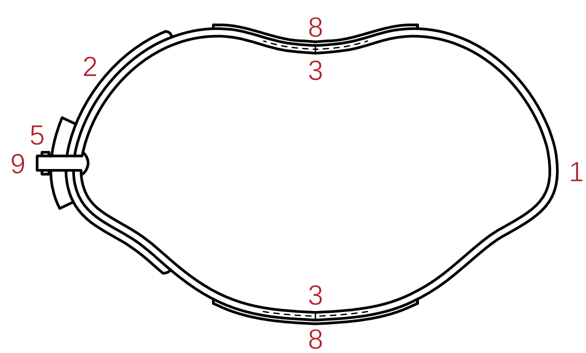
FRONT ELEVATION | 1:5



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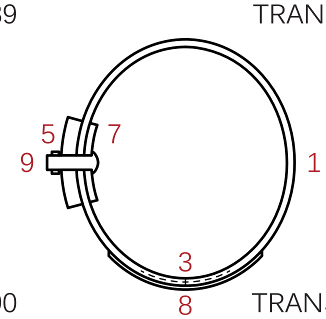
TRANSVERSE SECTION A | 1:5



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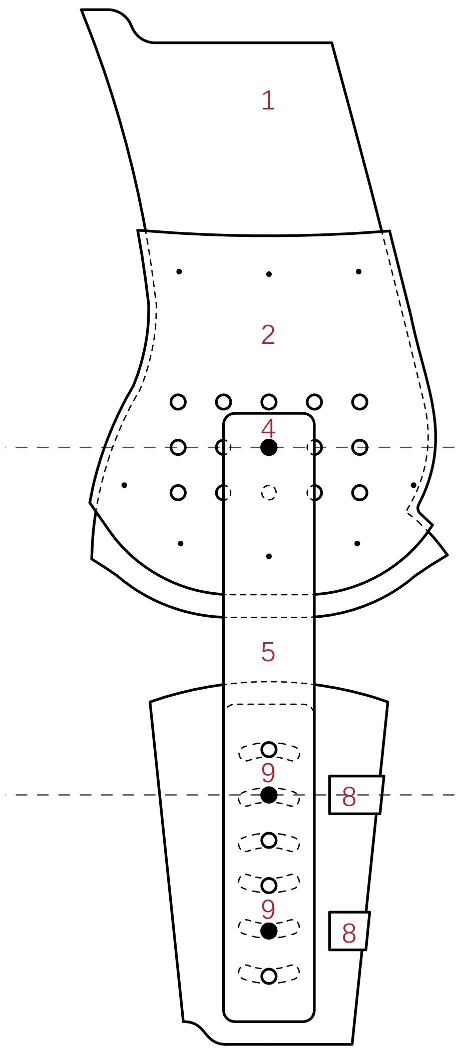
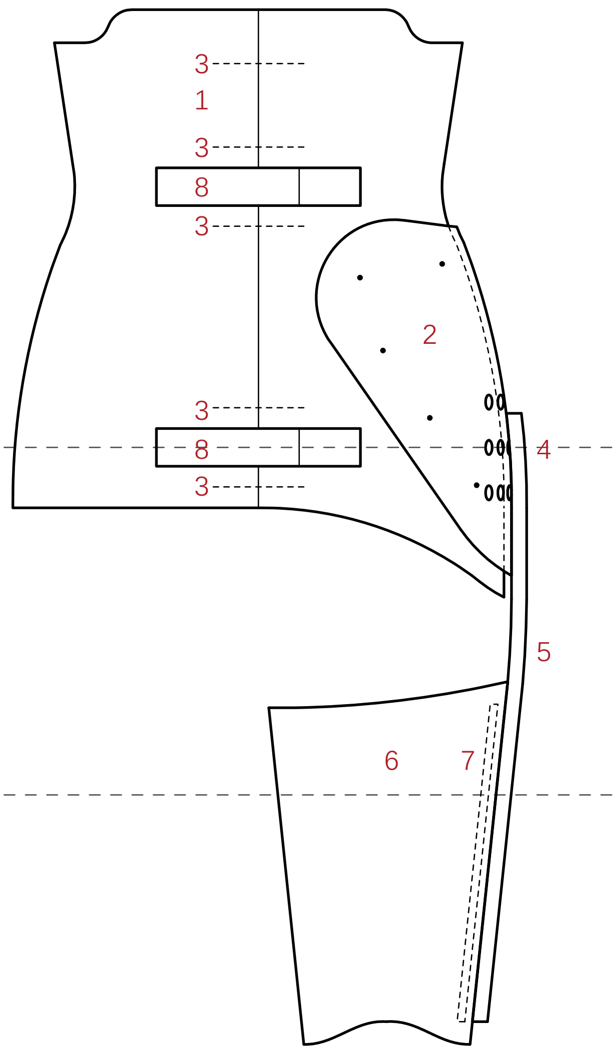
TRANSVERSE SECTION B | 1:5



091 RIGHT ELEVATION | 1:5



092 BACK ELEVATION | 1:5

COMPONENT [PROTOTYPE MATERIAL]

1 TORSO CUFF [4 PLY FIBREGLASS W/ REINFORCEMENT]

2 HIP PLATE [ALUMINUM]

3 SHEAR RESISTANT PINS [STEEL]

4 FEMORAL ROTATION POINT [ALUMINUM BOLT]

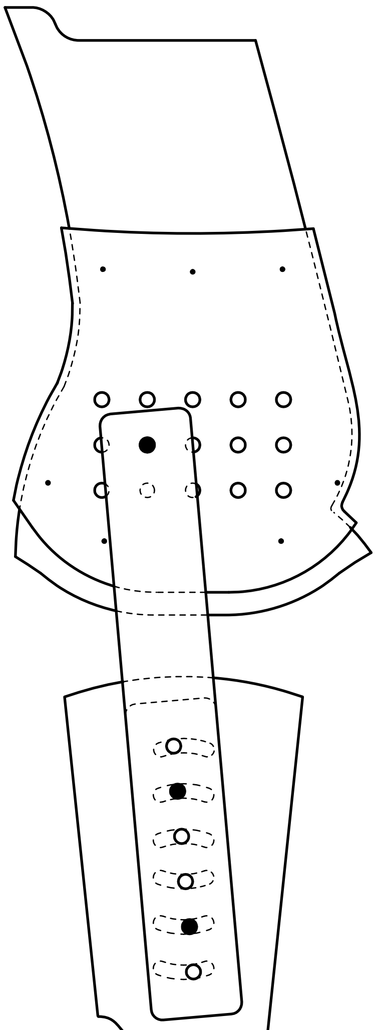
5 ANTI-COMPRESSION BRACE [ALUMINUM]

6 THIGH CUFF [4 PLY FIBREGLASS W/ REINFORCEMENT]

7 THIGH PLATE [ALUMINUM]

8 FASTERNERS [VELCRO]

9 THIGH CONNECTION [ALUMINUM BOLT, WASHER, NUT]



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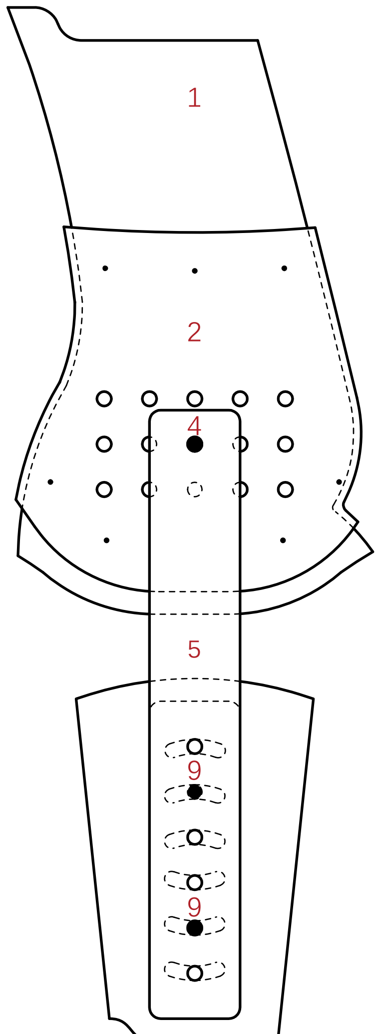

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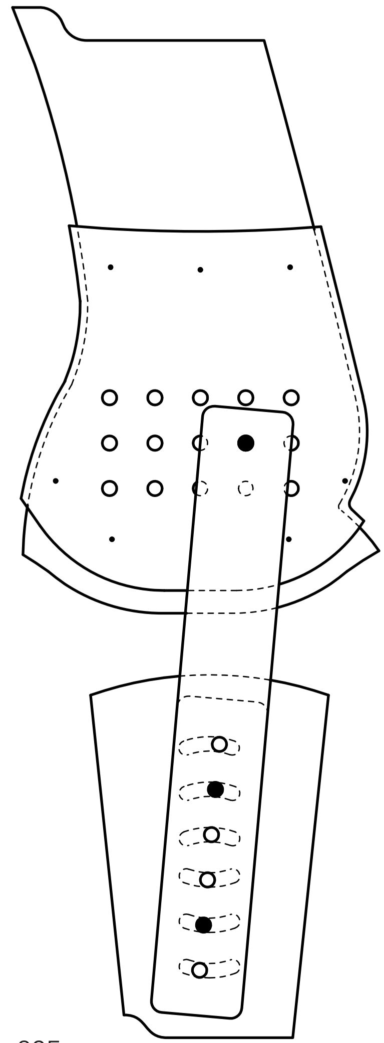

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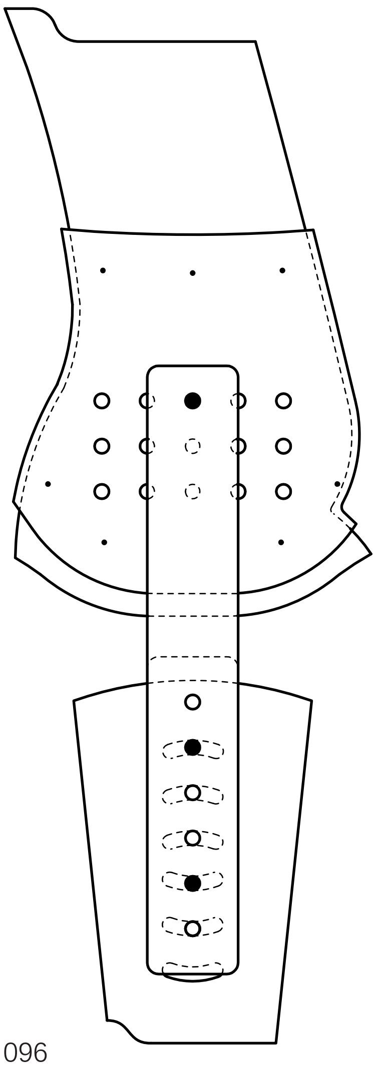

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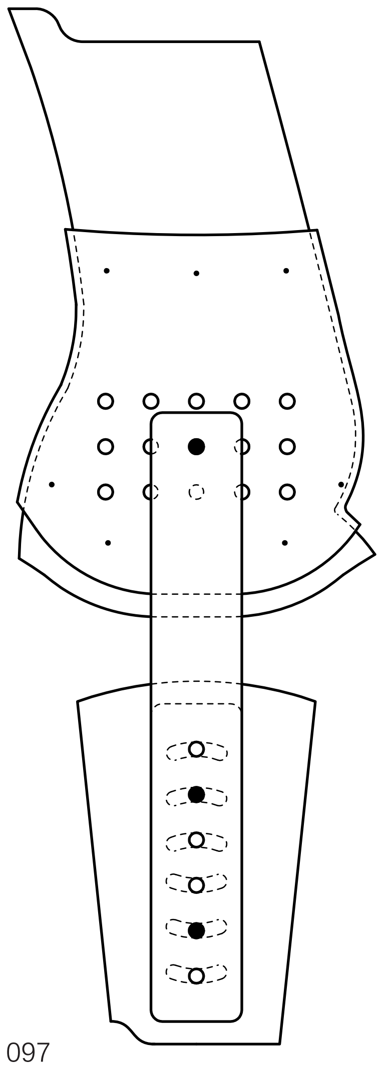

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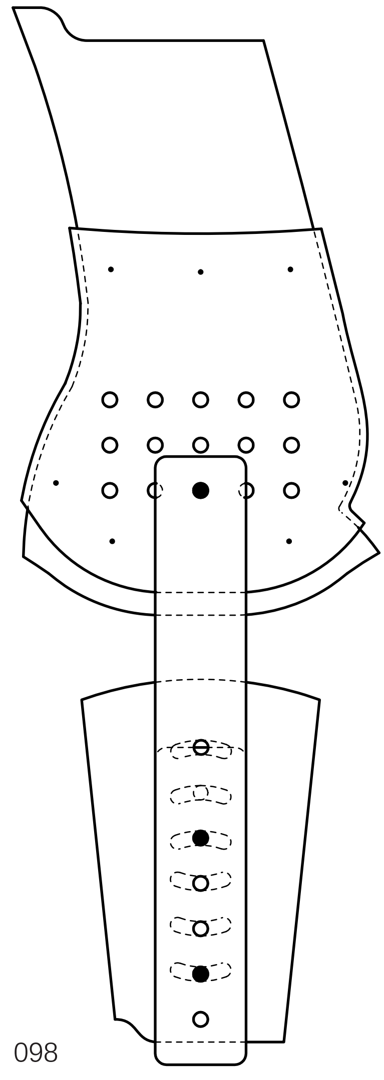

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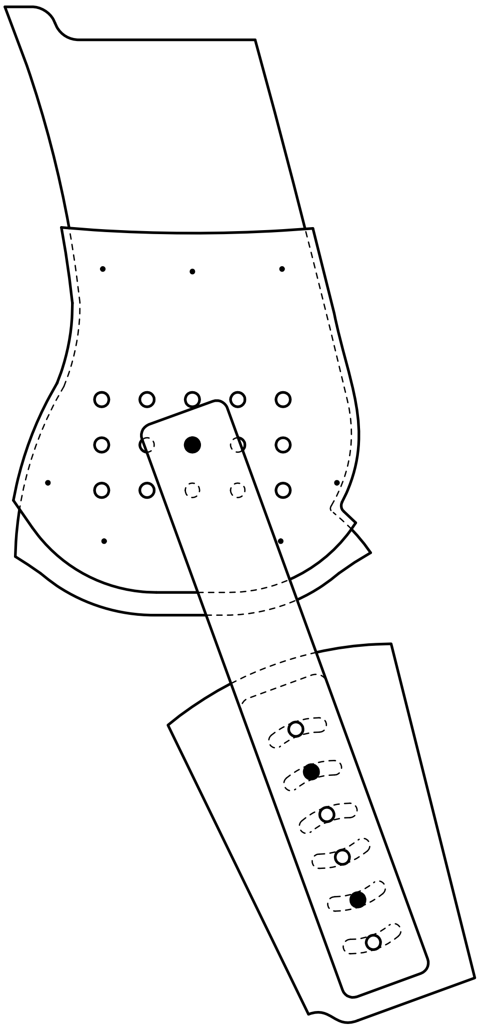
PIVOT POINT ADJUSTMENTS | 1:5



