Ultrasonography of the multifidus muscle in student circus artists with and without low back pain

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ABSTRACT

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Bianca Rossini

Low back pain (LBP) is a major global health issue. Athletes and performing artists also suffer from LBP. Student circus artists' daily training put constant stress on their spine and back. Proper back muscle function is critical for spinal stiffness and movement. Substantial research revealed structural and functional deficits of the lumbar multifidus muscle (LM) in patients with LBP. However, circus research remains scarce, and no data is available on the LM and LBP in this population. The purpose of this study was to explore the prevalence of LBP in student circus artists, investigate lumbar multifidus morphology and function in student circus artists with and without LBP and explore the relationship between LM asymmetry and LBP.

A total of 33 participants completed an online survey to acquire demographics, training history, brief injury history and LBP history. Thirty participants had body composition measurements and an ultrasound assessment of the LM at the 5th lumbar vertebrae. All examinations were performed at the participants' respective circus school. Our primary measures included the assessment of LM morphology and function using ultrasound (manuscript 1). Our secondary measures included pain, training activity, catastrophizing, medical history in the past year and LBP-related disability assessed via a survey and questionnaires (manuscript 1 and 2).

This study explored the burden of LBP in student circus artists. Assessing LM characteristics using ultrasound may be a useful tool to identify artists' injury risk and monitor changes following rehabilitation programs or throughout the school year leading to a more sustainable practice.

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LBP – Low Back Pain
LM – Lumbar Multifidus
CSA – Cross Sectional Area
BMI – Body Mass Index
EI – Echo-Intensity
EMG – Electromyography
ODI – Oswestry Disability Index
ADI – Athlete Disability Index
PCS – Pain Catastrophizing Scale
NPRS – Numerical Pain Rating Scale
DEXA – Dual Energy X-ray Absorptiometry
MF-BIA – Multi-Frequency Bio-Impedance Analysis
MRI – Magnetic Resonance Imaging
MFS – Micheli Functional Scale

CHAPTER 1: THEORETICAL CONTEXT

1.1 CIRCUS ARTISTS

Circus artists perform extreme acrobatic feats requiring high levels of artistic and athletic abilities. In the past years, the shift from traditional to modern contemporary circus has highlighted the need to develop elite circus artists ready to perform on global stages. Globally, over 650 and counting circus arts training centers are helping to fill the demand of new elite circus artists.[2–51] These professionals and student circus artists self-identify as artists.[2]

Professional artists work as independent contractors and are responsible for maintaining fit and healthy bodies. Most professional circus artists have atypical schedules, and many relocate frequently during touring. Follow-up treatments and consultations are often difficult and pose a new set of challenges for the artists needing medical attention, most artists on tour do not have direct access to conditioning teams of medical professionals.[3] Finding efficient and quick ways to identify and treat injuries and pain is essential to further the longevity of the artists' careers.

1.1.1 Student Circus Artists

In the context of this research, student circus artists will refer to students training in pre-professional programs at a circus institution. The National Circus School in Montreal and the Quebec Circus Arts School in Quebec City offer a similar 3-year collegial professional development program. The program aims to develop high-level circus artists ready to perform stages worldwide. Students may be accepted into a preparatory year to bring their acrobatic and artistic skill up to par before entering the collegial professional program. Each school year consists of two semesters separated by a 3-week winter break over Christmas.[4] During the school year, student circus artists perform high levels of repetitions with high impact loads on the spine during the 25+ hours of physical and artistic training per week.[1,5–7] Another feature of circus schools is that the male to female ratio is usually roughly 2:1.[4]

1.1.2 Circus Disciplines

Student circus artists are classified as specialists or generalists. A specialist will focus on mastering a single main discipline, while a generalist will train 2-3 disciplines in different discipline families. Circus disciplines are categorized into 5 main families: aerial acrobatics, floor acrobatics, equilibrium, manipulation, and clowning skills. Each family covers a wide range of subdisciplines. Impact loads on the spine will vary depending on the artist's specific discipline.[8] Disciplines may be performed by a single artist (solo), two artists (duo), or multiple artists (group). Artists may be classified as a carrier or a flyer depending on their role in duo or group performance. Carriers are a base for the flyer and launch the flyer into the air to execute acrobatic or balancing skills. Individual circus disciplines are listed in the Appendix A.

Aerial acrobatics involve hanging an apparatus in the air from a single point or multiple points. There are 9 main aerial disciplines taught at the circus schools in Quebec. This includes aerial hoop, straps, silks, swinging trapeze, and Russian cradle. Each have a specific movement vocabulary and involve various biomechanical movements and spinal loads.

Floor acrobatics can involve an apparatus such as the Chinese hoops, Russian bar, and Korean board. Other disciplines (i.e., hand to hand and contortion) require no apparatus.

An *equilibrium* artist may balance on the ground, on a stand or on an object. A variety of equilibrium disciplines exist such as tight wire, slack wire, hand balancing, Cyr wheel and bicycle.

Manipulation is juggling multiple of one or a variety of objects.

1.1.3 Body composition in circus artists

Circus artists' body composition goals are to improve function, performance and aesthetics.[4] Body composition was observed to vary slightly over the academic year as the subjective workload changes throughout the year at the National Circus School in Montreal.[4] Muscle and fat mass had a positive adaptation at the end of the school year despite negative changes following the students return from the 3 weeks winter break.[4] Overall, female students were found to have 7.0% higher fat mass than males.[4] Decker et al. attributed this fat mass difference to genetic and hormonal sex-based differences.[4] Male students in clown and manipulation disciplines had higher percent fat mass while female students in aerial arts had higher percent muscle mass and lower percent fat mass among all disciplines.[4] Despite Quebec circus schools' diverse approach to training, Decker et al. observed discipline-specific body composition differences when adjusting for height and body mass.[4]

1.1.4 Circus Injuries

In the scarce research currently available on circus, the ankle and spine were reported as the most injured anatomical locations and prime targets for prevention interventions in artists. Furthermore, the lumbar spine was found to be the most affected spine section in student circus artists.[1,9–11] Lumbar spine injuries represented 14% of all medical attention injuries at an Australian circus school, and spine injuries required the most initial and follow-up treatment.[1] Wanke et al. studied the overall injury rate of student circus artists in Germany. Wanke et al. reported a relatively low rate of 0.3 injuries per 1000 training hours when defining injury as work injury reported or a time-limited injury affecting the body during work, on the way to work or at home.[12] Stubbe et al. reported an injury rate of 3.3 injuries per 1000 training hours in the Netherlands.[11] Using the medical attention injury definition, the total injury rate in professional circus artists have been found to be 8.82–9.74/1,000 performances or shows.[13] The overall injury rate is lower than other comparable sports such as gymnastics.[9] Overuse and chronic injuries are more of interest in circus rather than acute injuries.

At the National Circus School in Montreal, the injury rate was reported to increase following extended breaks such as summer and winter breaks.[14] Students are more at risk of injuries returning from vacation. This particular finding in circus was reported to differ from the cumulative fatigue theory used in sports.[14] More generally, incidence of pathology seemingly increases after the age of 23 regardless of workload quantity in circus.[15] To date, there are no studies on screening and identification of chronic and overuse injuries of the spine in circus artists.[1] As the spine is a common site of injury and circus arts put repetitive loads and high spinal loads, identifying low back pain (LBP) characteristics in circus artists will lead to a more sustainable practice and potentially lower the risk of spine injuries.

1.2 Low Back Pain

Low back pain (LBP) is a very common symptom and remains the leading cause of disability worldwide.[16] The 2017 Global Burden of Disease Project reported a point prevalence of LBP of 7.8% or 577 million people.[17] LBP causes large medical and financial burden.[17] Yet, the specific causes and sources of LBP remain elusive.[16] LBP is a complex condition with multiple contributors to pain and disability apart from the biomechanics such as psychological factors, social factors, biophysical factors, comorbidities, and pain-processing mechanisms.[16]

Although increase in physical activity has been suggested to be preventive factor, it may also be a possible risk factor.[18]

LBP is also very common in athletes.[19,20] Athletes put high stress levels on their musculoskeletal system. Point prevalence of LBP ranges from 18–65% in Olympics athletes.[18] Sports with high spinal loads such as gymnastics and figure skating have reported higher LBP prevalence, 41% and 53% respectively, than sports with lower spinal loads such as curling (17%) in German elite athletes.[21] The most investigated potential risk factors of LBP in elite athletes are spinal load, age, sex, anthropometrics, and previous history of back pain. Other contributors of LBP such as psychological factors are well recognized in this population.[18] Further research is needed to explore the optimal dose-effect relationship between sports and LBP. While the spine was reported as a common site of injury in circus artists, there is currently no data on LBP prevalence in circus.