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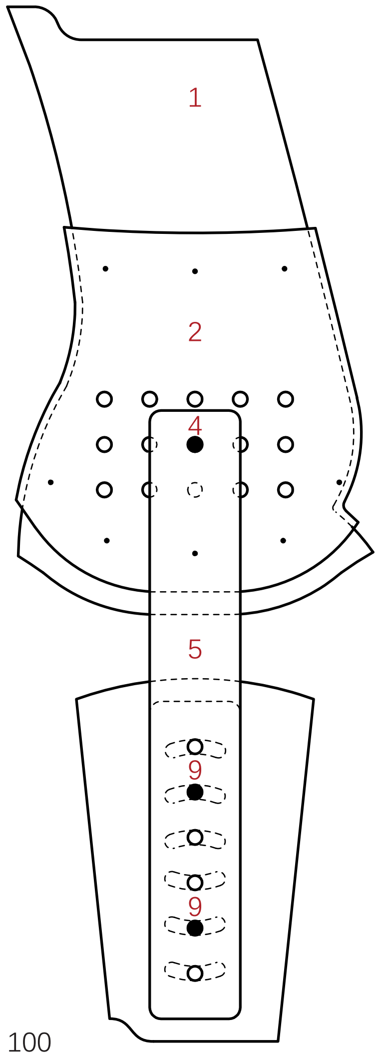

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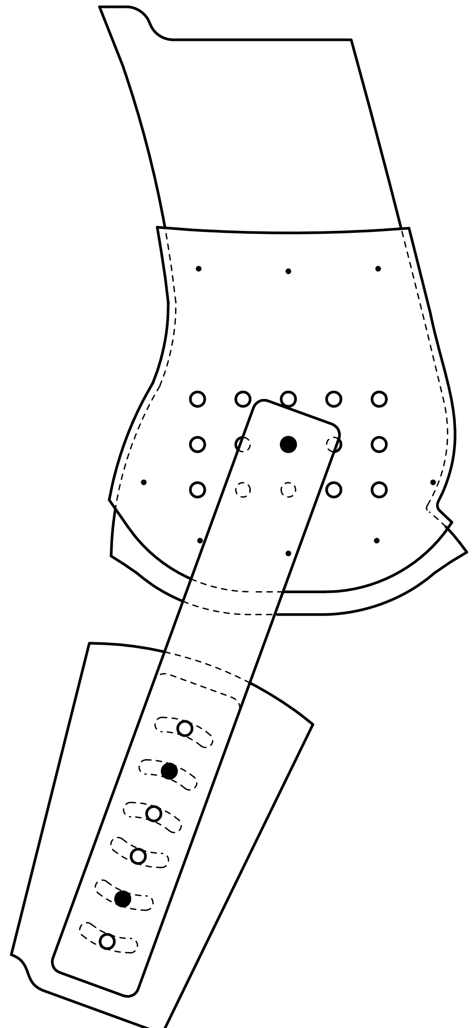

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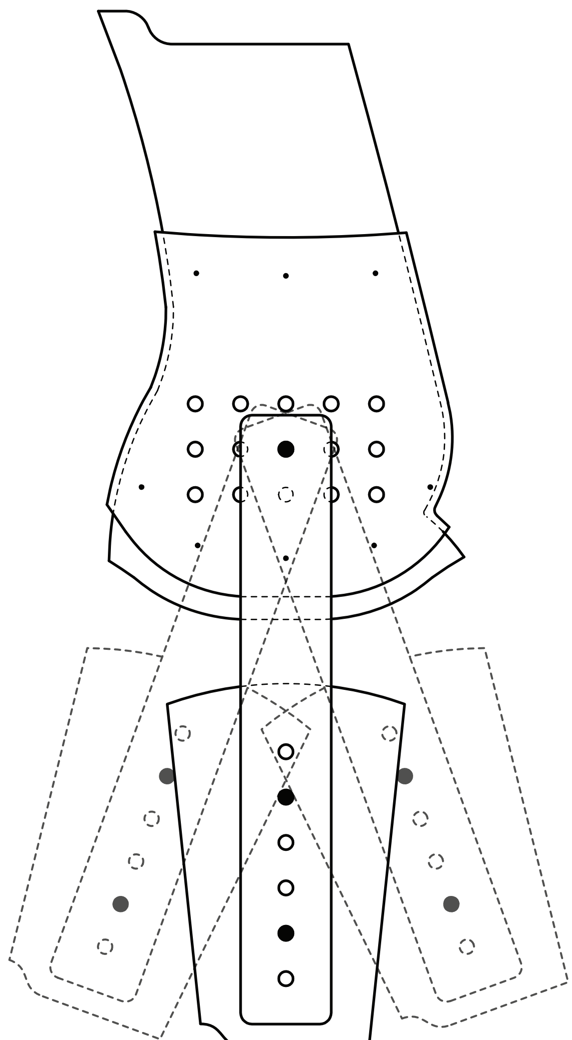

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WALKING | 1:5

ALTERNATIVE DESIGN OPTIONS

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OPTION 1

Basic Components:
- 1 Torso Cuff
- 1 Hip Plate
- 1 unilateral brace
- 1 Thigh Cuff
- 1 Thigh Plate

The Exoskeletal Pelvic Replacement is designed to perform in lieu of the amputated pelvic area. In order to resist compression of the affected leg into the abdominal cavity, the cuffs are fastened to the body and connected by a structural unilateral brace.

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OPTION 1B

Additional components:
- 1 unilateral brace
- 1 Thigh Cuff
- 1 Thigh Plate

If the load is inadequately dispersed throughout the Torso Cuff, it may be necessary to include an additional Thigh Cuff on the other leg. Doing so will decrease the eccentricity of the load, and potentially recentre the body's structure.

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OPTION 2

Basic Components:
- 1 Torso Cuff
- 1 Hip Plate
- 2 unilateral braces
- 1 Thigh Cuff
- 1 Calf Cuff

If the Thigh Cuff is unable to sit securely on the leg, a Calf Cuff will be included in order to stabilise the structure and transfer loads more effectively.

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OPTION 2B

Additional components:
- 1 unilateral brace
- 1 Thigh Cuff
- 1 Thigh Plate

See Options 1B and 2 for explanation.

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OPTION 3

Basic Components:
- 1 Torso Cuff
- 1 Hip Plate
- 3 unilateral braces
- 1 Thigh Cuff
- 1 Calf Cuff
- 1 Foot Plate

This option transfers forces directly between the Torso Cuff and the Foot Plate, thus bypassing the entire affected leg and pelvic area.

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OPTION 3B

Additional Components:
- 1 unilateral brace
- 1 Thigh Cuff
- 1 Thigh Plate

See Options 1B and 3 for explanation.

STRUCTURAL ANALYSIS

Structural and mechanical analyses were completed in order to evaluate the structural function of the prosthetic device.

PRIMARY STRUCTURAL CONSIDERATIONS

The spherical femoral head typically rests in the acetabulum, a socket in the pelvis. Axial loads along the leg are transferred from the head of the femur into the pelvis through this joint. When the quadriceps muscles contract, the hip joint serves as a lever fulcrum causing the leg to rotate forward (undergo flexion), and when the hamstrings contract it causes the leg to rotate backward (extension). The ball and socket joint at the hip allows the femur to move inward and outward in the coronal plane, adduction and abduction movements, respectively. Resisting these motions is important for gait and other activities that involve periods of support on a single leg. During an internal hemipelvectomy surgical procedure, the acetabulum is removed along the portion of the pelvis in which the spherical femoral head resides, and the head of the associated femur ceases to be properly constrained. As a result, the femur can move upward into the abdominal cavity when it is subjected to an axial load, and no pivot exists for flexion and extension or for adduction and abduction motions. The purpose of the Exoskeletal Pelvic Replacement is to carry these axial loads, serve as a fulcrum for flexion and extension movements and constrain abduction and adduction tendencies.

LOAD TRANSMISSION PATHS

Primary structural forces transfer through a human's skeletal system and never through soft tissues, such as the muscular system. Due to their dynamic nature, transferring loads through muscle is difficult. However, this is what the Exoskeletal Pelvic Replacement proposes; it intervenes the human body's typical transmission paths by transferring the forces through the abdominal and thigh muscles. In order for the prosthetic to accomplish this, the cuffs are firmly fastened to the body. The cuffs allow for the new load transmission path to be adjusted as follows, ascending from the foot: femur, to thigh muscles (quadriceps and hamstrings), to Thigh Cuff and Thigh Plate, through the bolts, to the Anti-Compression Brace, to pivoting bolt, to Hip Plate, to Torso Cuff, to abdominal muscles and ribs, and then back to the skeletal system via the spine.

FUNCTION

Another structural design consideration is the location of the pivot point - where the Hip Plate and Anti-Compression Brace meet via bolt - on the prosthetic wearer's body. The pivot point must be properly positioned in order to perform as the lever fulcrum. However, given the removal of the acetabulum, it is possible that the axis of rotation may have moved, therefore a definite rotation point may be difficult to locate. In order for the affected leg to move, the hamstrings must be located behind the pivot point.

RISK

Absolute structural failure of the Exoskeletal Pelvic Replacement could potentially cause serious harm. If the prosthetic were to fail while the user is walking, it is plausible that the femur could be forced upward into the body and puncture visceral organs. Due to the severity of this issue, fail-safe methods were incorporated into the design of each component of the Exoskeletal Pelvic Replacement. While the design drawings show the prosthetic in its most minimal form, the series of renderings, entitled "Alternative Design Options" (seen previous), include attachments to apply should the Torso Cuff alone never be deemed structurally sound.

TORSO CUFF

The Torso Cuff transfers loads to/from the spine and disperses them throughout the entire torso area. It also contains steel pins at the seams that address shear stresses.

HIP PLATE

Since the spherical femoral heads axis of rotation is no longer in a definite position, the Hip Plate was designed so that the pivot point could be adjusted accordingly. This was achieved by creating a grid of perforations on the plate; the typical rotation point is located in the centre. The Hip Plate was also designed to disperse loads across the entire torso area through the plates “wings”.

RIVETS

While it is unlikely that rivets would be used in a manufactured version of the Exoskeletal Pelvic Replacement, the calculations are relevant because they consider the forces that the Hip Plate and its attachments compensate for.

BOLTS

The bolts must be capable of transferring all potential forces through a single point. Therefore, such forces were calculated so that the appropriate bolts could be used.

ANTI-COMPRESSION BRACE

The Anti-Compression Brace is a unilateral brace responsible for transferring forces to/from the prosthetics torso components to/from the thigh components by bypassing the removed right pelvic area.

THIGH CUFF

The Thigh Cuff is responsible for keeping the femur at a specified distance from the prosthetics defined axis of rotation at the spherical femoral head. While the Thigh Cuff may not be the most difficult component to build, it is the most critical component of the assemblage structurally. It is crucial that the Thigh Cuff be tight enough to not slip from its desired positon, but not so tight that it compromises the blood circulation in the appendage. For this reason, additional prosthetic attachments have been proposed in order to remedy this potential issue.

THIGH PLATE

Currently the Thigh Plate is incorporated into the design in order to prevent stress fractures from occurring on the Thigh Cuff. It sandwiches the less structural Thigh Cuff material in between itself and the aluminum Anti-Compression Brace.

LOAD TRANSMISSION PATHS

TYPICAL SKELETAL STRUCTURE

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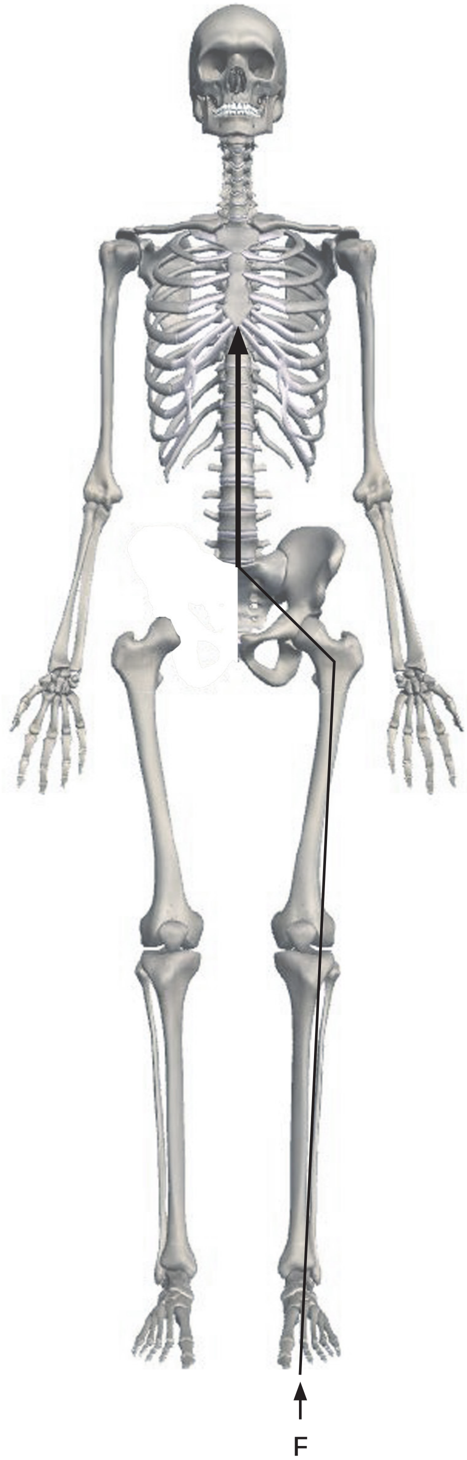
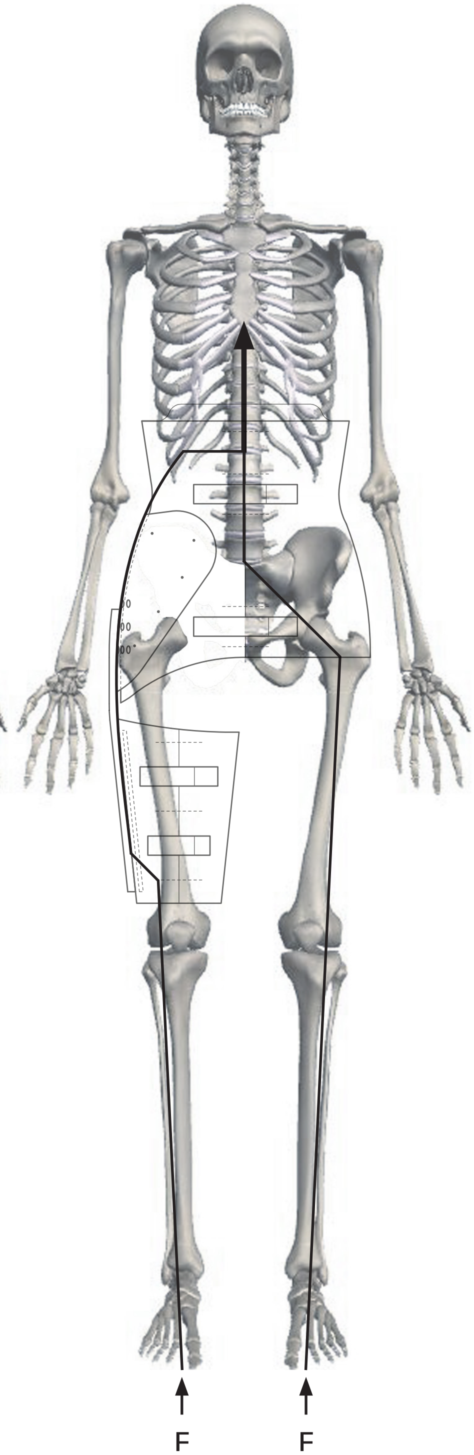


INTERNAL HEMIPELVECTOMY

110



PROSTHETIC INTERVENTION

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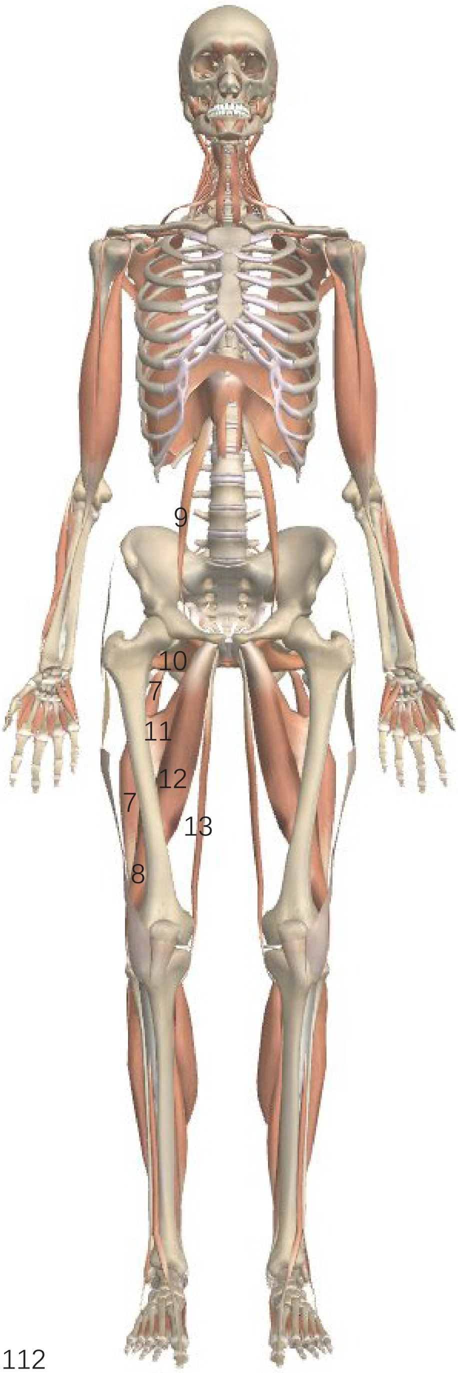
TYPICAL SKELETAL + MUSCULAR SYSTEMS



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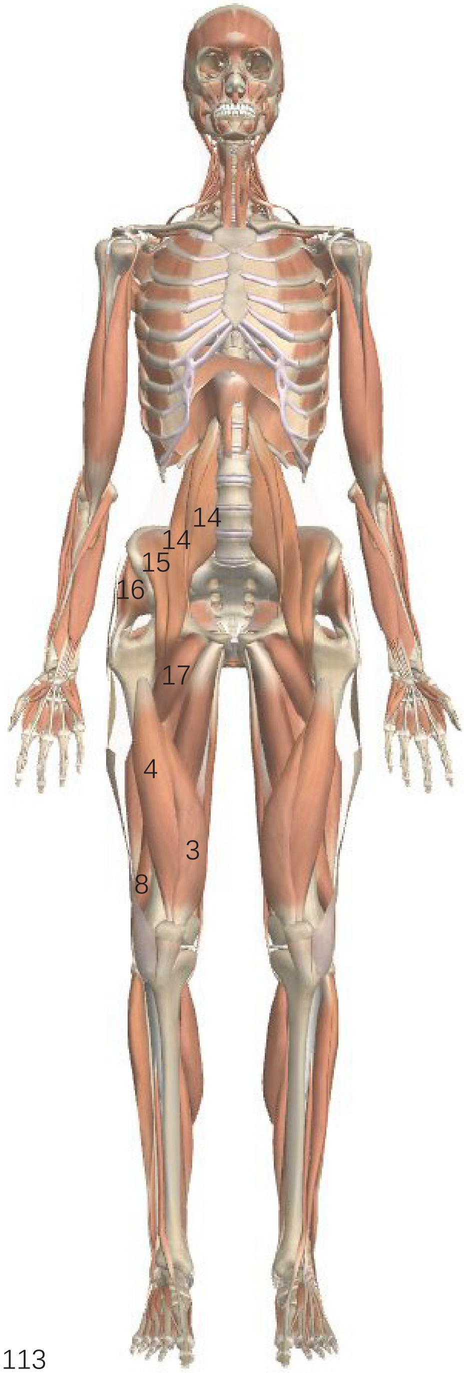

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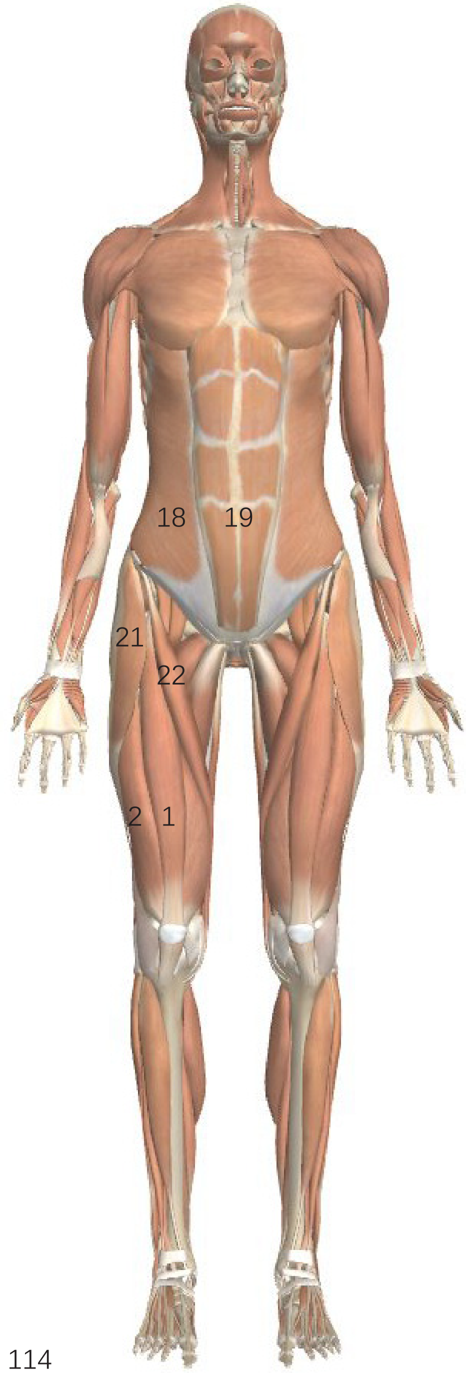

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FRONT ELEVATIONS [ANTERIOR VIEWS]

QUADRICEPS FEMORIS MUSCLE

1 RECTUS FEMORIS

2 VASTUS LATERALIS

3 VASTAS MEDIALIS

4 VASTUS INTERMEDIUS

HAMSTRING MUSCLES

5 SEMITENDINOSUS

6 SEMIMEMBRANOSUS

7 BICEPS FEMORIS LONGUS

8 BICEPS FEMORIS SHORT

ADDITIONAL MUSCLES

9 PSOAS MINOR

10 OBTURATOR EXTERNUS

11 ADDUCTOR BREVIS

12 ADDUCTOR LONGUS

13 GRACILIS

14 PSOAS MAJOR

15 ILLACUS

16 GLUTEUS MINIMUS

17 PECITINEUS

18 EXTERNAL OBLIQUE

19 RECTUS ABDOMINIS

20 ILIOTIBIAL BAND

21 TENSOR FASCIA LATA

22 SARTORIUS

23 RECTUS FEMORIS

24 GLUTEUS MEDIUS

25 GLUTEUS MAXIMUS

26 SACROTUBEROUS LIGAMENT

27 ILIOCOCCYGEUS

28 COCCYGEUS

29 LEVATOR ANI

30 QUADRATUS FEMORIS

31 INFERIOR GEMELLUS

32 MULTIFIDUS

33 PIRIFORMIS

34 SUPERIOR GEMELLUS

35 OBTURATOR INTERNUS

36 ADDUCTOR MAGNUS

37 ILIOCOSTALIS

38 INTERNAL OBLIQUE

39 LATISSIMUS DORSI

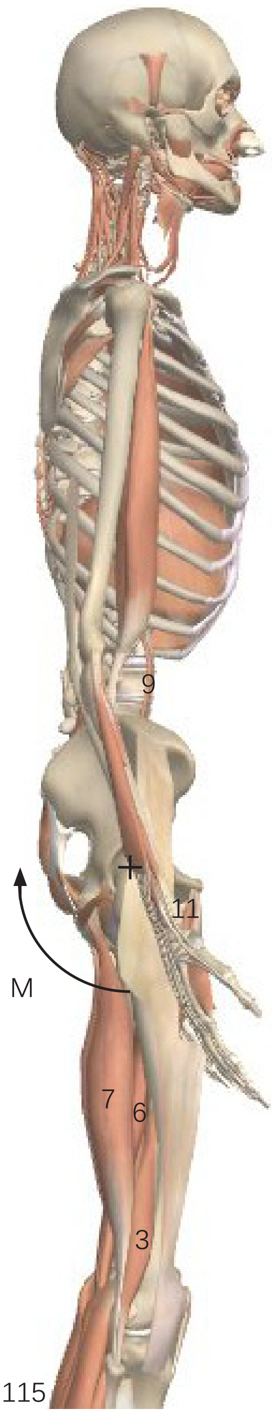
FORCES

M MOMENT

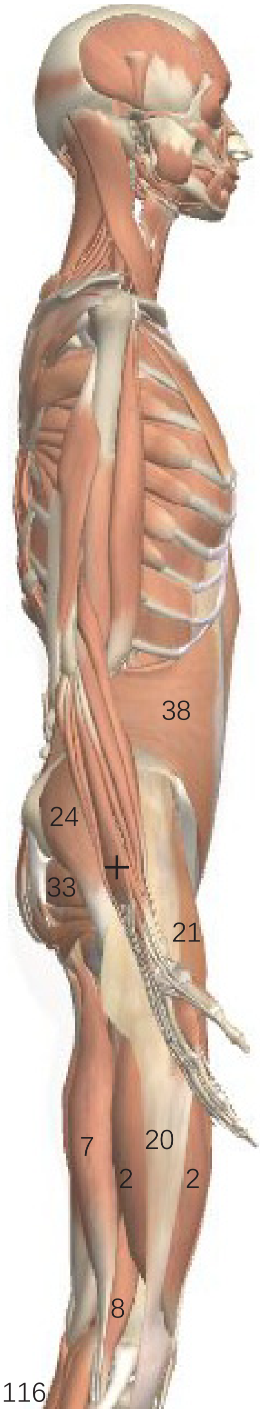
The quadriceps and hamstring work in synchronized opposition, making walking, running, jumping, and related activities possible.

The quadriceps are extensors of the knee joint. The rectus femoris in particular is also a flexor of the hip because it attaches to the ilium. The rectus femoris swings the leg forward for each step taken.

The hamstring contains the posterior thigh muscles that are extensors of the hip. They work in opposition to the quadriceps by pulling the leg backward after each step taken.