1.2.1 Low Back Pain Definition

LBP is defined as pain localized between the 12th thoracic vertebra and the gluteal fold.[16] The pain may be coupled with pain in one or both legs.[16] The pain can be centered or focused on one side of the body. Specific LBP caused by pathologies such as fractures, nerve root compression and spondylolisthesis only represents 10% of LBP cases.[22] The remaining 90% of LBP cases are defined as non-specific LBP with no known nociceptive cause.[22] Non-specific LBP is classified by pain duration in weeks. Acute, sub-acute and chronic LBP is pain lasting less than 6 weeks, between 6-12 weeks and over 12 weeks, respectively.[23] Furthermore, recurrent episodes of LBP are common.

Psychosocial factors have been primary targets of interventions in some patients and reported to interact with muscle changes in acute and chronic LBP patients.[24] It is important to consider other non-biological factors in LBP assessment and treatment. Pain catastrophizing is one of the most important psychological factors relating to pain chronicity and disability.[25] Assessing patient's or artist's pain catastrophizing level may better help developing the proper treatment for each individual.

1.3 PARASPINAL MUSCLES

Current literature has focused on some muscles and their relations to the spine and LBP. The paraspinal muscles are back muscles running in parallel along each side of the spine. These muscles offer both segmental stability, as well as assisting with the trunk with larger movements.[26] The main lumbar paraspinal muscles include the lumbar multifidus (LM), erector spinae (i.e., composed of the iliocostalis and longissimus), the psoas and quadratus lumborum.

1.3.1 Local versus global muscles

Spinal stability recruits local and global muscles. Local muscles such as LM attach directly to the lumbar vertebrae on the spine to provide segmental stability and positional control.[23] Global muscles such as erector spinae connect from the pelvis to the ribs and mainly help larger trunk movements including torque movement and trunk stabilization. Co-activation of the abdominal muscles (i.e. transverse abdominis) with paraspinal muscles is necessary to control spinal movement.[27] If there is a delay in local muscles recruitment before larger global muscles, the literature suggests that this leads to compensation from larger global muscles creating abnormal forces resulting in pain.[27] Thus, motor control exercises focus on retraining and restoring deep local muscles activation and co-contraction (e.g. LM and transversus abdominis) prior to larger global muscles.

1.3.2 Lumbar multifidus

The LM is a local muscle and the most medial paraspinal muscle. It provides segmental stabilization and proprioception to the lumbar spine.[28] This large muscle is composed of 5 overlapping layers; each layer covers 2 to 5 spinal levels. The LM size increases from L2 to L5.[28] In an upright position, the muscle plays a role in compression load and dynamic stability at the lumbar level. Through biomechanical models, the LM superficial fibers are suggested to help posterior sagittal rotation or extension of the lumbar spine while the LM deeper fibers are responsible for generating compressive forces between vertebrae with minimal rotation.[26] The deep fibers of LM need to activate before moving a limb as movement requires a stable axis.[28] Observing the LM in a functional upright position may result in better implications for performance and injury prevention.[29] Factors associated to LM morphology include age, sex, body composition, ethnicity, lifestyle and levels of physical activity.[26]

1.3.3 Imaging paraspinal muscle function

The gold standard to assess muscle activation is electromyography (EMG) which measures electrical activity in the muscle. However, it is invasive. Real-time ultrasound imaging is a noninvasive tool to assess muscle activation determined by the muscle thickness change from a rested to a contracted state.[30] EMG and ultrasound thickness change measurements are highly correlated (Pearson's correlation coefficient; r=.79; P<.001) and widely used to assessed LM activation.[30] Ultrasound measures of LM thickness at rest (ICC = .88) and contracted during a contralateral arm lift (ICC = .92) have good to excellent reliability in young adults.[31] Overall, percent thickness change of LM has good reliability (ICC = .74).[32] The lower reliability in thickness change has been suggested to be due to error magnification when combining rest and contracted thickness measurements.[32] Thus, ultrasound thickness change measurements is a valid and reliable method to assess LM activation.[30–33]

There are many ways to get the muscle to voluntarily contract such as guided contralateral leg lift or contralateral arm lift. However, the transducer on the skin can be disturbed by lower body movement distorting images. Therefore, a contralateral upper limb movement is the preferred controlled motion for assessed LM thickness in a contracted state.[26] A prone position imaging will show the resting LM while a standing position, or functional weight-bearing position, will show an active LM in its stabilizing role.[34] As the muscle is already contracted when standing, the thickness change is expected to be smaller in a standing position compared to prone imaging where the muscle contracts from total rest in a young healthy sample.[35] Thus, imaging the muscle in different positions may prove useful to better understand muscle activity.

1.4 FACTORS ASSOCIATED WITH LM CHARACTERISTICS

1.4.1 Age

There is a natural decline in skeletal muscle mass and strength with age. A 15-year longitudinal study with males (mean age at baseline: 47) reported an association between greater age and decrease in LM CSA at L5-S1 and a trend for LM asymmetry to increase with age.[36] A cross-sectional study in the asymptomatic general population in their 20s to 60s reported an increase of fatty infiltration in LM with most significant changes in low lumbar levels L4-S1.[37]

No significant associations were found between paraspinal muscles changes (i.e.. size, composition, or asymmetry) with history of LBP.[36] LM CSA atrophy with age may result from disuse, denervation and decrease in number of muscle fibers indicating LM changes can be reversed through activity.[38] While age affects muscles, age may not play a significant factor in LM morphology and function in a group of young highly physically active circus artists.

1.4.2 Sex

There is conflicting evidence on whether sex is associated with LM characteristics.[39] In the general population, Crawford et al observed higher fat infiltration in the LM in females compared to males when controlling for Body Mass Index (BMI).[37] Likewise, larger CSA LM were found in male varsity athletes compared to female athletes.[29,40,41] However, there was no significant difference in LM CSA between male and female dancers (i.e.. ballet and ballroom) after controlling for body size.[42,43] Gildea et al. suggested this finding may be due to similar high demands on the spine in both sexes (i.e. lift, leg extension hold and prolonged trunk extension).[42] It remains unclear whether sex will be correlated with LM morphology and function in circus artists.

1.4.3 Physical Activity

Physical activity type and duration have long-term effects on muscle characteristics. Athletes' muscles tend to be larger than in the general population.[29,39,42] LM CSA at L5 was reported to be positively associated with weekly physical activity level regardless of LBP presence or absence.[33] LM CSA at L5 in soccer players was around 7.83-7.91 cm^2 in females and 9.84-10.03 cm^2 in males. [29] For comparison, Stokes et al. reported LM CSA approximations at L5 in the general population (females: 7 cm^2; males: 9 cm^2).[26]

Some sports and art forms are asymmetrical in essence. In professional ballet dancers, the right LM CSA was larger correlating with most dancers' dominant side. Gildea et al. attributed this finding to the lateral training bias in ballet that favors the right side in training and choreographies.[42] Asymmetry may be associated with the specific demands of the art or sport rather than LBP.[39] However, LM CSA asymmetry was not found to be significantly different in hockey players in prone and standing ultrasound imaging.[40] The relationship between LM CSA asymmetry and physical activity warrants further investigation.

1.4.4 Body composition

LM characteristics must be adjusted for variability in anthropometric measures and body composition for comparisons between individuals. While BMI is often used for these adjustments, BMI is a poor measure of body composition in athletes as lean mass and fat mass cannot be distinguished. Some studies in athletic populations found no correlations between BMI and LM CSA.[29,40,41] However, LM CSA and thickness change were correlated with athletes' height, weight, total bone mass, and total lean mass.[29,40,41] Thus, it is important to obtain complete body composition measures in athletic population to draw conclusions on LM role in LBP.

1.5 IMPLICATIONS OF PARASPINAL MUSCLE STRUCTURAL CHANGES

The functional impairments (i.e. decreased strength, endurance and proprioception) of lumbar muscles were found to play a role in the development of LBP.[39] There is evidence to support a causal relationship between a nociceptive cause and changes in paraspinal muscle characteristics.[24] Changes in paraspinal muscles are reported to differ between different classification of LBP (acute, subacute, chronic).[24] In particular, increased fatty infiltrations of LM may lead to lumbar dysfunction contributing to spinal passive stiffness and LBP.[26] However, the specific role of LM alterations in LBP is not fully understood.[39]

Stages and duration of LBP are suggested to relate to different LM structural and functional changes.[24] Decrease in LM CSA was observed at the onset of acute LBP.[24] Subacute and chronic LBP animal studies have reported the recovery of LM size after induced LBP episode; however, the LM still developed fibrosis, fat infiltration and slow-to-fast muscle fiber transition.[24] LM atrophy in chronic LBP patients was found to persist in long-term follow-up studies.[26] Such functional impairments may increase the risk of injuries.[44] Both the duration and recurrence of LBP in each individual must be considered to tailor a proper treatment plan for each individual. Developing proper tools to assess athletes and performers current stage of LBP and muscle characteristics are needed to help develop the most effective course of action.

1.6 LM MORPHOLOGY AND FUNCTION IN ARTISTS

Circus training requires high physical and artistic demands most comparable to elite gymnastics and other performing arts such as dance and ballet. All require trunk stability for high-intensity repetitive movements and specific skill set leading to muscle adaptations in these artists and athletes. A proper activation and function of the LM is needed to engage the sequential firing of muscles in the trunk generating force and rotational power of the spine.[27] LM size has been reported to be larger in athletes than non-athletes.[29,40,45] Despite muscle adaptations, smaller LM CSA, greater LM side-to-side asymmetry and smaller thickness change has been associated with LBP in some elite athletic populations.[29,40,41,45] However, other elite athletic populations such as weightlifting have not reported any associations between these LM changes and LBP.[46]

In athletes, elite gymnasts with sway-back posture were reported to have a smaller decrease in LM thickness from rest to contraction indicating LM dysfunction from L1 to L5 in a prone position.[34] Fortin et al. reported that smaller LM CSA was associated with LBP in varsity hockey players.[40] Hockey players' LM was imaged in a standing position which revealed the muscle behaving differently.[40] The players with LBP had a significantly greater asymmetry in standing as compared to athletes with no LBP.[40] The LM CSA was also increased from the prone to standing in line with previous study in young healthy individuals as the muscle contracts in an active standing position.[29,40] This result was suggested to be a maladaptive strategy related to motor control impairments contributing to pain.[29] Furthermore, Hides et al. reported an association between increased risk of lower limb injury and LM changes (smaller CSA, smaller % thickness change) in a longitudinal study of professional soccer players.[45] Further investigations are needed to confirm the athlete LM profile characteristics and associations. Most of the studies in athletes had small sample sizes (n~30) due to availability of elite athletes. Thus, establishing the proper LM profile in circus artists should investigate LM measures in prone and standing position to develop proper targeted treatment and prevention interventions.

In performing artists, there is conflicting evidence on the relationship between LM characteristics and LBP. Ballet dancers have high demands on trunk due to extreme range of motion and tolerance of high compressive forces similar to circus artists. Gildea et al. studied 4 trunk muscles (LM, lumbar erector spinae, psoas, and quadratus lumborum) using MRI in ballet dancers. The authors reported that a smaller LM size was associated with LBP and LBP combined with hip-region pain in classical ballet dancers.[42] However, it remains unclear if the difference in LM was due to atrophy in LBP dancers or hypertrophy of the muscle in non-LBP dancers.[42] Smyers Evanson et al. reported LM asymmetry in elite ballroom dancers where the left LM was larger in all dancers, but the degree of asymmetry was not related to LBP.[43] Each artistic population has a unique LBP profile and relation to LM morphology and function. Thus, identification and treatment interventions should reflect this unique profile.

Current exercise interventions report mixed evidence on ability to change paraspinal muscle morphology and its relation to LBP patient outcome.[47] The largest effects on trunk morphology and function were observed with machine resistance exercises or motor control exercises with non-machine based resistance exercises.[47] Targeting deep low back muscles was shown to improve motor control.[33] Preliminary evidence of interventions targeting LM activation in elite athletes have shown improvements on LM morphology.[48,49] Elite cricketeers with LBP were reported to have LM atrophy despite being highly active.[48] A 6-week trunk stabilization rehabilitation using ultrasound imaging feedback training on trunk muscle activation replaced high resistance exercises in elite cricketers with LBP during a 12-week training camp.[48] The intervention decreased players' pain, restored symmetry and significantly increased LM CSA at L5 (% increase from before to after the intervention on both sides of the body: 20.7-26.2%) more than in the non-LBP group (4.6-4.8%).[48] Furthermore, self-managed exercises for motor control training targeting LM were effective at maintaining size in elite soccer players with and without LBP.[49] However, to date, there are no exercise intervention studies that were conducted in performing sports such as gymnasts, dancers or circus artists. Artistic populations may also benefit from motor control training targeting the LM to improve sequential firing of muscles for trunk stability and decrease the risk of injury.

1.7 RATIONALE

LBP is highly prevalent in athletic and performing arts populations. Student circus artists' lumbar spine is the second most injured anatomical location. The presence and prevalence of LBP in circus arts warrants further attention as high-intensity and repetitive spinal loads may lead to LBP. In athletic and artistic populations, the literature suggests potential associations between LBP and LM morphology and functional deficits differing slightly between each sport and art form. There are some mixed results as seen in ballroom dancers where the LM asymmetry was associated to the art and not with LBP.[43] Current exercise interventions combining motor control interventions and resistance exercises report mixed evidence with regards to the effect of exercise on paraspinal muscle morphology and functional and its relation to LBP patient outcome.[47] Preliminary evidence is promising in elite athletes as incorporating exercises targeting LM activation has improved LM morphology.[48,49] Additional research is needed to elucidate which sports and performing arts is most affected by LBP and LM morphological and functional deficits.

Given the scarce research on student circus artists and high prevalence of chronic, overuse and spine injuries, the primary aim of this thesis was to investigate the relationships between LBP and LM characteristics in this unique athletic and artistic population in both prone and standing positions. The secondary aim of this thesis was to explore the LBP profile in a sample of student circus artists to further the understanding of LBP disability and how it might affect daily training and activities to provide better prevention and treatment plans. By identifying the LM profile in this population and its role in the high rates of spine injuries in circus artists, we will be better informed to develop targeted treatment and rehabilitation plan for circus artists.

1.8 Objectives & hypotheses

Given the current gap in the literature, the objectives of this thesis were to:

1) explore the prevalence and severity of LBP in student circus artists

2) investigate LM morphology and function in student circus artists with and without LBP

We hypothesized that:

i) student circus artists would experience high prevalence of LBP similar to other elite athletes and performing artists.

ii) student circus artists with LBP would have smaller LM size and reduced percent thickness change compared to students with no LBP

iii) student circus artists with LBP would have greater LM asymmetry compared to non-LBP students.

CHAPTER 2

Manuscript 1:

Ultrasonography of the multifidus muscle in student circus artists with and without low back pain

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ABSTRACT

Context: Degenerative structural changes and functional deficits of the lumbar multifidus (LM) muscle were observed in athletes with LBP. While spinal injuries are common in circus artists, we are not aware of any study that has assessed LM characteristics in this population.

Objectives: To investigate LM morphology and function in student circus artists and to explore the relationship between LM characteristics and LBP.

Methods: Thirty-one college circus students were recruited from circus schools. Participants completed an online survey to acquire demographic data and LBP history. Body composition was measured using multi-frequency bio-impedance analysis. Ultrasound examinations at L5 were performed to assess LM cross-sectional area (CSA), echo-intensity, thickness at rest, and thickness during contraction. Measures were obtained in prone and standing positions. The difference between sex and side was assessed using independent and dependent t-test, respectively. The relationship between body composition and LM characteristics was assessed with Person's correlations. The LM characteristics' difference between artists with and without LBP was assessed with Analysis of covariance using lean body mass, height and % body fat as covariates.

Results: Males had significantly larger LM CSA and greater thickness change from rest to contracted than females. Females had higher echo-intensity than males. LM CSA asymmetry in prone was greater in artists reporting LBP in the previous 4-weeks ($p=0.029$) and 3-months ($p=0.009$). LM measures were correlated with lean body mass, height, and weight ($r=0.40$-0.77, $p\leq0.05$). LM echo-intensity was correlated with % body fat ($r=0.48$, $p=0.006$). LM thickness at rest and contracted was negatively correlated with % body fat ($r=-0.36$-0.43, $p<0.05$), in prone and standing positions.

Conclusion: This study provided novel insights into LM characteristics in circus artists. Greater LM asymmetry was observed in artists with a history of LBP. In accordance with previous studies in athletes, LM morphology and function were highly correlated with body composition measurements. Additional studies are needed to supplement our findings and investigate further aspects of LM neuromuscular motor control in circus artists.

INTRODUCTION

Pain and injury are detrimental to a circus artist's health and career.[5,12] Student circus artists push their limits daily when loading, twisting and bending their spine to achieve greater physical and artistic range.[1,5–7] Spinal injuries are reported as the second most injured body part in circus artists and the lumbar spine as the most affected spinal section in the sparse research on injury rate and anatomical location.[1,9,11] A study with an Australian circus school reported that 14% of all injuries were to the lumbar spine and that spinal injuries required the most initial and follow-up treatment.[1] Athletes in sports with high spinal loads have a higher rate of lower back pain (LBP) than other athletes.[18] Identifying LBP profile in circus artists may lead to a more sustainable practice, potentially decrease the risk of spinal injuries and assist with the screening of overuse spine injuries.[1]

The lumbar multifidus muscle (LM) provide segmental stabilization and proprioception to the lumbar spine.[44] Smaller LM and greater asymmetry between sides has been linked to LBP in some athletic populations.[29,34,40,45] Similar degenerative structural changes and functional deficits were observed non-athletic populations with LBP.[50,51] Ultrasonography is commonly used to accurately assess LM morphology (e.g. cross-sectional area (CSA) and CSA asymmetry thickness and echo-intensity) as well as function (e.g. contraction) in real-time. [15-17] While the gold standard to assess muscle activation is electromyography (EMG), LM muscle function can also be evaluated by assessing the change in LM thickness from a rested to a contracted state (e.g. contralateral arm lift) using real-time ultrasound imaging.[30] Ultrasound thickness change measurements has been shown to be a valid and reliable method to assess LM activation.[30–33] All these LM measures have been investigated in various populations including athletes and performing artists.