115



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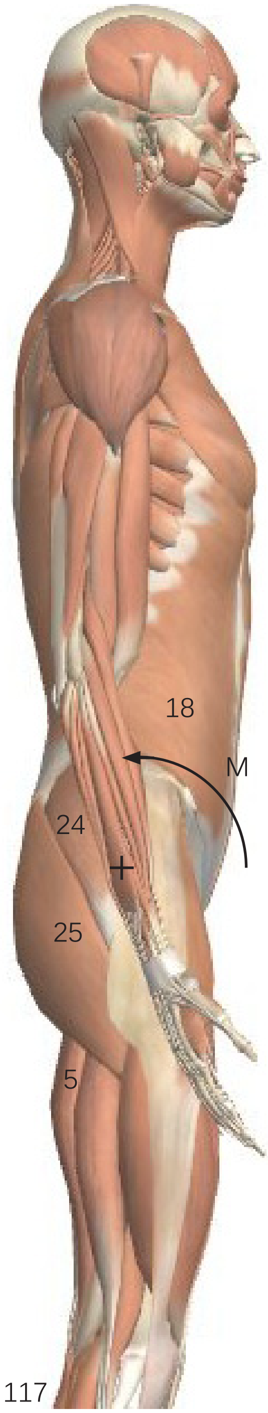

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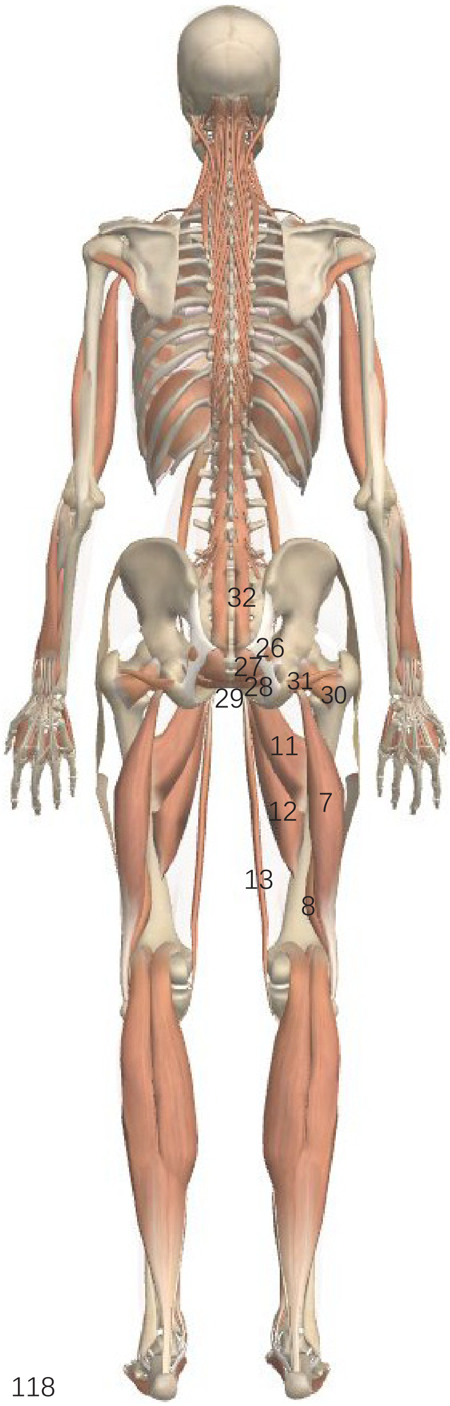
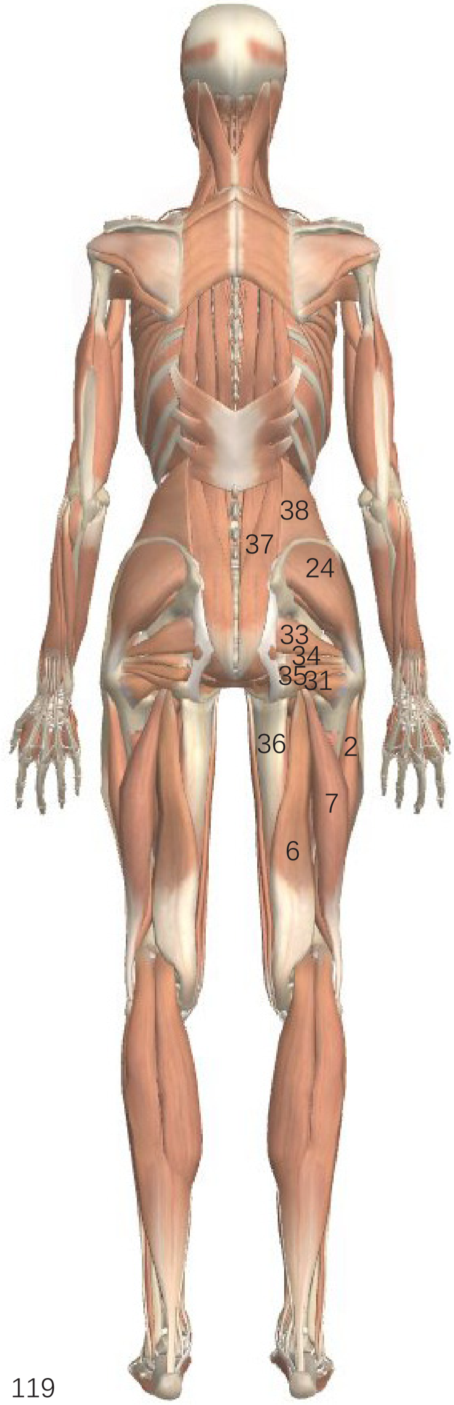
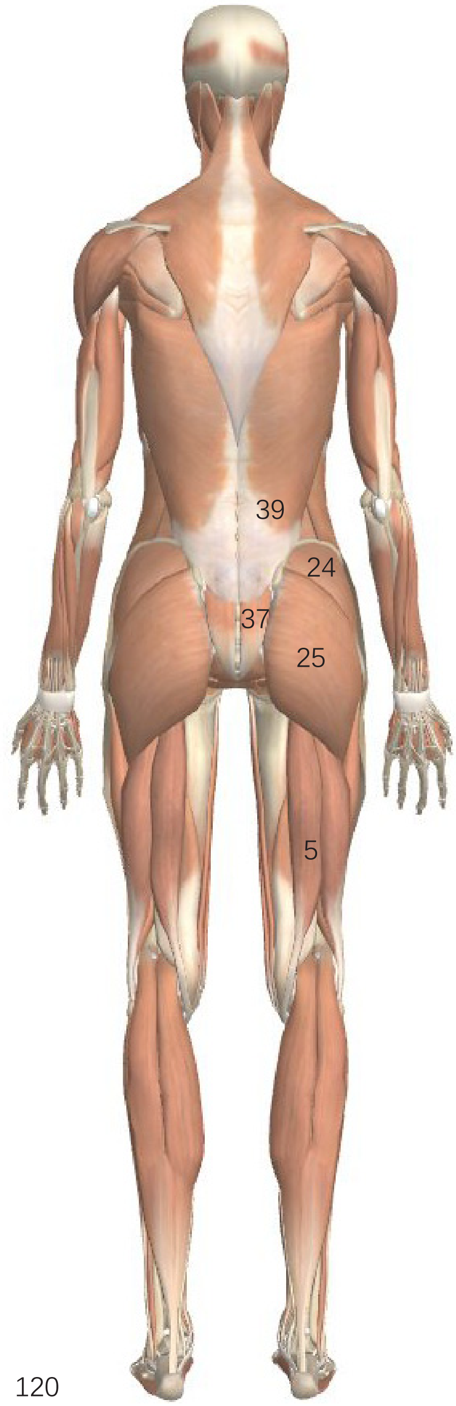
MUSCULAR FORCES - RIGHT ELEVATIONS [RIGHT LATERAL VIEWS]



118



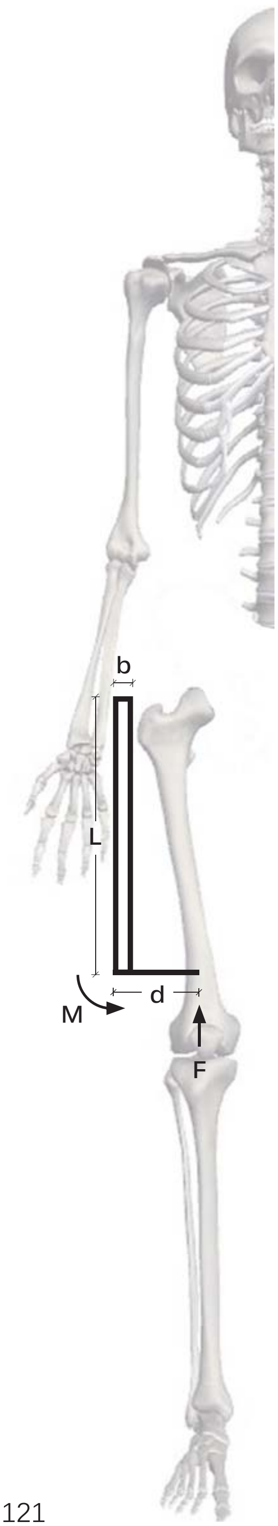
119



120

BACK ELEVATIONS [POSTERIOR VIEWS]

STRUCTURAL CAPACITY OF ANTI-COMPRESSION BRACE



Force:

f	= m x a	where:	f	=	force
	= w		m	=	mass
	= 135 lbs		a	=	acceleration
			w	=	constant force due to gravity

Factored Force:

F	= f x factor	where:	F	=	factored force
	= f (z + s)		z	=	dynamic effect (stepping force applied by human body while walking)
	= 135 x (1.5 + 1.5)				
	= 405 lbs				
			s	=	safety factor, including muscle forces

Moment of a Force:

M	= F x d	where:	M	=	moment about indicated axis
	= 405 lb x 4.5 in		d	=	perpendicular distance
	= 1822 in lb				

Aluminum:

σ	= 35 000 lb si	where:	σ	=	allowable bending stress

Moment of Inertia:

I	= $\frac{b \times t^3}{12}$	where:	I	=	moment of inertia about indicated axis
			b	=	length of line on the cross section (width)
			t	=	thickness of beam, perpendicular to axis (height)

Bending Moment:

$$\sigma = \frac{M \times y}{I}$$

$$= \frac{M \times \frac{t}{2}}{\frac{bt^3}{12}}$$

$$35\,000 = \frac{1822 \times \frac{t}{2}}{\frac{2.375 \times t^3}{12}}$$

$$t^2 = \frac{1822 \times 12}{2.375 \times 35\,000 \times 2}$$

$$t = 0.36 \text{ in}$$

$$= \frac{3}{8}''$$

where:

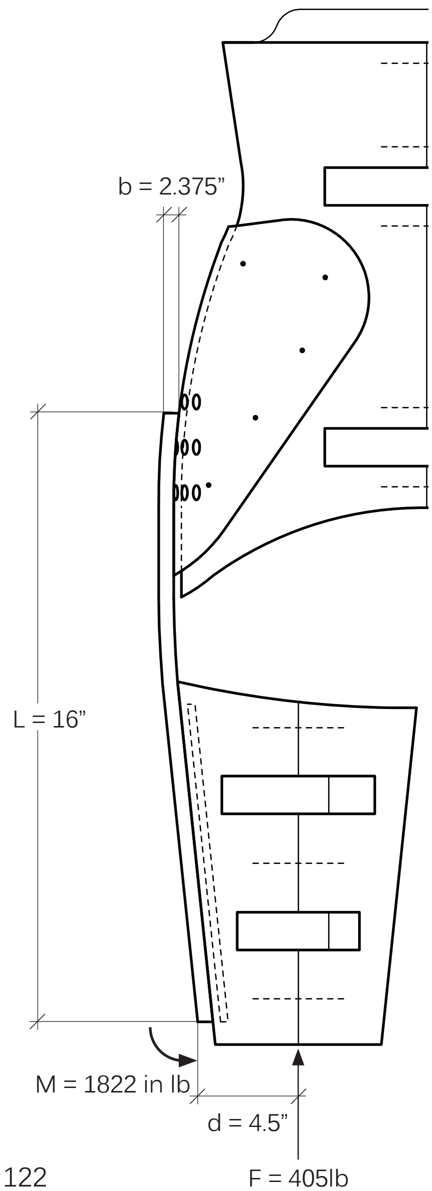
y = distance between the two centroids, perpendicular from the indicated axis

θ = radians

L = length of beam

E = Young's modulus for aluminum

π = pi



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Rotation for ⅜":

$$\theta = \frac{ML}{EI}$$

$$= \frac{ML}{E \times \frac{(b \times t^3)}{12}}$$

$$= \frac{1822 \times 16}{10 \times 10^6 \times \frac{(2.375 \times 0.375^3)}{12}}$$

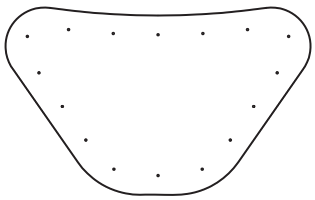
$$= 0.28$$

$$deg = \theta \times \frac{180}{\pi}$$

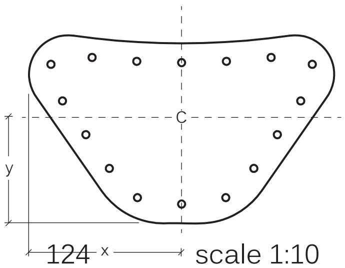
$$= 0.28 \times \frac{180}{\pi}$$

$$= 16.04^\circ$$

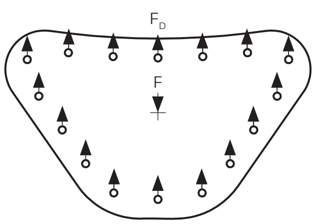
STRUCTURAL CAPACITY OF RIVETS



123 scale 1:10



124 scale 1:10



125 scale 1:10

Centroid:

$$y = \frac{\Sigma Ay}{\Sigma A}$$

$$= 5.51 \text{ in}$$

$$x = \frac{\Sigma Ax}{\Sigma A}$$

$$= 7.94 \text{ in}$$

Rivet Shear Force:

$$F_D = \frac{P}{N}$$

$$= \frac{0.405}{16}$$

$= 0.03$ k lb

$= 30$ lb per rivet

where: F_D = force on each rivet caused by the load which passes through the centroid of the rivet (lbs)

P = applied load

N = number of rivets

Distance:

$d_1 = 2.85$

$d_2 = 2.91$

$d_3 = 3.11$

$d_4 = 2.76$

$d_5 = 0.86$

$d_6 = 0.9$

$d_7 = 2.66$

$d_8 = 4.18$

$d_9 = 4.51$

where: $d_\#$ = perpendicular distance from rivet to x-axis of centroid

Moment of a Force:

$F_i = \alpha\, d_i$

$M = \Sigma F_i \times d_i$ where: M = moment

$= \alpha\, \Sigma d_i^2$ F_i = individual force on each rivet

$= \alpha\, \Sigma d_i^2$ d_i = perpendicular distance from rivet to x-axis of centroid

$= \alpha\, \Sigma d_i^2$

$= \alpha\, [d_1^2 + 2d_2^2 +$ α = coefficient of proportionality

$2d_4^2 + 2d_5^2 + 2d_6^2$

$2d_7^2 + 2d_8^2 + d_9^2]$

$1822 \text{ in lb} = \alpha\, [2.85^2 + 2(2.91^2) + 2(3.11^2) +$

$2(2.76^2) + 2(0.86^2) + 2(0.90^2) +$

$2(2.66^2) + 2(4.18^2) + (4.51^2)]$

$= a\, (8.12 + 16.94 + 19.34 +$

$15.24 + 1.48 + 1.62 +$

$14.15 + 34.94 + 20.34)$

$= \alpha\, (132.17)$

$$\alpha = \frac{1822}{132.17}$$

$= 13.79$

Rivet Compression Force:

$F_{Cmax} = \alpha\, d_{max}$

$= 13.79 \times 4.51$

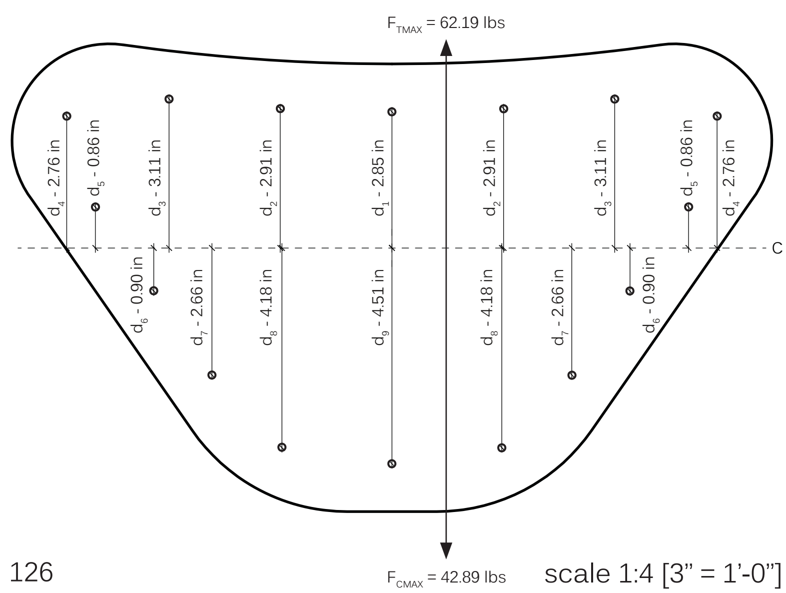
$= 62.19 \text{ lbs}$

Rivet Tension Force:

$F_{Tmax} = \alpha\, d_{max}$

$= 13.79 \times 3.11$

$= 42.89 \text{ lbs}$



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scale 1:4 [3" = 1'-0"]

STRUCTURAL CAPACITY OF BOLTS

Bolt Shear Stress:

$$\tau = \frac{V}{A} = \frac{V}{\pi r^2} = \frac{405}{\pi 0.1875^2} = \frac{405}{0.11} = 3682 \text{ lbs/in}^2$$

where:

τ = average shear stress

V = shear

A = area

r = radius of bolt

PHYSICAL ANALYSIS

PROFESSIONAL EXPERIENCE ▸

KRISTAL: Can you explain what your clinics slogan,

JONI: To use movement, to use our bodies, to use our mental health is how we (as humans) empower ourselves.