Professional ballet dancers with LBP were found to have smaller LM size as compared to their asymptomatic counterpart.[42] Elite gymnasts with sway-back posture were reported to have a smaller LM thickness change from a rest to contracted state at all lumbar levels (e.g. L1 to L5) when compared to controls (e.g. gymnasts with normal posture), indicating possible LM dysfunction.[34] Smyers Evanson et al. reported LM asymmetry in elite ballroom dancers, with the left LM being larger in all dancers, however the degree of asymmetry was not related to LBP.[43]

Given the previous findings and sport specific demands, each artistic populations appears to have a unique LBP profile and relation to LM morphology and function. Currently, there is an absence of research with regards to LM characteristics and LBP history in circus artists.

As muscle morphology is influenced by age, sex, physical activity levels and body composition, [52,53] adjusting for such anthropometric factors is critical when assessing the relation between LM morphology and lumbar pathology. Body mass index (BMI) is most frequently used to adjust for inter-subject variability; however, it remains a poor indicator of body composition, especially in athletic populations.[22] While dual energy X-ray absorptiometry (DEXA) is the gold standard to assess body composition, it is costly, not readily accessible, and not portable. Multi-frequency Bioimpedance Analysis (MF-BIA) is an affordable alternative, that provides a quick, non-invasive and portable option to accurately assess body composition.[54]

Given the scarce research on student circus artists and high prevalence of spinal injuries, we investigated the relationship between LM characteristics and LBP in this unique athletic population. The aims of this study were to 1) investigate LM morphology and function in student circus artists and their relations with body composition, and 2) to examine the relationship between LM characteristic and LBP status. We hypothesized that circus artists with LBP would have smaller LM, greater side-to-side asymmetry, and reduced function (e.g., percent thickness change).

METHODS

Participants

Thirty-one student circus artists aged 21.06 ± 2.56 (ranging from 18-29 years old) pursuing a 3-year diploma of collegial studies in circus arts were recruited from the National Circus School (n = 25) and the Quebec Circus Arts School (n = 6). While all eligible students were invited to take part in this study, the sample size was influenced by the artists' availabilities and is comparable to previous related study with elite athletic and performing arts' populations. Exclusion criteria were any history of spinal fracture, spinal surgery, or visible spinal deformities (i.e., scoliosis >10°). We spent one week in each school to collect in-person outcome measures. Self-reporting survey responses were collected the week prior to and during the in-person assessment. All data was collected during a high intensity-training period in mid-October and the first week of November 2021. Due to Covid-19, the training hours of the 2020-2021 school year have been cut down by 50% to allow all students to continue their training safely. In Fall 2021, training hours were increased to 5-6 hours/day (75%). All circus students signed a consent form prior to enrolling. The study was approved by Concordia Ethics (CER: 30014948) and by National Circus School Ethics Committee (CER 2122-07C).

Procedures

Participants filled out a self-reported online survey on demographics, training, injury history and LBP (see Appendix B). Based on the survey, participants were divided into 2 groups: LBP and no LBP. During in-person assessments, height was recorded with a stadiometer (Doran Scales, DS5100). Participants' body composition was obtained with MF-BIA (Inbody 230 in Montreal) or bioimpedance spectrometry (Impedimed SBF7 in Quebec City) prior to an ultrasound assessment. Participants were instructed to fast for 2 hours, drink minimal amounts of water and not exercise prior to the body composition measurement.[14] Participant compliance to these instructions was recorded. The ultrasound was used to measure the LM CSA, thickness, and echo-intensity at L5 in both prone and standing positions.

Online Survey and Injury History

The survey collected participants' age, sex, school year (Preparatory, 1, 2 or 3), circus disciplines, spinning side preference, preferred hand grip and split symmetry. Participants specified the number of training years and weekly hours spent on each discipline. Further questions collected the type, location, and duration of any injury in the 12 months prior to the study. Injury was defined as any injury requiring medical attention. For LBP history, participants were asked to answer "yes" or "no" for the presence of LBP in the 4-weeks and in the 3-months prior to the ultrasound. If the participant answered "yes" to the presence of LBP, they were asked to specify pain intensity using a numerical pain rating scale (0 = no pain; 10 = worst possible pain), pain location (left, right, centered) and pain duration in weeks in the previous 4-weeks and the previous 3-months. Participants with a history of LBP also had to complete the Oswestry Disability Index (ODI)[55], the Athlete Disability Index (ADI),[56,57] and the Pain Catastrophizing Scale (PCS)[58] questionnaires.

A recent history of LBP in the previous 4-weeks was coded as either “no LBP” or “LBP 4-weeks”. Similarly, history of LBP 3-months prior to assessment was coded as either “no LBP” or “LBP 3-months”.

Body composition (MF-BIA)

Participants were instructed to wear minimal clothing as well as to remove all metal and footwear. Most participants complied fully with the fasting and no-exercise instructions previously stated in the procedures; however, some students had eaten in the past 2 hours (mostly 40-60 minutes prior) and 2 students had training prior to the measures. While previous studies have reported statistically significant changes in body composition when the protocol was not followed, the studies reported no clinical significance. Hence, noncompliance to the instructions above would not cause changes above clinically acceptable levels of bioimpedance measures.[59,60] For the Inbody 230 (Montreal site, n=25), the participants stood barefoot on the platform with the soles of the feet on the electrodes and grabbed the handles with their thumbs and fingers to keep contact with the electrodes. Participant’s age, height, and sex were input into the Inbody 230 screen. The participants stood for less than a minute with the elbows extended and shoulders abducted at approximately 30-degree angle. Total body mass, fat mass, lean mass, and muscle mass measures were obtained. The results were collected and documented into a spreadsheet. For the Impedimed SBF7 (Quebec site, n=6), the participants lay prone on the physiotherapy table for 3 to 5 minutes. Electrodes were placed on one side of the body following the equipment’s instructions after shaving any hair on the area to allow electrodes to stick properly. Four electrodes were placed on the wrist, hand, ankle, and foot. Measures obtained were total body water, extracellular fluid, intracellular fluid, free fat mass, fat mass and BMI. Absolute mass values were scaled to body mass and height. The results were collected and documented into a spreadsheet.

Ultrasound Imaging

LM was assessed using a LOGIC e ultrasound (GE Healthcare, Milwaukee, WI) with a 5-MHz curvilinear probe. Imaging parameters were: 5 MHz frequency, 60 gain, 8.0 cm depth.[26]

Reliability and validity of ultrasound imaging for LM size and thickness has been established.[26,32,33]

LM Measurements

Participants lay prone on a physiotherapy table with a pillow under their abdomen to flatten the lumbar curve within 10° of horizontal.[26,30] Participants lay their arms relaxed on each side at shoulder level. They were instructed to relax the paraspinal musculature. The L5 spinous process was located by palpation and visual confirmation on the ultrasound. Ultrasound gel was applied to the skin. The ultrasound probe was placed transversely over the L5 spinous process for imaging. Three transverse images were taken bilaterally to obtain LM CSA. For participants with large LM, the left and right muscles were imaged separately by moving the transducer laterally.

For LM function (e.g., contraction), images were taken in a parasagittal view to measure muscle thickness. Three images were taken at rest and three images during contraction. Participants held a handheld weight based on their bodyweight (<68.2kg = 0.68kg weight, 68.2–90.9kg = 0.9kg weight, >90.9kg = 1.36kg weight).[30] The handheld weight is used to obtain around 30% submaximal voluntary isometric contraction.[30] The weight was held overhead with a 90° flexion in the elbow.[30] Participants performed a contralateral arm lift by lifting the weight 5 cm off the table for 3 seconds to obtain at image at contraction. Participants had 1 trial and 3 recorded arm lifts on each side.

All measures for LM size and function were repeated in a standing position. Participants were asked to stand barefoot on the ground with their arms relaxed at their sides. They were instructed to march on the spot for a few steps and stop where their feet land in their normal upright resting position. The LM at L5 was imaged. For muscle thickness measures, the same procedure mentioned above was used. The contralateral arm lift was performed with the shoulder in 90° flexion and an elbow extension with the palm facing down.[35]

Image Assessment

Ultrasound images were stored and analyzed offline. LM CSA was measured by tracing the muscle borders (Figure 1). The asymmetry of the LM CSA was calculated using the following formula: % asymmetry = [(larger side – smaller side)/larger side × 100]. LM function was assessed by tracing the muscle thickness (Figure 2) and calculating the % thickness change as follow: thickness % change = [(thickness contraction – thickness rest)/thickness rest) × 100].[29] Echo intensity (EI) values was measured using a gray scale analysis. Each pixel was assigned a number from 0 (black) to 255 (white) using a standard histogram function via the Horos DICOM viewer software (version 4.0.0 RC5). Higher EI values reflected greater amounts of muscle fat and connective tissue.[26,39] Each measure was obtained by averaging the measures from the 3 images. One participant was recovering from a shoulder injury and was unable to perform the right contracted thickness measure in prone. All images from the right contracted thickness measure standing for one participant were eliminated as the image quality was poor. From the 372 images, 8 additional individual images were discarded due to lack of clarity.

Figure 1 – LM size at L5. *Transverse image of the lumbar multifidus muscle at L5 showing the cross-sectional area (CSA), in prone (left) and in standing (right) positions.*

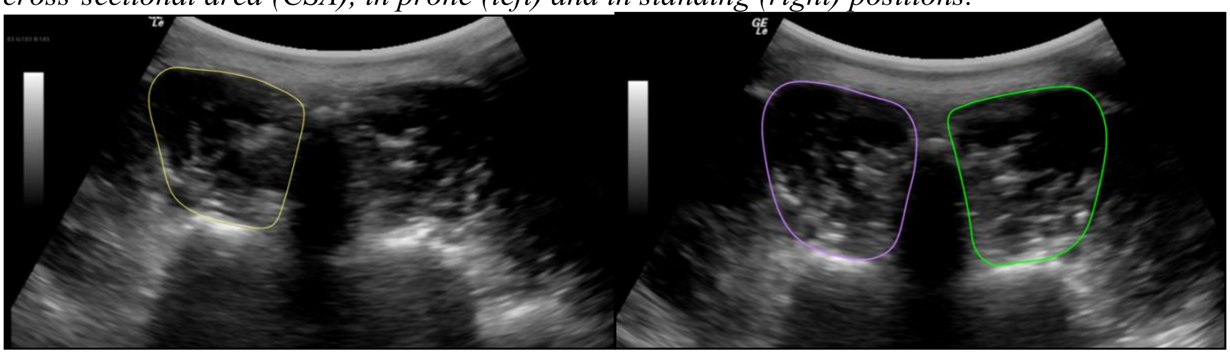
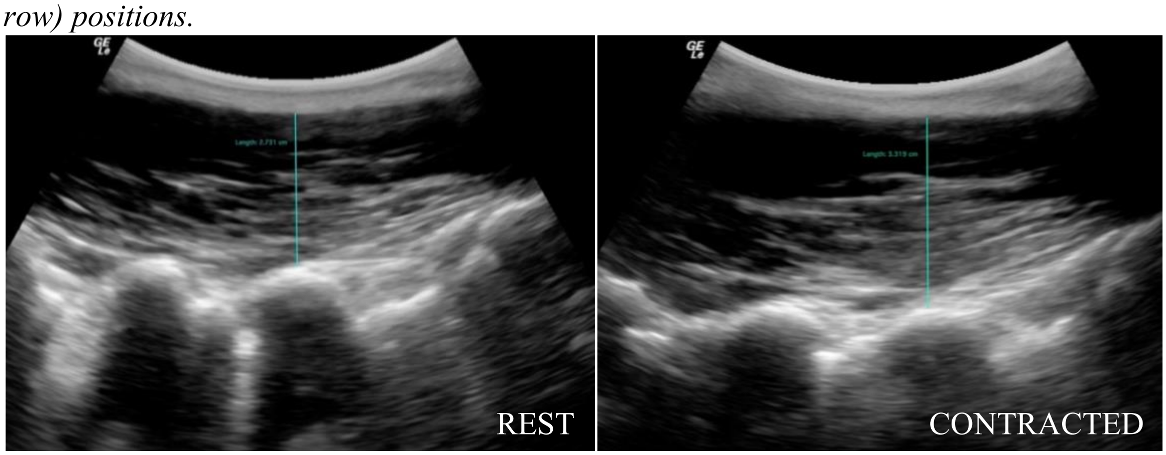
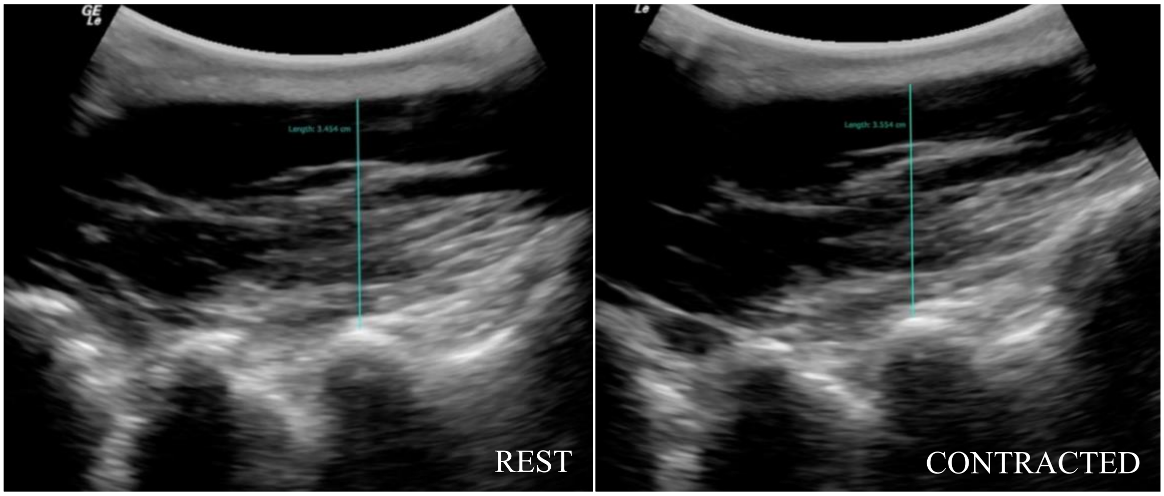


Figure 2 – LM function at L5. *Parasagittal image of the lumbar multifidus muscle at L5 illustrating LM thickness at rest and during contraction, in prone (top row) and standing (bottom row) positions.*





Reliability

The reliability of the examiner performing the ultrasound was assessed prior the beginning of this study and following a training period to familiarize the rater with the equipment and method. Intra-rater reliability (n=10) was good to excellent with intraclass correlation coefficient (ICC) ranging from 0.91-0.95 for CSA, from 0.96 to 0.99 for thickness measures in prone and standing and 0.98-0.99 for LM EI. Similarly, between-days intra-rater reliability (n=5) had ICCs ranging from good to excellent from 0.83-1.00 for CSA, from 0.81 to 0.99 for thickness measures in prone and standing and 0.51-0.80 for LM EI. Inter-rater reliability was also assessed (n=8) and ICCs ranged from good to excellent with 0.830-0.982 for CSA, 0.81-0.98 for thickness measures and 0.71-0.77 for LM EI.

Statistical Analysis

Descriptive tables for participants' characteristics, history of injury, body composition, LBP answers and LM measures was obtained. Exploratory data analysis was used to verify the normality assumption. Paired t-tests were used to compare LM size and function between the left and right sides, within male and female artists except for LM CSA asymmetry where the Wilcoxon signed-rank test was used as this measure was not normally distributed. Person's correlations were used to assess the relationship between body composition and LM characteristics. Analysis of covariance (ANCOVA) was used to assess the difference in LM characteristics between circus artists with and without a history of LBP. Separate analyses were performed for the presence of LBP at 4-weeks and 3-months. As lean body mass had a higher correlation with LM characteristics than weight, height, lean body mass and % body fat were used as covariates to adjust for anthropometric differences. All tests were performed using SPSS (version 26.0.0.0) with significance level set at <0.05.

RESULTS

The artists' demographic characteristics are presented in Table 1. The average number of years of circus training was 7.97± 4.26 years and an average of 4.73± 2.58 years in their main circus discipline. Seventy percent (n=22) of students reported 30 separate injuries in the past 12 months, 58.1% (n = 18) reported having had LBP in the previous 3 months.