CULTURE ▸

PHYSIOTHERAPIST “JONI,”

MOBILE IMPAIRMENTS + SPACE

QUESTIONNAIRE BY KRISTAL O’SHEA | TRANSCRIBED BY KRISTAL O’SHEA

EDUCATION: BScKin, MScPT
PROFESSION: Physiotherapist
SPECIALTY: Sports Medicine/Orthopedics

KRISTAL: *What mobile impairments do you typically address?*
JONI: *Mostly issues with gait - whether it is post-surgical (ACL repair, hip/knee replacements) or from soft tissue injury (ankle, sprains, meniscal tears).*

KRISTAL: *Can you explain what your clinics slogan, “empowering through movement,” means to you?*
JONI: *What it means to me is that at the end of the day, our*

“empowering through movement,” means to you?

and physical strength to take us to [a] state of optimal

health is everything to us and being in a state of optimal health is the ultimate empowerment. To use movement, to use our bodies, to use our mental and physical strength to take us to this state of optimal health is how we (as humans) empower ourselves.

KRISTAL: *Are there any cultural misconceptions that you are aware of against people with mobile impairments?*
JONI: *I can’t speak from any educated standpoint on this subject, but I do know that many cultures see others with any sort of impairment - be it physical, psychological, etcetera - as being cursed or damned and are often very stigmatized and made to be an outcast.*

KRISTAL: *Do you consider prosthetics an extension of the human body?*

JONI: *Yes, prosthetics are no different than wearing shoes on where they never wear shoes. They develop strong ground below them. We grow up putting our feet in shoes; and shoe wear becomes essential for us to mobilize.*

KRISTAL: *Personally, I feel that Oscar Pistorius' participation in the Olympics was monumental to the cultural acceptance of handi-capable individuals and their prosthetic aids. Would you agree? Why?*
JONI: *I would agree, but then it also generates much discussion that in a technological era, perhaps at some point the design of a prosthetic aid is more advanced than the capabilities of the human body. At what point can we not classify the two as equal?*

KRISTAL: *Is there anything in regards to culture and mobile impairments that you would like to include?*
JONI: *Living in an urban area where the atmosphere is very fast-paced... it can often be "every man/woman for themselves," and we use this as an excuse not to help those with mobile impairments (i.e. giving up a seat on the subway, helping someone up a flight of stairs, holding a door open, etcetera).*

our feet. Some people grow up in environments/cultures
muscles and callouses on their feet to withstand the
our skin stays supple and our muscles stay relatively weak
Is a prosthetic any different?

KRISTAL: *Is there some sort of prosthetic that you wish existed but currently does not, for any of your mobility impaired patients? Please describe the prosthetic and the expected benefits.*
JONI: *A prosthetic pelvis - although relatively rare for an individual to need one. I had the pleasure of getting to work with someone whom despite making remarkable gains after an internal hemipelvectomy, could potentially have continued success with a prosthetic of some sort that would normalize her weight-bearing.*

ARCHITECTURE ▸

EXOSKELETAL PELVIC REPLACEMENT

KRISTAL: *Do you consider prosthetics to be an extension of the human body?*
JONI: *Yes, prosthetics are no different than wearing shoes on our feet. Some people grow up in environments/ cultures where they never wear shoes. They develop strong muscles and build amazing callouses on their feet to withstand the ground below them. We grow up putting our feet in shoes; our skin stays supple and our muscles stay relatively weak and shoe wear becomes essential for us to mobilize. Is a prosthetic any different?*

KRISTAL: *In your professional opinion, what are the most difficult architectural elements for the mobility impaired to interact with and why?*
JONI: *In my experience, stairs, and crossing the street in the allotted time period.*
KRISTAL: *Are there any more that are perhaps more subtle that individuals without a mobile impairment night not consider?*
JONI: *Yes. Curbs and escalators.*

KRISTAL: *Are there any architectural elements that you recommend or use during physiotherapy sessions to rehabilitate your patients?*
JONI: *Yes. Stairs, curbs, and dynamic surfaces (bosu ball and unstable ground).*

KRISTAL: *The Exoskeletal Pelvic Replacement will perform in lieu of the amputated pelvic area by transferring weight/forces from the thigh to/from the torso area. Do you foresee any pain or discomfort caused from this on the knee joint, that wouldn't already be expected from typical, attached spine, force transfers?*
JONI: *If it is designed to work like a hemipelvis would, then I can't see this creating an issue at the knee.*

KRISTAL: *Do you forsee any pain or discomfort caused from [the Torso Cuff]?*

JONI: *I would think that initially skin irritation... and breathing the exoskeleton would defacilitate the core musculature core recruitment.*

KRISTAL: *The Exoskeletal Pelvic Replacement involves the use of something similar to a corset in order to transfer forces to/from the torso area. Do you foresee any pain or discomfort caused from this?*
JONI: *I would imagine that there would be a period of adjustment and very precise measurements that need to be accounted for. I would think initially skin irritation would be a source of discomfort and breathing mechanics/rib mobility may be an issue. I also wonder if the exoskeleton would defacilitate the core musculature or if it could be designed in such a way to promote improved core recruitment.*

KRISTAL: *Have you ever worked with a patient who has undergone an internal hemipelvectomy, where no internal structure was replaced to rejoin the skeleton? If yes, please provide the rehabilitative exercises*

mechanics/rib mobility may be an issue. I also wonder if or if it could be designed in such a way to promote

that you prescribe/practice for the purpose of increasing your patients' mobility.
JONI: *Too many to list!*

- *stair retraining*
- *hip/core/back/abdominal/quad strengthening*
- *gait retraining*
- *upper body strengthening*
- *proprioception/stability training*

KRISTAL: *It has been documented that during the rehabilitation of internal hemipelvectomy patients, patients exercise walking and jumping on their affected leg – without anything in place to resist the compression of the leg up through the body. Is there a concern that the femur will push on and/or puncture the above visceral organs, such as the intestines, kidney, etcetera?*

KRISTAL: During the rehabilitation of internal hemipelvectomy patients,

Is there a concern that the femur will push on

JONI: When done at the correct stage of rehabilitation, the muscles of the hip/core are strong enough to dynamically support the pelvis (i.e. provide a relatively stable base for the femur to push against).

JONI: *When done at the correct stage of rehabilitation, the muscles of the hip/core are strong enough to dynamically support the pelvis (i.e. provide a relatively stable base for the femur to push against).*

KRISTAL: *Do you have any medical concerns for patients willing to test the Exoskeletal Pelvic Replacement?*
JONI: *No.*

KRISTAL: *Would the Exoskeletal Pelvic Replacement be useful during rehabilitation exercises for patients who have undergone an internal hemipelvectomy at your practice?*
JONI: *Yes - if designed well. I would imagine it could help faciliate faster return to full weight-bearing and decrease any leg-length discrepancy with gait retraining.*

patients exercise walking and jumping on their affected leg... and/or puncture... visceral organs?

KRISTAL: *In your professional opinion, would the Exoskeletal Pelvic Replacement be practical for everyday use?*
JONI: *Unsure. It is difficult for me to make an assumption, but given that the design would be helpful in gait retraining and return to functional tasks, then I imagine it could be.*

KRISTAL: *Are you aware of a prosthetic that has already been designed for this purpose?*
JONI: *No.*
KRISTAL: *Are you aware of any reason why a prosthetic for this purpose has not already been designed?*
JONI: *Likely because it is still a relatively new procedure.*
KRISTAL: *Do you have any additional medical concerns regarding the Exoskeletal Pelvic Replacement?*
JONI: *No.*

PROFESSIONAL EXPERIENCE ▸

PHYSIOTHERAPIST “JOAN,”

AMBULATION

QUESTIONNAIRE BY KRISTAL O’SHEA | TRANSCRIBED BY KRISTAL O’SHEA

EDUCATION: B.Sc. PT

PROFESSION: Physiotherapist

SPECIALTY: Orthopedics, certified Active Release Techniques provider

KRISTAL: *What mobile impairments do you typically address?*
JOAN: *Primarily orthopedic based mobility impairments. Both chronic and acute. Chronic example: osteoarthitis in hip or knee. Acute example: fracture, sprains.*

KRISTAL: *Have you noticed a common cause of your patients’ mobile impairments?*
JOAN: *Causes are varied. In older populations, osteoarthritis seems to be the predominant cause of mobility restriction seen, followed closely by surgery, or simply loss of balance requiring assistive aid. In younger populations, causes of mobility impairments tend to be short term, primarily from injury (eg. sports), and mild.*

KRISTAL: *Can you explain what the phrase, “empowering through movement” means to you?*
JOAN: *“Empowering through movement” to me means bettering your physical fitness, mental status, and overall health through movement and exercise.*

KRISTAL: *Is there anything in regards to your profession and mobile impairments that you would like to include?*
JOAN: *I have previously worked in a pediatric setting (some orthopedic cases but primarily neurological) where I dealt with significantly more mobility impairments. These stemmed from Cerebral Palsy, Spina Bifida and Gross developmental delays. Conditions were permanent. I was responsible for prescribing*

CULTURE ▸

KRISTAL: Are there any cultural misconceptions that you are aware of against

JOAN: In our culture… it is often assumed when a patient that they have cognitive impairments as well.

PROSTHETICS ▸

mobility aids for these children, including braces, walkers, canes, power scooters, standers and other forms of mobility devices.

KRISTAL: *Are there any cultural misconceptions that you are aware of against people with mobile impairments?*
JOAN: *Yes, I have noticed quite a few. In our culture, mobility impairments are looked at as disabilities. It is often assumed when a patient requires something more extreme than crutches/walker/cane (for example forearm crutches or young individual in a wheelchair), that they have cognitive impairments as well.*

Adults tend to avoid asking questions if they believe the mobility impairment is a permanent one, whereas children are more inclined to feel comfortable asking their peers. Adults perceive mobility impairments as a definite NEGATIVE and are often uncomfortable when talking about it; whether out of sympathy or lack of understanding of the person's condition.

people with mobile impairments?

requires something more extreme than crutches...

KRISTAL: *Personally, I feel that Oscar Pistorius' participation in the Olympics was monumental to the cultural acceptance of handi-capable individuals and their prosthetic aids. Would you agree?*
JOAN: *I do in a sense. But I feel that even when competing in the same category as athletes who are not impaired, athletes with prosthetics will continue to be looked at differently... at least for the near future anyways. It's a matter of level playing field. Regardless of how good/bad that athlete will be, there is intrinsically something that sets him/her aside from the rest of the athletes; their prosthetic.*

KRISTAL: *Is there some sort of prosthetic that you wish existed but currently does not, for any of your mobility impaired patients?*
JOAN: *I would like to see a brace created for patients having undergone internal hemipelvectomies. Having worked with one such patient, I have learned that they are able to eventually*

JOAN: Having worked with [an internal hemipelvectomy] mobilise without an assistive device, however I feel femur would assist in weight bearing into their affected leg.

mobilize without an assistive device, however, I feel something that supported the superior portion of their femurs would assist in weight bearing into their affected legs.

KRISTAL: *Do you consider prosthetics to be an extension of the human body?*
JOAN: *Yes I do. I believe that a prosthetic becomes just as much a part of you as your own body parts. It makes you who you are.*

KRISTAL: *In your professional opinion, what are the most difficult architectural elements for the mobility impaired to interact with and why?*
JOAN: *Stairs if the impairement is in the lower extremity. Heavy doors which require significant base of support and trunk support to open; with lower limb prosthetics, there is decreased transfer of strength from lower limb, through core and into the upper extremities to open it. I have also noted that public transportation*

patient, I have learned that they are able to eventually something that supported the superior portion of their

in general (the sudden starts/stops), with occasional lack of seating, can also be a huge limitation to community ambulation.
KRISTAL: *Are there any more architectural elements that are perhaps more subtle that individuals without a mobile impairment might not consider?*
JOAN: *Weather changes floor surfaces significantly: ice outdoors, slippery indoors when raining.*
KRISTAL: *Are there any architectural elements that you recommend or use during physiotherapy sessions to rehabilitate your patients?*
JOAN: *Uneven surfaces to mimic ambulating on grass, gravel, snow, etcetera, and stepping on/over objects to mimic sidewalks and obstacles in one's path.*

KRISTAL: *Do you forsee any pain... caused from the [Torso Cuff]?*

JOAN: *There is a significant amout of lumbar side flexion that the lack of hip stabilising musculature). Because of this, accomodate this movement while still*

KRISTAL: *The Exoskeletal Pelvic Replacement will perform in lieu of the amputated pelvic area by transferring weight/forces from the thigh to/from the torso area. Do you foresee any pain or discomfort caused from this on the knee joint, that wouldn't already be expected from typical, attached spine, force transfers?*
JOAN: *If the brace was attached above the knee, then I would expect little discomfort other than what would already be generated from altered biomechanics in that lower limb. The prosthetic would need to be fitted properly to the individual patient in order not to restrict the use of their quadriceps and hamstring musculature inserting into the knee.*

KRISTAL: *The Exoskeletal Pelvic Replacement involves the use of something similar to a corset in order to transfer forces to/from the torso area. Do you foresee any pain or discomfort caused from this? If yes, please explain your concern, the severity of your*

occurs when weight bearing on the affected leg (due to the [Torso Cuff] would have to be malleable enough to providing the the needed pelvic support.

concern, and offer any recommendations that you may have. (For example: organ relocation, broken ribs, etc.)
JOAN: *Other than possible skin irritation, it would be difficult to determine if there would be any discomfort. Again, it would have to be individually fitted.*

One thought is that when watching a patient with internal hemipelvectomy walk unassisted, there is a significant amount of lumbar side flexion that occurs when weight bearing on the affected leg (due to lack of hip stabilizing musculature). Because of this, the "girdle" would have to be malleable enough to accommodate this movement while still providing the needed pelvic support.

KRISTAL: *Have you ever worked with a patient who has undergone an internal hemipelvectomy, where no internal structure was replaced to rejoin the skeleton? If yes, please provide the rehabilitative exercises that you prescribe/practice for the purpose of increasing your patients' mobility.*

JOAN: *Yes. A large variety of exercises were used, and differed significantly from early rehab to later stages.*

Initially, focus was placed on painfree mobilization of the hip joint, having the patient learn to tolerate any weight bearing through that joint, ambulate with an assistive device, and learn how to actively move that affected leg (working on proprioception as the muscular attachments at that joint have completely changed).

Further on in rehab, focus turned to decreasing the need for assistive devices needed for ambulation, working on balance to improve community ambulation, strengthening core and upper extremities as well as working on cardiovascular endurance to benefit overall conditioning and health.

Strengthening exercises for lower leg and knee were used throughout the rehabilitation process.

KRISTAL: *It has been documented that during the rehabilitation of internal hemipelvectomy patients, patients exercise walking and jumping on their affected leg – without anything in place to resist the compression of the leg up through the body. Is there a concern that the femur will push on and/or puncture the above vital organs, such as the intestines, kidney, etc? Please explain your answer and the severity of your concern.*

JOAN: *A definite concern in my eyes. As this procedure is relatively new, there have not been many previous rehabilitation results to compare with. I personally have not had a patient put full weight jumping onto that affected limb. I would never encourage any sports or activities that could cause sudden upwards force of the femur (eg. skiing). I have noted that scar tissue formation and the patient's ability to stabilize using abdominal muscles provides a significant superior barrier, or roof, to the femur, but I am not nearly 100% confident that this barrier*

KRISTAL: During the rehabilitation of internal hemipelvectomy patients,
Is there a concern that the femur will push on

JOAN: A definite concern... I have noted that scar tissue formation and the patient's ability to stabilize using abdominal muscles provides a significant superior barrier, or roof, to the femur, but I am not 100% confident that this barrier would be enough to prevent internal damage should a sudden upward force be exerted through the leg.

would be enough to prevent internal damage should a sudden upward force be exerted through the leg.

KRISTAL: *Do you have any medical concerns for patients willing to test the Exoskeletal Pelvic Replacement?*
JOAN: *I would recommend gradual use of the exoskeleton; starting at 5-10 minutes of use and increasing as tolerated. Watching for skin integrity if the support is to be placed immediately against the skin.*

KRISTAL: *Would the Exoskeletal Pelvic Replacement be useful during rehabilitation exercises for patients who have undergone an internal hemipelvectomy at your practice?*
JOAN: *I would like to say yes! I have used in my own practice a thick resistance band to provide some similar support while gait training. Something fitted to my patient's body with more supportive forces would be even better!*

patients exercise walking and jumping on their affected leg... and/or puncture... visceral organs?

KRISTAL: *In your professional opinion, would the Exoskeletal Pelvic Replacement be practical for everyday use?*
JOAN: *I believe so. Especially if it improved the comfort of ambulation and provided the patient with a better sense of safety and stability at that joint. My only concern would be the size of it and the patient's perception of prosthetics and if they were comfortable with others knowing they used it.*

KRISTAL: *Are you aware of a prosthetic that has already been designed for this purpose? If yes, please supply the name of the product.*
JOAN: *No.*
KRISTAL: *If no, are you aware of any reason why a prosthetic for this purpose has not already been designed?*
JOAN: *Like I said previously, this is a relatively recent surgical*

KRISTAL: *Would the Exoskeletal Pelvic Replacement*

JOAN: *I believe so... My only concern would be... the patient's with others knowing they used it.*

procedure and I do not believe there has been a need for such a support until now.

KRISTAL: *Do you have any additional medical concerns regarding the Exoskeletal Pelvic Replacement?*

JOAN: *No.*

be practical for everday use?

perception of prosthetics and if they were comfortable

PROTOTYPE CONSTRUCTION

The final prototype constructed for *Pros+Tithenai* is a functional prototype. Its specific purpose is to test the comfort, snuggness, ergonomics, adjustability, basic structure, and fluidity of movement on a fully mobile and structural body. Out of basic convenience – since I knew that I would have my body on me at all times – my own body was used whenever needed throughout the entirety of the prototyping process.

Construction of the prototype was divided into 5 material stages, appearing in the necessary order of operations: Plaster, Templates + Testing, Fibreglass, Aluminum, and Assembly. The following process documentation is an account of how I completed the prototype – including explanations, reasoning, reflections, and future revisions – in the order in which they were completed.

PLASTER

BODY CAST

The plaster body cast was constructed first so that it could be used to form all future prototype components.

STEP 1: MAKE THE MOULD

One layer of moistened impregnated plaster cloth was smoothed onto the front half of the nude body. Immediately following, this process was repeated on the back half of the body, keeping a 10mm (3/8in) gap between the two mould halves. The mould was given an hour and a half to dry prior to removal.

STEP 2: REINFORCING THE MOULD

Once the two halves of the mould dried completely, they were properly positioned together using clamps and rope. Using the remaining impregnated plaster cloth, the halves were joined together with plaster. Three additional layers were applied to the mould to reinforce its structure. Each layer was given time to dry in between.

STEP 3: CREATING THE RIGID FOAM INSERT

A rigid foam insert was made in order to substantially decrease the weight of the body cast.

The foam was built up in horizontal layers and was reduced approximately 25mm [1in] from the interior walls of the mould. Sections of insulation, 5 layers at a time, were hot glued together. The gauze was used to encourage adhesion of the plaster to the foam, as well as for reinforcement. All foam segments were then positioned inside the plaster mould and secured in place with hot glue.


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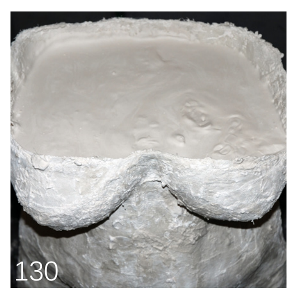
STEP 4: POURING THE PLASTER CAST

A ratio of 2/3 ash plaster and 1/3 cold water was mixed 2 litres (0.5 gallon) at a time in a jug with a spout. The plaster was then gently poured into the mould cavity. Immediately following, the cavity was agitated to release air bubbles. This process was repeated as quickly as possible until the entire cavity was filled. Nearly 23kg (50lbs) of dry plaster was used; resulting in a final weight of 19kg (42lbs) after the cast had cured.

STEP 5: REMOVING THE MOULD

After the cast was given three days to dry, a utility knife was used to remove the mould from the plaster cast.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STEP 6: SIZE ADJUSTMENT

Due to the substantial weight of the plaster cast, the plaster cloth mould noticeably stretched out during the casting/drying process. The cast increased in size 40-100mm in width and depth compared to the original body. Using a radial palm sander, the cast was reduced to an approximate uniform size increase of 40mm in width and depth. Since all future mockups and prototypes


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were formed using the cast, I decided to use the excess size as a tolerance allowance, as well as to test the adjustability of the prototype for when I tested it on my own body.

TEMPLATES + TESTING

Prior to creating the templates, all pertinent body measurements were recorded to assist with the design of each component and verify the accuracy of the finished prototype. The templates were also used to create a cardboard and plastic mockup of the prototype. This allowed any perceived issues to be addressed prior to constructing the more expensive and labour intensive fiberglass and aluminum prototype.

TORSO CUFF

STEP 1: CREATE PRELIMINARY TEMPLATE

Using trace paper, a preliminary template was made by smoothing the paper onto the body and sketching the shape of the component directly onto the paper covered body. This was done in order to create an ergonomic shape.

STEP 2: REFINE TEMPLATE

After having scanned the template and it was inserted into a 2D computer aided design and drafting software, the shape of the cuff was refined. The template of the Torso Cuff was divided into two halves at the sagittal plane.

STEP 3: CUT PLASTIC SHAPE

The 1:1 paper templates were adhered to a 1.5mm [0.06in] plastic sheet, and then cut out using a utility knife with a plastic laminate blade.

STEP 4: FORM SHAPE

The plaster body cast was positioned on its side and one plastic cut-out was properly positioned on top. Using an industrial heat gun, the plastic was then heated and formed onto the plaster cast. The cast was positioned on its side in order to use gravity as an advantage when draping the heated plastic over the cast.

Once completed, the plastic was removed, the plaster cast was rolled over, and the process was repeated using the remaining plastic cut out.

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STEP 5: TRIM

Using electrical tape, the two plastic halves were positioned into place on the plaster cast. Using a permanent marker, I then proceeded to sketch on the plastic forms, gently following the contours of the cast, in order to determine the final shape of the Torso Cuff. Once a definite shape was determined, a Dremel was used to trim the excess plastic.

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STEP 6: ATTACH FASTENERS

Two reusable cable ties were hot glued to each halve of the torso cuff. This allowed for the snugness and adjustability of the plastic Torso Cuff to be tested when fastened onto my body.

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STEP 7: LOCATING PIVOT POINT

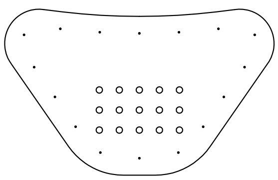
The contra-lateral femoral head – the pivot location of the prosthesis – was located by twisting my right foot from left to right in the same location, while pressing my fingers underneath the iliac crest. Once located, I drew a mark on my skin indicating its position, put the Torso Cuff back on and transferred the mark onto the plastic. The Torso Cuff was removed from the body and the mark was drilled using an electric screw driver.

LEG CUFF

STEP 1: MAKE LEG CUFF

Torso Cuff steps 1-6 in Template + Testing were repeated for the right leg only. Note that the Leg Cuff remained as one whole piece, with its seam running vertically along the front of the leg.

HIP PLATE



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STEP 1: CREATE TEMPLATE

2D computer aided design and drafting software was used to draft the Hip Plate template. The shape of the Hip Plate was informed by the shape of the Torso Cuff, the path of the structural forces it would endure, and ergonomics.

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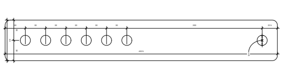
STEP 2: MOCKUP HIP PLATE

Using spray adhesive, a 1:1 paper printout of the Hip Plate was adhered to cardstock. The shape was cut out and the holes were drilled using an electric screw driver.

ANTI-COMPRESSION BRACE

STEP 1: CREATE TEMPLATE

2D computer aided design and drafting software was used to draft the Anti-Compression Brace template. The length and hole locations were determined using the measurements of the body taken prior; the pivot point is located directly over the contra-lateral femoral head. The width of the Anti-Compression Brace was determined by adjusting the scale of the component to the width of the leg. The width/structural integrity of the Anti-Compression Brace was then verified using structural equations.



138

STEP 2: MOCKUP COMPONENT

Using spray adhesive, a 1:1 paper printout of the Anti-Compression Brace was adhered to cardstock. The shape was cut out and the holes were drilled using an electric screw driver.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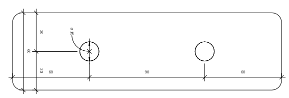
THIGH PLATE

STEP 1: CREATE TEMPLATE

2D computer aided design and drafting software was used to draft the Thigh Plate template. The length and hole locations were determined using the measurements of the body taken prior. The width of the Thigh Plate matches the Anti-Compression Brace.


140

STEP 2: MOCKUP COMPONENT

Using spray adhesive, a 1:1 paper printout of the Thigh Plate was adhered to cardstock. The shape was cut out and the holes were drilled using an electric screw driver.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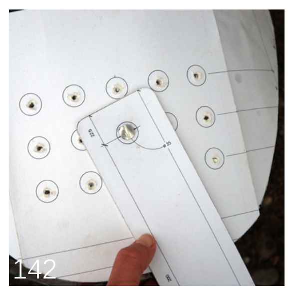
STEP 3: POSITION THIGH PLATE ON LEG CUFF

The Thigh Plate was positioned into place on the Leg Cuff, and the holes were transferred from the Thigh Plate onto the Leg Cuff. The holes were then drilled using an electric screw driver.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ASSEMBLY OF MOCKUP

STEP 1: ASSEMBLE

3 Chicago Screws were used to assemble the 4 components. 1 screw was inserted over the contra-lateral femoral head and 2 into the Thigh Plate. Note that an internal hemipelvectomy patient's typical pivot location of the contra-lateral femoral head may have changed. The prosthesis accounts for this by offering 14 other pivot point locations with a corresponding Thigh Plate adjustment.


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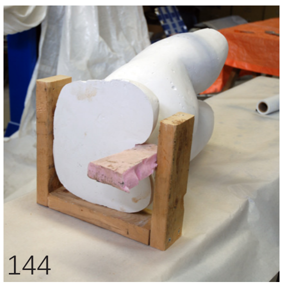
STEP 2: TEST

I fastened the mockup to my body to test its comfort, snugness, ergonomics, adjustability, basic structure, and fluidity of movement. I took note of any adjustments needed for the following prototype.

FIBREGLASS



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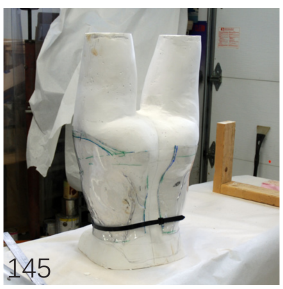
TORSO CUFF - PREPARATION

STEP 1: BUILD A JIG

Since the Torso Cuff was to be made in two separate halves – divided at the sagittal plane – I decided to work the fibreglass with the plaster cast on its side so that the resin would be least negatively affected by gravity. This required a jig to hold it in place. The jig was made with three small pieces of scrap dimensional lumber and a piece of rigid foam insulation used as a wedge.



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STEP 2: TRACE MOCKUP TORSO CUFF

The previously made plastic mockup Torso Cuff was properly positioned onto the plaster cast and outlined directly onto the plaster with a black permanent marker.