Table 1 - Participants' Characteristics ((mean + SD) or n)

	All (n = 31)	**Male (n = 13)**	**Female (n = 18)**
Age (yrs.)	21.06 ± 2.56	21.46 ± 2.30	20.78 ± 2.76
Height (cm)	168.39 ± 8.63	175.12 ± 5.72	163.53 ± 6.98
Weight (kg)	63.37 ± 8.67	68.77 ± 8.14	59.48 ± 6.90
Total lean mass (kg)	54.06 ± 9.57	61.77 ± 8.31	48.50 ± 5.91
Total body fat %	14.94 ± 5.64	10.22 ± 4.40	18.35 ± 3.63
Body mass index	22.28 ± 2.09	22.39 ± 2.28	22.20 ± 2.02
Program Year (n)			
Preparatory year	7	3	4
1st year	7	1	6
2nd year	9	4	5
3rd year	8	5	3
Years of circus training (yrs.)	7.97 ± 4.26	9.85 ± 4.02	6.61 ± 4.00
Type of artists (n)			
Specialists	24	7	17
Generalists	7	6	1
Main Discipline (n)			
Floor Acrobatics	11	8	3
Aerial Acrobatics	14	2	12
Balancing	5	3	2
Juggling	1	0	1
Time training main discipline (yrs.)	4.74 ± 2.58	5.46 ± 1.98	4.22 ± 2.88
Time training main discipline (Hr / week)	7.94 ± 2.78	8.15 ± 4.00	7.78 ± 1.52
Hand Grip Preference (n)			
Left	3	1	2

Right	22	8	14
No Preference	6	4	2
Medical History in previous 12 months (n)			
Students who reported injuries	22	10	12
Injuries to the head, neck, trunk	8	1	7
Injuries to the arms	12	7	5
Injuries to the legs	10	3	7

Table 2 - LBP Characteristics ((mean + SD) or n)			
	All (n = 18)	**Male (n = 7)**	**Female (n = 11)**
Total LBP reports	18	7	11
in previous 4 weeks (answered "yes")	14	6	8
in previous 3 months (answered "yes")	16	6	10
LBP in previous 4 weeks			
Duration (weeks)	2.35 ± 0.44	1.48 ± 1.36	3.01 ± 1.57
Location (n)			
Centered	7	4	3
Left	3	0	3
Right	4	2	2
Intensity (0-10 scale)	4.36 ± 2.21	4.25 ± 1.13	4.44 ± 2.85
LBP in previous 3 months			
Duration (weeks)	17.65 ± 8.82	6.00 ± 6.06	24.00 ± 44.42
Location (n)			
Centered	10	5	5
Left	3	0	3
Right	3	1	2
Intensity (0-10 scale)	4.63 ± 2.29	4.50 ± 1.67	4.70 ± 2.68
Questionnaires on LBP			
ODI scores %	9.33 ± 7.67	9.14 ± 6.82	9.45 ± 8.49
ADI scores %	16.20 ± 11.36	14.29 ± 7.25	17.42 ± 13.56
PCS score (/52)	10.63 ± 8.23	9.00 ± 7.70	11.58 ± 8.70
ODI interpretation results, No.			
Minimal Disability	17	7	10
Moderate Disability	1	0	1
Severe Disability	0	0	0
ADI interpretation results, No.			
Minimal Disability	12	5	7
Moderate Disability	5	2	3
Severe Disability	1	0	1

LM Characteristics

LM characteristics of male (n=13) and female (n=18) artists are presented in Table 2. In prone, the right LM CSA was significantly greater in males ($p<0.01$). EI was significantly greater in females as compared to males ($p<0.01$), and higher on the right side within females ($p=0.01$). LM thickness at rest (left side), contracted (both sides), and % thickness change (right side) were significantly larger in males than females (all $p<0.05$). There was no difference in LM CSA asymmetry between sex.

In standing, LM CSA, thickness at rest and contracted on both sides was greater in males ($p<0.01$, $p<0.05$, respectively). Female artists had greater LM thickness at rest on the right ($p=0.036$). There was no difference in LM CSA asymmetry between sex.

Table 3 - LM characteristics in circus artists

	Female (n = 18)		Male (n = 13)	
	Right	Left	Right	Left
PRONE				
CSA (cm²)	**6.83 ± 1.13**	6.86 ± 1.11	**8.01 ± 1.19**	7.88 ± 1.10
CSA asymmetry (%)	2.91 ± 3.89		2.21 ± 2.33	
Echo intensity (arbitrary units	**51.76 ± 10.74 ***	**47.02 ± 13.13**	**37.23 ± 7.11**	**36.40 ± 5.95**
Thickness (cm)				
Rest	2.65 ± 0.26	**2.70 ± 0.27**	2.87 ± 0.39	**2.96 ± 0.31**
Contracted	**2.80 ± 0.27**	**2.87 ± 0.28**	**3.20 ± 0.43**	**3.24 ± 0.31**
Percentage change (%)	**5.71 ± 5.04**	6.46 ± 4.20	**11.78 ± 4.71**	9.52 ± 5.31
STANDING				
CSA (cm²)	**7.70 ± 1.23**	**7.79 ± 1.16**	**9.44 ± 1.25**	**9.48 ± 1.14**
CSA asymmetry (%)	2.17 ± 2.42		3.07 ± 2.91	
Thickness (cm)				
Rest	**3.06 ± 0.35 ***	**3.19 ± 0.30**	**3.45 ± 0.45**	**3.52 ± 0.39**
Contracted	**3.25 ± 0.34**	**3.31 ± 0.30**	**3.57 ± 0.43**	**3.66 ± 0.36**
Percentage change (%)	6.47 ± 5.39	3.99 ± 2.57	3.61 ± 2.78	4.10 ± 2.73

** Indicates difference (p <0.05) between left and right within sex*
Bold indicates difference (p<0.05) between sex

Associations between LM characteristics and body composition

LM CSA was significantly correlated with height (prone: $r = 0.55$, $p<0.01$; standing: $r = 0.66$, $p<0.001$), weight (prone: $r = 0.73$, $p<0.001$; standing: $r = 0.74$, $p<0.001$), total lean mass (prone: $r = 0.73$, $p<0.001$; standing: $r = 0.77$, $p<0.001$) and % body fat (prone: $r = -0.43$, $p=0.02$; standing: $r = -0.51$, $p<0.01$). LM thickness at rest and during contraction in both prone and standing had similar significant correlations. LM EI was only correlated to % body fat ($r=0.48$, $p=0.01$). The EI mean was significantly and negatively correlated with percent thickness change in prone (r = -0.40, p=0.03); however, this correlation was insignificant in standing measures (r = 0.22, p=0.24). LM CSA (prone: r = -0.43, p = 0.02; standing: r = -0.51, p<0.01), contracted thickness measure in prone (r = -0.43, p=0.02) and both thickness measures standing (rest: r = -0.37, p = 0.04; contracted: r = -0.36, p<0.05) were correlated with total % body fat. BMI was significantly correlated with CSA in prone (r = 0.44, p=0.01); however, BMI was not significantly correlated with CSA in standing (r = 0.35, p=0.06). All thickness measures in prone and standing were significantly correlated with BMI (r = 0.50-0.57, p <0.01). However, the correlation coefficients for BMI with LM measures were smaller than other body composition measures.

LBP comparisons

Comparisons between LM characteristics of artists reporting LBP in the past 4 weeks and 3 months are presented in Table 3 and 4, respectively. LM asymmetry in the prone position was significantly greater in artists reporting the presence of LBP in the previous 4-weeks or 3-months ($p = 0.022$, $\eta^2 = 0.180$ and $p= 0.010$, $\eta^2 = 0.224$, respectively). There were no other significant differences for LM characteristics (in prone or standing) between artists with and without a history of LBP.

Table 4 - Adjusted means[a] (mean (SE)) of LM measurements in prone and standing for artists with and without LBP in past 4-weeks			**p-values**
	No LBP (n = 17)	**LBP (n = 14)**	
PRONE			
CSA (cm^2) [b]	*7.25 (0.23)*	*7.38 (0.25)*	*0.713*
CSA asymmetry (%) [b]	**1.32 (0.79)**	**4.19 (0.88)**	**0.029**
Echo intensity (arbitrary units) [b]	45.65 (2.69)	42.26 (2.99)	0.431
Thickness (cm)			
Rest	2.76 (0.06)	2.79 (0.06)	0.780
Rest Asymmetry (%)	6.28 (1.25)	5.77 (1.40)	0.797
Contracted [b]	3.00 (0.07)	3.01 (0.07)	0.910
Contracted Asymmetry (%)	7.79 (1.18)	6.80 (1.27)	0.593
Percentage change (%)	8.55 (1.14)	8.04 (1.23)	0.773
Percentage change Asymmetry (%)	3.57 (0.88)	5.17 (0.95)	0.251
STANDING			
CSA (cm^2) [b]	8.38 (0.25)	8.56 (0.28)	0.664
CSA asymmetry (%) [b]	2.58 (0.69)	2.51 (0.77)	0.948
Thickness (cm)			
Rest [b]	3.28 (0.07)	3.28 (0.08)	0.994
Rest Asymmetry (%)	5.66 (1.27)	5.93 (1.42)	0.894