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STEP 3: PREPARE THE CAST

The torso of the plaster body cast was carefully wrapped with electrical tape. This was done to ensure that a non-permeable layer separated the unsealed cast from the fibreglass. Where the cast indented, it was important to pre-stretch the tape and then gently adhere it to the cast in order to prevent the tape from lifting.

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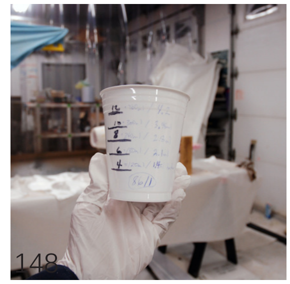
STEP 4: TRACE MOCKUP TORSO CUFF

The plastic Torso Cuff was again properly positioned onto the tape covered plaster cast. Using a silver permanent marker, the shape of the cuff was traced onto the electrical tape.

STEP 5: CREATE MEASURING CUP

The quantity of resin to hardener was determined prior to application and marked on a plastic cup.



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<u>**TORSO CUFF – RIGHT SIDE**</u>

STEP 6: CREATE TEMPLATE

Using trace paper, a basic template of the right side of the torso (drawn to the sagittal plane) was made by smoothing the paper onto the body and tracing the previously made silver lines.

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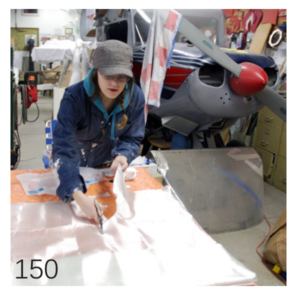
STEP 7: CUT FIBREGLASS CLOTH

Following this, the template was traced onto fibreglass cloth and cut out with pinking shears. 2.5cm [1in] extra was included around the perimeter of the template. The fiberglass piece was then dry fitted onto the plaster cast; any needed adjustments were noted. Next, the piece was removed, smoothed out, and then used to cut 3 additional fiberglass pieces, keeping the needed adjustments in mind. In addition, a 13cm [5in] x 18cm [7in] rectangle was cut to reinforce the Hip Plate perforations.



150

STEP 8: CUT REINFORCEMENT FIBREGLASS CLOTH

2 - 7.5cm [3in] wide strips of reinforcement fibreglass were cut to line the seams.

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STEP 9: DRY FIT & FORM CLOTH

The 4 cut fiberglass pieces were numbered and formed onto the plaster cast, one atop of the other. Each piece, as well as the plaster cast, was marked with a line at the top and bottom of the torso area, indicating where each piece should be placed. Each piece was removed – being careful to retain their form – and then set near the plaster cast.

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STEP 10: FIBREGLASS APPLICATION

Immediately after mixing the fibreglass resin with the hardener, a thin coat of resin was applied to the tape covered plaster cast. The first fibreglass piece was gently padded into place – working down from the indicator lines/centre of the cloth. Using a wide paint brush, the fibreglass was then saturated by pressing (not brushing!) the cloth with resin, working from top/centre, downwards/outwards. This process was done in order to avoid air bubbles getting trapped in the saturated cloth, which causes weak spots.

Immediately following, the next fibreglass piece was positioned into place, padded down, and saturated with resin.

Next, 2 fibreglass reinforcement strips and the hip plate reinforcement piece were pre-saturated in an aluminum tray by using the same paint brush technique. The 3 pieces were positioned into place and quickly patted down with the brush one at a time.

Afterwards, the remaining 2 fibreglass layers were positioned into place, padded down, and saturated with resin one at a time.

STEP 11: LET DRY

Let dry for 24 hours.

STEP 12: TRIM SEAM EDGE

Using a thin scrap piece of aluminum cut with a shear, a straight line was drawn 1.5cm [0.5in] from the sagittal plane on both the front and back of the Torso Cuff – closest to the rough edge. Using a Dremel with a ceramic cutting wheel attached, the rough edge was cut off. The tape was not cut during this process; any nicks were re-taped.

TORSO CUFF – LEFT SIDE

STEP 13: CREATE A TEMPLATE

The previously used trace paper template made during Step 6 was horizontally flipped and adjusted to create the left Torso Cuff template. By positioning the template on the plaster cast body, a transversal line was sketched across the hips so that the right leg area (where the Torso Cuff scoops down to house the Hip Plate) could be trimmed off.

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STEP 14: CREATE A JOGGLE

A transition between the vertical edges of the right Torso Cuff and the plaster cast was created with strips of electrical tape. Starting from the edge, 5cm [2in] of the right Torso Cuff half was covered with tape, for both the front and back seams. The right Torso Cuff half was then covered with wax paper and taped in place. This was done to create a joggle in the Torso Cuff when the left Torso Cuff half was constructed. The joggle was built into the Torso Cuff for adjustability and comfort purposes.

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STEP 15: CUT FIBREGLASS CLOTH

Step 7 from Torso Cuff - Right Side was repeated.

STEP 16: CUT REINFORCEMENT CLOTH

2 - 7.5cm [3in] wide strips of reinforcement fibreglass were cut to line the seams.

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STEP 17: FIBREGLASS FORMING & APPLICATION

Steps 9, 10 and 11 from Torso Cuff - Right Side were repeated.

STEP 18: REMOVE TORSO CUFF

Both halves of the Torso Cuff were removed from the plaster cast. After the electrical tape was removed, the inside of the fibreglass was still tacky, so the Torso Cuff was given 24 hours to dry.

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STEP 20: TRIM SEAM EDGE

Using the straight piece of aluminum scrap, a straight line was drawn 5cm [2in] from the sagittal plane on both the front and back of the left Torso Cuff – closest to the rough edge. Using a Dremel with a ceramic cutting wheel attached, the rough edge was cut off.

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TORSO CUFF - FINISHING

STEP 21: TRIM ALL REMAINING EDGES

Placing both halves of the Torso Cuff back onto the plaster cast, the lines drawn during Step 2 were traced (you can see through the fibreglass) onto the face of the fibreglass Torso Cuff. The Dremel was again used to trim the excess fibreglass.

STEP 22: SAND EDGES

A palm sander was used to smooth all edges of the Torso Cuff.

STEP 23: LOCATE PIVOT POINT

The pivot point location of the prosthesis was transferred from the plastic Torso Cuff onto the fibreglass Torso Cuff with a permanent marker.

Notes:

2 layers of plastic gloves were worn while working with the fibreglass and resin. This was done so that if the top gloves were to get sticky with resin, they could quickly be disposed of and a new top layer could be worn without getting any resin on the skin.

Each Torso Cuff half received 2 to 2.5 small batches of mixed resin at a time; using a new paintbrush every time. It was very important to move quickly before each batch of resin started to cure.

THIGH CUFF

STEP 1: PREPARE THE CAST

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While the plaster body cast was on its left side in the jig, the right leg of the cast was carefully wrapped with electrical tape. This was done to ensure that a non-permeable layer separated the unsealed cast from the fibreglass.

STEP 2: DRAW TORSO CUFF OUTLINE

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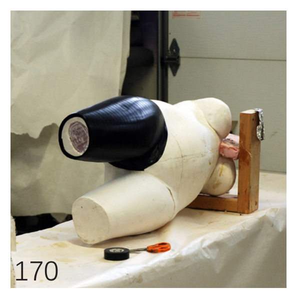
Using a silver permanent marker, I roughed in the shape of the Thigh Cuff onto the electrical tape. I wanted to determine the final shape of the Torso Cuff after I had dry fitted it on my own body, so the outline was drawn larger than necessary.

STEP 3: CREATE TEMPLATE

Using trace paper, a basic template of the Torso Cuff was made by smoothing the paper onto the plaster body cast and tracing the previously made silver lines.

STEP 4: CUT FIBRGLASS CLOTH



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Afterwards, the template was traced onto fibreglass cloth and cut out with pinking shears. 2.5cm [1in] extra was included around the perimeter of the template. The fiberglass piece was dry fitted onto the plaster cast; any needed adjustments were noted. The piece was then removed, smoothed out, and used to cut 3 additional fiberglass pieces, keeping the needed adjustments in mind.

STEP 5: CUT REINFORCEMENT FIBREGLASS CLOTH

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1 - 7.5cm [3in] wide strip of reinforcement fibreglass was cut to be positioned under the Thigh Plate.

STEP 5: DRY FIT & FORM CLOTH

The cut fiberglass pieces were numbered and formed onto the plaster cast, one atop of the other. Each piece, as well as the


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plaster cast, was marked with a line at the top and bottom of the thigh area, indicating where each piece should be placed. Each piece was removed – being careful to retain their form – and then set near the plaster cast.

STEP 6: FIBREGLASS APPLICATION


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Immediately after mixing the fibreglass resin with the hardener, a thin coat of resin was applied to the tape covered plaster thigh. The first fibreglass piece was gently padded into place – working down from the indicator lines/starting edge of the cloth and around the leg. Using a wide paint brush, the fibreglass was then saturated by pressing (not brushing!) the cloth with resin. This process was done in order to avoid air bubbles getting trapped in the saturated cloth, which causes weak spots.


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Immediately following, the next fibreglass piece was positioned into place, padded down, and saturated with resin.

Next, the fibreglass reinforcement strip was pre-saturated in an aluminum tray by using the same paint brush technique. The piece was positioned into place and quickly patted down with the brush.


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Afterwards, the remaining 2 fibreglass layers were positioned into place, padded down, and saturated with resin one at a time.

STEP 7: LET DRY

Let dry for 24 hours.

STEP 8: TRIM SEAM EDGE


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Using a thin scrap piece of aluminum cut with a shear, a straight line was drawn vertically down the centre of the thigh. Using a Dremel with a ceramic cutting wheel attached, a slit was cut into the Torso Cuff.

STEP 9: REMOVE TORSO CUFF

The Thigh Cuff was removed from the plaster cast and the tape was also removed and disposed of.

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STEP 10: LET DRY

After the electrical tape was removed, the inside of the fibreglass was still tacky. The Thigh Cuff was given 24 hours to dry.

STEP 11: TRIM THIGH CUFF

While wearing the Torso Cuff, I carefully positioned the Thigh Cuff onto my right leg. With the assistance of a mirror, I sketched the finished form of the Thigh Cuff onto the fibreglass. After removing the prototype components, the Dremel was again used to trim the access fibreglass.

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STEP 12: SAND EDGES

A palm sander was used to smooth all edges of the Thigh Cuff.

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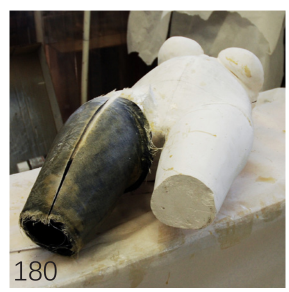
ALUMINUM

HIP PLATE

STEP 1: ADHERE TEMPLATE

A 1:1 paper template of the Hip Plate was adhered to 1/16in sheet aluminum.



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STEP 2: ALUMINUM FABRICATION

Using a band saw, the shape was cut from the metal. The edges were smoothed using a file. The holes were drilled using a drill press. The metal was finished with a radial palm sander.

STEP 3: CURVATURE

The aluminum Hip Plate was originally fitted to the fibreglass Torso Cuff using a metal rolling machine. However, the surface contact between the two materials was minimal. Afterwards, the Hip Plate

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and Torso Cuff were secured onto the plaster body cast and hit with a wood mallet until the metal conformed to the curvatures beneath.


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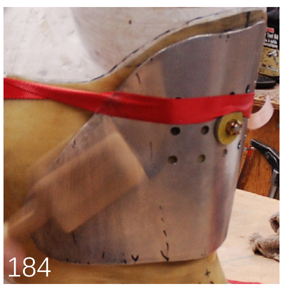
ANTI-COMPRESSION BRACE

STEP 1: ADHERE TEMPLATE

Using the template from Anti-Compression Brace, Templates + Testing, Step 1, a 1:1 paper template was adhered to 1/2in thick x 2 1/2in wide aluminum bar.

STEP 2: ALUMINUM FABRICATION

Using a band saw, the desired length was of the aluminum was cut. Later, a milling machine was used to drill the holes, round the corners, and reduce the width of the aluminum to 60cm [2.375in].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STEP 3: CURVATURE

A hydraulic pipe bender was used to adjust the plane of the anti-compression brace to conform to the curvature of the body. (Typically such a tool would not be used to bend a flat piece of metal, but it was all that was available and it worked.)


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THIGH PLATE

STEP 1: ADHERE TEMPLATE

Using the template from Thigh Plate, Templates + Testing, Step 1, a 1:1 paper template was adhered to 1/2in thick x 2 1/2in wide aluminum bar.


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STEP 2: METAL FABRICATION

Using a band saw, the desired length was of the aluminum was cut. Later, a milling machine was used to drill the holes, round the corners, and reduce the width of the aluminum to 60cm [2.375in].

ASSEMBLY

HIP PLATE @ TORSO CUFF

STEP 1: PRE-DRILL HIP PLATE + TORSO CUFF

With both the fibreglass Torso Cuff and Hip Plate correctly positioned on the plaster body cast, the areas of contact between the two surfaces were identified, marked and drilled. Clecos were used to hold the components in place while drilling.

STEP 2: RIVET COMPONENTS TOGETHER

Following this, the Clecos, Hip Plate and Torso Cuff were removed from the plaster body cast. Then, a few Clecos were reinserted into the two components in order to hold the pieces securely together. The rivets were inserted into the holes from the inside of the Torso Cuff while an aluminum washer was held on the exterior side. The components were then fastened together using a pop rivet gun.

Note: In future versions of this model, when advanced manufacturing tools are available, the Hip Plate would be fully adhered to the Torso Cuff.

FABRIC INNER LAYER FOR TORSO CUFF + THIGH CUFF

STEP 1: CUT FABRIC

The fleece – selected because it is woven, durable, and comfortable – was first laid flat on a table. Following this, each cuff was individually rolled onto the fabric, which created an indent on the fabrics surface. The shapes were then cut from the fabric.


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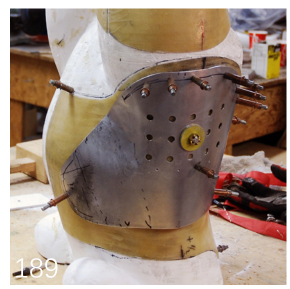
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STEP 2: DRYFIT THE FABRIC

Each piece of fabric was then dry fitted onto the interior wall of each component.

STEP 3: ADHERE FABRIC TO INTERIOR WALLS OF CUFFS

By gently folding the fitted fabric in half, the left exposed half of the fibreglass cuffs were sprayed with spray adhesive. The lifted halves was smoothed back down onto the fibreglass and adhered. This process was repeated for the other halves of fabric.


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STEP 4: TRIM EDGES

After an hour of dry time had passed, the edges of the fabric were trimmed down to approximately 2.5cm [1in] from the fibreglass edges.