Contracted [b]	3.42 (0.07)	3.43 (0.08)	0.944
Contracted Asymmetry (%)	6.14 (1.04)	4.43 (1.20)	0.314
Percentage change (%)	4.78 (0.72)	4.55 (0.84)	0.845
Percentage change Asymmetry (%)	2.42 (0.83)	3.90 (0.96)	0.279

[a] Adjusted means for lean body mass and height
[b] Adjusted means for lean body mass, height and total body fat %
***bold** = P<0.05*

Table 5 - Adjusted means[a] (mean (SE)) of LM measurements in prone and standing for artists with and without LBP in past 3-months			**p-values**
	No LBP (n = 15)	**LBP (n = 16)**	
PRONE			
CSA (cm^2) [b]	7.27 (0.25)	7.35 (0.24)	0.822
CSA asymmetry (%) [b]	**0.82 (0.83)**	**4.30 (0.80)**	**0.009**
Echo intensity (arbitrary units) [b]	44.62 (2.99)	43.65 (2.88)	0.830
Thickness (cm)			
Rest	2.75 (0.06)	2.80 (0.06)	0.544
Rest Asymmetry (%)	7.55 (1.30)	4.64 (1.25)	0.137
Contracted [b]	3.00 (0.07)	3.01 (0.07)	0.940
Contracted Asymmetry (%)	7.96 (1.22)	6.69 (1.22)	0.493
Percentage change (%)	8.68 (1.19)	7.95 (1.19)	0.684
Percentage change Asymmetry (%)	4.46 (0.95)	4.18 (0.95)	0.845
STANDING			
CSA (cm^2) [b]	8.56 (0.28)	8.37 (0.27)	0.638
CSA asymmetry (%) [b]	2.67 (0.76)	2.43 (0.73)	0.831
Thickness (cm)			
Rest [b]	3.28 (0.08)	3.27 (0.08)	0.934
Rest Asymmetry (%)	4.90 (1.35)	6.60 (1.31)	0.398
Contracted [b]	3.42 (0.08)	3.43 (0.07)	0.946
Contracted Asymmetry (%)	5.78 (1.13)	5.04 (1.13)	0.675
Percentage change (%)	4.65 (0.78)	4.71 (0.78)	0.957
Percentage change Asymmetry (%)	3.18 (0.91)	2.94 (0.91)	0.863

[a] Adjusted means for lean body mass and height
[b] Adjusted means for lean body mass, height and total body fat %
***bold** = P<0.05*

DISCUSSION

Few studies have assessed LM characteristics in artistic sports and athletic populations with LBP. We are not aware of any other studies that has assessed LBP profile and LM muscle size and function in circus artists. This study provides novel insights with regards to LM characteristics in male and female circus artists, with and without a history of LBP. Overall, 18 artists (58%) reported LBP, out of which 45% and 52% reported LBP in the previous 4-weeks and 3-months, respectively. Other studies investigating performing arts reported higher prevalence, with 74% of ballet dancers reporting chronic LBP and 63% of ballroom dancers experiencing LBP from months to years.

Our findings revealed that LM CSA in circus artists was comparable to elite dancers [42,43] and greater than non-athletic healthy subjects of similar age and higher % body fat.[61] Other studies in athletic populations with larger stature (e.g., hockey, rugby, American football, soccer) reported greater LM CSA at the same level. [29,40,41,45] When comparing LM morphology between populations, one should remember that each sport requires different physicality and physical profile. For example, the right/dominant LM CSA was reported to be larger in all ballet which the authors attributed to the dominance and lateral training bias in ballet.[42] Similar results were reported in elite ballroom dancers and in varsity football players which had lateral bias, a larger LM CSA, on their dominant side due to the nature of the art or sport.[43,62] In contrast to these arts and sports, circus training favors symmetrical training, especially in training facilities and circus schools. This could partly explain the very small asymmetry values observed in our sample of circus artists. Furthermore, circus artists tend to be very lean with small stature and have unique demands to stabilize their spine without having to react to unexpected hits or loss of stability such as in football or hockey.[29,40,41,45,62] In accordance with previous studies in athletic and non-athletic populations, [29,40,41,62] we also observed significant difference in LM morphology characteristics between male and female circus artists. Our sample of males were taller, heavier, and had lower percent body fat then the females, which likely explains the larger CSA, lower EI and larger thickness measures prior to adjusting for anthropometric differences such as height, lean body mass and percent body fat.

Few studies in athletes have examined LM morphology and function in standing rather than in prone.[29,40,41,62] Assessing LM characteristics in a functional upright position may result in better implications for performance and injury prevention.[29] LM CSA is expected to increase from a prone to standing position as the muscle contracts in an active supportive position. On the contrary, % thickness change is greater in prone as compared to standing, as the LM muscle is already contracted in a stabilizing role while standing.[26,28] Our results corroborate with previous studies in athletes and showed greater LM CSA and smaller % thickness changes in standing,[29,40,41,62] except for the right side in female artists where larger % thickness change was observed in standing. This could be an adaptation related to the demands of the art on stabilization and proprioception to the lumbar spine. A possible explanation is that most female artists weighted less than 150 pounds, hence, used the smallest handheld weight (e.g., 0.68kg).[30] Indeed, the original study that determined the required handheld weight based on bodyweight to elicit a 20-30% LM involuntary contraction was developed in a general non-athletic population.[30] Circus artists are leaner and have stronger and more flexible shoulders than the general population.[63] While this protocol worked for other athletic and artistic populations such as rhythmic gymnastics,[29,34,40,41,62] it is possible the small handheld weight might have been too small to produce the expected involuntary LM contraction in circus artists due to their increased shoulder control, strength and flexibility. Additional aspects of LM neuromuscular control should be investigated in circus artists.

In accordance with previous studies in varsity athletes, [29,40,41,62] LM CSA was positively correlated with lean body mass, weight, and height, though these correlations were stronger in circus artists. LM CSA was negatively correlated with % body fat as was reported in soccer players ($r = -0.41$),[29] but this was contrary to other varsity athletes where it was positively correlated.[40,41,62] Percent body fat was positively associated with EI as in varsity athletes ($r=0.76$),[40,62] and negatively associated with LM CSA as in varsity soccer players.[29] The negative correlation between total percent body fat and thickness change in prone was also reported in football athletes.[62] This finding is in accordance with Schryver et al. and provide additional evidence that body composition may negatively affect muscle function.[62] Contrary to studies in varsity athletes,[29,40,41] BMI was correlated with LM CSA in our sample. This may be due to our sample of circus artists that had lower percent body fat and large developed muscles as compared to previously studied athletes that tend to have bigger stature.[4,29,40,41,62] Of note, lean body mass was the best predictor of LM CSA in circus athletes. Thus, body composition predictors for LM size may vary between active populations.

Contrary to our hypothesis, circus artists with an history of LBP did not have a smaller LM. This finding was also reported in ballroom dancers and other elite athletic populations.[43,46,64] However, professional ballet dancers with hip or back pain were reported to have a smaller LM than dancers without pain at the lower lumbar levels (L3 to L5).[15] The inconsistent findings may relate to the specificity of each discipline. LM EI in circus artists was not associated with LBP status but highly correlated with body composition. While we are not aware of any previous studies that investigated LM EI in performing arts, this findings corroborates with previous studies in varsity athletes.[29,40,42,43] Furthermore, we found no significant differences in LM % thickness change (e.g., contraction) between artists with and without LBP. While elite female artistic gymnasts with sway back posture were reported to have a decrease in thickness as a result of sway-back posture,[13] literature findings with regards to LM dysfunction in athletic populations with LBP are mixed.[29,41]

Our results, however, revealed that circus artists with LBP had greater CSA asymmetry in prone, a finding that was also reported in professional ballet dancers.[42] Previous studies in non-athletic populations suggested side-to-side asymmetry above 8-10% as a probable threshold related to pathology and LBP.[26,61] However, circus artists rarely fall within the normative data as different arts and sports have varying demands. Despite a low-level asymmetry present in our sample, the association between LBP and LM asymmetry suggest that a lower threshold value (below 8%) may be problematic and possibly led to LM dysfunction in circus artists. Due to the cross-sectional nature of this study, whether LM asymmetry happened prior to pain onset or as result of pain remains unclear. Furthermore, in accordance with ballet dancers, smaller LM was not associated with the side of pain identified.[15] Further investigations are required to confirm and expand our findings and determine if LM asymmetry could be an indicator or predictor of LBP in circus artists.

Limitations of this study include the small sample size which may have effected some analyses; however, it was comparable to other studies in elite athletes and professional performing arts.[29,40–43] Decreased training due to COVID and non-adherence for the body composition measurements were limitations as it may have affected our overall results. LM measurements were only obtained at a single spinal level. Further investigations should examine LM characteristics at other spinal levels and other trunk muscles that contribute to segmental control and spinal stability in circus athletes.