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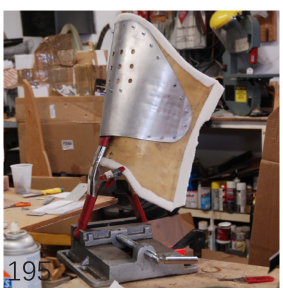
STEP 5: ADHERE FABRIC EDGES TO EXTERIOR WALLS OF CUFFS

Using a scrap piece of cardboard to protect the exterior surface from overspray, the 2.5cm [1in] edge was sprayed with the spray adhesive, then smoother over the edge of the fibreglass cuffs.

STEP 6: DRY

The cuffs were given an additional hour to dry.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<u>**ANTI-COMPRESSION BRACE @ THIGH CUFF**</u>

STEP 1: LOCATE CONNECTION POINTS

While wearing the Thigh Cuff and holding the Torso Cuff and attached Anti-Compression Brace onto my body, the location for the bolts in the Thigh Cuff were determined and marked.


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STEP 2: DRILL HOLES

The components were then removed and the holes were drilled into the Thigh Cuff. The bolts, nuts, and washers were inserted and the Anti-Compression was fastened to the Thigh Cuff.


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<u>**CUFF FASTENERS**</u>

STEP 1: LOCATE POSITION OF FASTENERS

While tightly holding the assembled prosthetic to my body, the position of the fasteners – which were influenced by the contours of the fibreglass – were located. Two fasteners were located at each seam.


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STEP 2: ADHERE FASTENERS

Velcro with a peel-and-stick backing was used as the fastener for this prototype. Once cut to the correct size, each piece was adhered to the fibreglass cuffs.


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COMPLETED PROTOTYPE

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CONCLUSION

CONCLUSION

The architectural considerations derived from *Pros+Tithenai* are endless. The obvious Phase 2 of the Exoskeletal Pelvic Replacement is to further develop the prosthetic under the advisement of additional specialized individuals and commence human testing. However, Phase 2 could additionally take on other forms. Prosthetics, either symbolically or theoretically, have been a prevalent fascination in the architectural discipline since its origin. Architecture should always – in some way or another – be a prosthetic for the human body. If a built space does not increase the spatial experience of a given place, then the only purpose it serves is to make buildings that do appear even better.

While the Exoskeletal Pelvic Replacement takes a large step sideways from architecture into the biomechanical disciplines, it also takes a bigger step forward into proving the potential – and possibly commonly unforeseen – benefits of interdisciplinary collaborations. Thus, I would like to conclude *Pros+Tithenai* by reflecting on both the Exoskeletal Pelvic Replacement and benefits to interdisciplinary collaborations.

This essay contains:

- INTERDISCIPLINARY COLLABORATIONS
- TESTING LIMITATIONS
- PROTOTYPE CONSTRUCTION
- CHANGES MADE TO PROTOTYPE DURING CONSTRUCTION
- NECESSARY DESIGN CHANGES
- PERFORMANCE CRITERIA + OBSERVATIONS
- FUTURE FABRICATION OF EXOSKELETAL PELVIC REPLACEMENT
- FINAL DESIGN
- REMAINS TO BE SEEN
- CONCLUSION

INTERDISCIPLINARY COLLABORATIONS

As a student of architecture, realistically, I am training to become a proficient consultant.

The completion of a building depends on the collaboration of several trades and disciplines. For the Exoskeletal Pelvic Replacement, this reliance on other disciplines was not only made evident during the design and construction of the prototype, but it was also made clear when researching precedents such as Bespoke Innovations. I never expected to physically realize something that only lingered in the periphery of architectural theory – or was already "claimed" by another discipline – entirely by myself.

It is unfortunate that many skilled individuals detest the idea – for whatever reason – of collaborative projects that displace an individual's singular professional title. The purpose of any team member isn't to know, do, or be in control of everything. For example, being the leader of *Pros+Tithenai*, I initially found it difficult to locate the femoral head – which is the very thing that the prosthetic intervenes. Fortunately however, another team member with experience in the field of biology was able to teach me how. Similarly, I was able to share architectural ideas, strategies and approaches to prosthetics that others from different disciplines were unfamiliar with.

Each discipline, understandably, develops a unique way of thinking; a unique way to approach our own bodies, environments and projects. While I admit that the pace while constructing the Exoskeletal Pelvic Replacement was much slower than I had originally anticipated – having trade experience myself – these expanses of time were filled with invaluable informative discussions where differing views, approaches and insights were shared. By creating an open, communicative interdisciplinary team, I am certain that the increase in knowledge and insight amongst collaborators, and potential spectators and/or beneficiaries, will forever be invaluable to how one views any future projects.

Throughout the various stages of design and development of the Exoskeletal Pelvic Replacement, contributing individuals specialized in at least one of the following disciplines: architecture, aircraft fabrication, electromechanical engineering, plastic injection moulding, biomechanical engineering, metalworking, woodworking, and physiotherapy. During the construction of the Exoskeletal Pelvic Replacement prototype, the following disciplines were sought after: specialized metal fabricator capable of using an English wheel and 3D metal CNC [computer numerical control] technologist. In future developments of the prosthetic, the following additional disciplines would be recruited: kinesiology and orthotics.

TESTING LIMITATIONS

The Exoskeletal Pelvic Replacement was never fully tested. This was due to the University of Waterloo's understandably strict standards on how projects such as this must be approached, and unfortunately meeting their requirements for human testing at this stage was impossible. I can only speculate on how the prosthetic will function on a desiring [half of pelvis removed] human body.

PROTOTYPE CONSTRUCTION

I was concerned initially about the outcome of every future mockup and prototype to be built because of the deformations that occurred while the plaster body cast cured. While I tried my best to reshape the plaster form, I was fully aware that reshaping an already formed 50lb block of plaster into an identical replica of my own body was impractical. However, this initial "error" guaranteed a tolerance allowance, meaning that adjustability would always be incorporated into the design. In fact, after having trimmed up the fibreglass Torso Cuff, I noted that it would have been better if I kept even a few more extra pounds on the mannequin.

One specialty that would have been a great contribution to the construction of the Exoskeletal Pelvic Replacement would have been a metal fabricator capable of using an English wheel, shot bag, and hammer. The Hip Plate not surprisingly proved very difficult to form to the fibreglass bodice. After several attempts to conform the metal using rollers, it was finally discovered that securing the Hip Plate and Torso Cuff onto the plaster cast and hitting the metal with a wood mallet proved most successful. Also not surprisingly, the metal Hip Plate is my favourite component of the prosthetic.

In addition, the curvature of the leg needed to be reduced from the interior side of the Thigh Plate. This was necessary in order to increase the comfort and frictional surface area of the assembled Thigh Cuff on the leg. Unfortunately a metal CNC capable of performing this task was inaccessible during the construction of the prototype.

CHANGES MADE TO PROTOTYPE DURING CONSTRUCTION

As typically occurs during any project, certain design details needed to be reconsidered on site in order to complete construction. Such details included the Thigh Plate, Hip Plate rivet fastening, shape of the Thigh Cuff, and shear resistant pins.

The Thigh Plate was excluded from the Exoskeletal Pelvic Replacement prototype. The reason being is that the Thigh Plate needed to be glassed into the Thigh Cuff, with bolts already inserted, in order to sit in the right plane surrounding the leg. While this could have easily been completed, the problem was that the Anti-Compression Brace perforations had already been milled, and I wanted the opportunity to adjust the Thigh Cuffs position prior to making any permanent connections.

As previously mentioned, conforming the Hip Plate to the body proved to be very difficult. Fortunately, however, the bottom edge, “wings,” and perforations did conform to the fibreglass Torso Cuff. Therefore, the locations of the rivets were adjusted accordingly. If I had of followed the previously made Hip Plate rivet template, some of the rivets would have served no structural purpose.

The Thigh Cuffs profile was adjusted to conform to the shape of my leg. After trimming the fibreglass Thigh Cuff as was drawn, I temporarily fastened it to my leg and proceeded to walk, sit, etc. During this time I found that the cuff would pinch the back of my leg, just above the knee. In response, I kept trimming a slight curve in the back of the cuff, testing its comfort each time in between, until I found the Thigh Cuff to be ergonomic.

The shear resistance pins were not included in the prototype. However, they are a necessary component to a structural Exoskeletal Pelvic Replacement so that the cuffs may be properly aligned prior to fastening, and the shear forces at the seams can be controlled.

NECESSARY DESIGN CHANGES

The adjustability of the Anti-Compression Brace was overlooked during the design process, and was not realized until after fabrication. The Anti-Compression Brace needs to be curved in order to conform to an individual's body, but the current design of the brace does not allow for vertical adjustment. This can be addressed in two ways. The Anti-Compression Brace could contain 3 pivot point holes – in contrast to the current singular hole – that line up with each row of the Hip Plate's perforations. This would keep the ergonomic curve of the Anti-Compression Brace in the correct location. For a more individualized prosthesis, all other Exoskeletal Pelvic Replacement components could be fabricated and fitted to the wearer's body, and afterwards the Anti-Compression Brace would be fabricated accordingly. All additional Hip Plate and Anti-Compression Brace perforations could be eliminated if this avenue were explored.

PERFORMACE CRITERIA + OBSERVATIONS

To reiterate, the primary function of the Exoskeletal Pelvic Replacement is to transfer forces to/from the skeleton through the prosthetic in lieu of the amputated pelvic area. While I could not test if the prosthetic successfully was able to adjust the load transmissions for the reasons previously mentioned, I tested other aspects of the design on myself. I tested the comfort, snugness, ergonomics, adjustability, basic structure, and fluidity of movement on my fully mobile and structural body. I first tested each cuff separately and then the entire assembled device.

The acrylic plastic torso cuff mockup was very brittle. I quickly decided that a better model would be needed to test anything worth noting. However, it did prove valuable while determining the trim lines on the fibreglass Torso Cuff.

The fibreglass Torso Cuff was much more successful than the plastic version. The 4 ply fibreglass with localized reinforcement layer performed very well. The Torso Cuff was both rigid and flexible which allowed it to conform to the body as needed when adjusted/fastened to the body with Velcro. Although I found the Torso Cuff to be very comfortable, if I were using it as a structural device I may think differently. With that in mind, I speculate that the thick fabric lining would address any additional conformance concerns within reason. All other comfort issues would have to be addressed by a kinesiologist and orthotist.

The fibreglass Thigh Cuff was also very rigid. In retrospect, I should have formed a joggle in it as well to make fastening it onto the thigh easier.

As originally predicted, the Thigh Cuff was unable to reach a state of certain structural stability; it was incapable of transferring forces to/from the leg without probable failure. I came to this conclusion by completing several tests on the Thigh Cuff. Due to the natural conical shape of the leg, and therefore Thigh Cuff, the cuff could be pulled down the leg with relative ease. Fastening the Thigh Cuff any tighter would only cause potential blood circulation issues. While wearing the complete assemblage made it impossible for the Thigh Cuff to be pulled downward, on an unattached skeletal leg, it would be possible for the femur to slip up into the body when a force is applied. This causes for serious medical concerns. In order to address this, two other designs were proposed: one that includes a Calve Cuff to lock the Thigh Cuff in position, and another that bypasses the entire leg by transferring forces to/from the floor.

Since this failure was predicted, it should be noted that the reason the Exoskeletal Pelvic Replacement was limited to the Thigh Cuff – instead of including a Calf Cuff and/or transferring the forces directly to the ground initially – was to test the device in its most minimal form first. The less that the body could be intervened, the better. If the Exoskeletal Pelvic Replacement did transfer forces directly to the floor, I speculate that the wearer would need to complete daily exercises in order to ensure that the health of the affected leg is maintained. Retaining muscle mass would also prevent the prosthesis from having to be refitted frequently.

FUTURE FABRICATION OF EXOSKELETAL PELVIC REPLACEMENT DEVICES

Marketed Exoskeletal Pelvic Replacement prosthetics would likely follow the same basic construction process but with greater accuracy and results due to the use of more advanced machines. Two construction methods come to mind. The first method requires either a physical or electronic profile of the body. Then, a stamping die could be made with a 3D CNC machine and the rest could be made accordingly. The other method would require an electronic 3D profile of the body, and then the prosthetic could be fabricated using 3D printing technologies. Both methods would prove to be very costly.

FINAL DESIGN

The final design would not be as adjustable; instead, it would be constructed specifically for its user. While minimal adjustability would be incorporated into the design to account for the dynamism of a user's body, the prosthetic would not be capable of adjusting to any given body; that is, the pivot point would be located prior to fabricating the prosthetic so all unused perforations shown in the current prototype could be eliminated. Doing so would increase the potential for the user to accept the prosthetic as part of their identity.

REMAINS TO BE SEEN

While the following concerns were considered during the design and construction process, only advanced future studies will be capable of testing the following potential concerns: the impact of transferring forces through soft tissues, effects on muscle mass (gain and loss), body dynamism (weight gain and loss) and adjustability, performance on different body types, eccentric loads, etcetera. These factors, and any others that could arise, would have varying degrees of influence on the final design of the Exoskeletal Pelvic Replacement.

CONCLUSION

The architectural significance of *Pros+Tithenai* was much greater than I had originally anticipated. Architecture is the design of space; it is not limited to the design of buildings. Every avenue of *Pros+Tithenai*, whether it was research, design, or construction, lead me to consider how the body perceives space, but also how space perceives the body; how both can transform and shape (into) one another. The human body is capable of becoming enmeshed within a fluid network belonging to its surrounding environment. Whether this be achieved through cybernetic environments, or perfectly proportioned historic buildings, such a spatial dialogue is vital to the success of any great architecture.

While it is difficult to express the perceived value in which I have discovered by completing *Pros+Tithenai* for any of my future architectural explorations, I can now say that I completely understand why it is that prosthetics – no matter how abstract – continue to reappear in architectural discourse. In the same way I discovered that technology has advanced without anthropological considerations, I am also left to admit that architecture has done the same. Fortunately however, given the emerging disciplines of interactive environments and responsive architecture that readily accept the technologically advanced, desiring human, prosthetic architecture will become increasingly prevalent in future environments. Incorporating mutual interaction between architecture and its occupants will become vital to the profession.

“Our great failure to be well-adapted to any particular environment, which forced us to survive by building the objects we require to stay alive, turns out to be our great strength. We have expanded allover the globe precisely because we are ***not*** *adapted to survive in any particular environment – at least, not survive on unaided. But aided by the things we can make, from spears to guns, from fur hats to jet skis, from skyscrapers to satellites, we can succeed everywhere and anywhere. All we have to do is set our minds to it, and build the supports that our fragile bodies need”*

- Timothy Taylor, *The Artificial Ape,* p. 186, 2010.

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