CONCLUSION

Student circus artists presented differences in LM morphology between males and females in prone and standing positions. Artists with LBP had larger side-to-side asymmetry in the LM CSA at 5th lumbar vertebrae when imaged in prone. Our results suggest the importance to evaluate muscle characteristics at rest as well as in movement. Future studies should confirm our results and explore the asymmetry threshold specific to this circus population for clinical significance. Future research should also evaluate the effects of LM exercise intervention targeting LM muscle on reducing and preventing LBP in athletic and artistic populations.

CHAPTER 3

Manuscript 2:

Low Back Pain in Student Circus Artists: an exploratory study and comparison between the Oswestry Disability Index and the Athlete Disability Questionnaire

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ABSTRACT

Introduction: Low back pain (LBP) is a major global health issue affecting everyone, even performing artists. Student circus artists' intense daily training put constant stress on their back. While the literature on circus artists is scarce, the spine was reported as the second most injured and prime target for injury prevention. However, the presence and severity of LBP in this unique population remains unclear.

Objectives: To explore the prevalence and severity of LBP in student circus artists and to compare scores between the Oswestry Disability Index (ODI) and the Athlete Disability Index (ADI) questionnaire to assess the level of disability in circus artists reporting LBP.

Methods: Thirty-three students (19 females and 14 males) aged 21.15±0.44 in the college circus program were included in this study. Participants filled out an online self-reported survey on demographics, training history, and LBP. Participants who reported LBP also filled a numerical pain rating scale (NPRS; scale 0-10 converted to 0-100), ODI, and ADI to measure LBP disability. LBP disability level was classified as mild, moderate, or severe as previously defined by each scale. Descriptive statistics were obtained for the population and LBP characteristics. Pearson's correlation coefficients were used to evaluate the relationship between the NPRS, ODI and ADI.

Results: A total of 18 students (55%) reported LBP. The mean pain intensity on the NPRS was 4.53±2.01. The mean score for ODI and ADI was 9.33%±7.67 and 16.20%±11.36, respectively. The was a significant positive correlation between the ODI and ADI ($r=0.77$, $p<0.001$) and between the NPRS and ADI ($r=0.52$, $p=0.03$), but no correlation between NPRS and ODI ($r=0.29$, $p=0.25$). Based on the ODI scores, 88.89% of the artists reporting LBP were classified with mild disability, 11.11% moderate, and 0% severe disability as compared to 66.67%, 27.78% and 5.55% with the ADI, respectively.

Conclusion: Our findings provide novel insights regarding high prevalence of LBP and related disability in circus artists. While the correlation between ODI and ADI was strong, our findings suggest that the ADI may be a better tool to assess LBP-related disability in athletes due to more accurate classification of the levels of disability and statistically significant correlation with the NPRS.

INTRODUCTION

Low back pain (LBP) is one of the most common health complaints.[17] Yet the specific causes and sources of LBP remain elusive.[16] Although increase in physical activity has been suggested to be preventive factor, it may also be a possible risk factor.[18] Athletes and circus artists put high stress levels on their musculoskeletal system. While the spine was reported as a common site of injury in circus artists,[1,9–11] we are not aware of any previous study that has assessed LBP prevalence in circus artists.

Multiple questionnaires were developed and validated to assess functional disability levels in adult patients with LBP including the Oswestry Disability Index (ODI),[55] the Roland-Morris Disability Questionnaire[66] and the Quebec Back Pain Disability Scale.[67] However, all these self-reported assessment tools were designed for the non-athletic general population, and each assesses different functional aspects and limitations related to LBP. To our knowledge, only the Micheli Functional Scale (MFS) and the Athlete Disability Index (ADI) were designed to evaluate LBP-related disability in athletes.[57,68] The MFS was developed to assess pain disability in young athletes aged 12-22, and focuses mainly on three physical activities (e.g., back extension, flexion, and jumping) while omitting questions on daily and social activities. Although some athletes with LBP only experience pain during training or sport specific activities and absent or minimal disability in their daily activities, others may experience pain during a variety of activites.[56] The ADI provides a broader assessment of LBP-related disability in athletes of all ages.[56,57]

Assessing athlete's disability is necessary to determine proper treatment course and to gain a better global understanding of LBP in clinical and research settings. Given the scarce research on student circus artists and high prevalence of spinal injuries, we aimed to explore LBP profile in this unique athletic population. The aims of this study were to examine LBP prevalence and profile in a sample of circus artist students and to assess and compare the level of LBP-related disability using the ODI and the Athlete Disability Index ADI.

METHODS

Participants

Thirty-three student circus artists aged 21.15 ± 2.50 (ranging from 18-29 years old) pursuing a 3-year diploma of collegial studies in circus arts were recruited from the National Circus School (n = 25) and the Quebec Circus Arts School (n = 8). All eligible students were invited to participate in this study. Exclusion criteria included a previous history of spinal fracture, spinal surgery, or visible spinal deformities (i.e., scoliosis >10°). This study was approved by Concordia Ethics (CER: 30014948) and by National Circus School Ethics Committee (CER 2122-07C) and all participants completed a consent form acknowledging that their data would be used to research purposes.

Procedures

Participants filled out a self-reported online survey (see Appendix B). The survey was completed in English or French, based on the student preferred language. The survey was divided into demographics, training history, injury history in the previous year and LBP. In the demographics, the participants' age, sex, school year (Preparatory, 1, 2 or 3), circus disciplines, spinning side preference, preferred hand grip and split symmetry were collected. Participants specified the number of training years and weekly hours spent on each discipline as well as history of training in elite sports in the training section. Further questions collected the type, location, and duration of any injury in the 12 months prior to the study. Injury was defined as any injury requiring medical attention.

For LBP section, participants were asked to answer "yes" or "no" for the presence of LBP in the previous 4-weeks and in the previous 3-months. If a participant answered "no" to both questions, they were coded as "no LBP". Participants who answered "yes" to one or both of the LBP questions were coded as "LBP" and asked about symptom duration. Acute LBP was defined as pain lasting < 3months, while chronic LBP was defined as pain lasting > 3 months.

Artists that reported the presence of LBP were also asked to specify pain intensity using a numerical pain rating scale (NPRS) (0 = no pain; 10 = worst possible pain), pain location (left, right, centered) and pain duration in weeks and to complete 3 self-administered questionnaires including the ODI (maximum score of 50),[55] the ADI (maximum score of 36)[56] and the Pain Catastrophizing Scale (PCS).[58]

The ADI has 12 questions covering pain intensity, pain during stretching and strengthening exercises, technical skills, rotational back movements, fear of pain, recreational activities as well as questions similar to the ODI concerning sitting, walking, sleep, sexual activity and personal care.[56,57] Each question is scored from 0 to 3 with a total maximum score of 36.[56,57] Higher values indicate a more severe disability. The ADI was reported to have good face and content validity, as well as high internal consistency and test-retest reliability.[56,57]

The NPRS score were converted to a 0-100 scale. The ODI and ADI scores from the questionnaires were converted into percentage to define disability levels using the equation: (participant score/maximum score) x 100. LBP disability for the ODI and ADI was classified as minimal (0-20%), moderate (20-40%), severe (40-60%), very high (60-80%), and sports retirement (80-100%) as previously defined by the ODI and the ADI.[55,56] For PCS scores, a score below 30 indicated a low catastrophizer and above 30 indicated a high catastrophizer.[58]

Statistical Analysis

Descriptive statistics (e.g., mean±standard deviation for continuous variable and frequency/percentage for categorical variables) were obtained for participants' characteristics, injury history, and LBP history. Person's correlations coefficients were used to assess the relationship between the NPRS, pain duration, PCS, ODI and ADI scores. All tests were performed using SPSS (version 26.0.0.0) with significance level set at <0.05

RESULTS

Participants' characteristics are presented in Table 1. Our sample of student circus artists had 19 females and 14 males. 11 students reported floor acrobatics as their main discipline, 15 as aerial acrobatics, 6 as balancing and one as juggling. No students reported clowning as their main discipline. 73% (n=24) of students reported 33 separate injuries in the past 12 months.

Table 1 - Participants' Characteristics ((mean + SD) or n)			
	All (n = 33)	**Male (n = 14)**	**Female (n = 19)**
Age (yrs.)	21.15 ± 2.50	21.57 ± 2.24	20.84 ± 2.70
Program Year (n)			
Preparatory year	7	3	4
1st year	8	2	6
2nd year	10	4	6
3rd year	8	5	3
Years of circus training (yrs.)	8.15 ± 4.45	10.36 ± 4.31	6.53 ± 3.91
Type of artists (n)			
Specialists	25	7	18
Generalists	8	7	1
Main Discipline (n)			
Floor Acrobatics	11	8	3
Aerial Acrobatics	15	3	12
Balancing	6	3	3
Juggling	1	0	1
Time training main discipline (yrs.)	4.73 ± 2.50	5.43 ± 1.91	4.21 ± 2.80
Time training main discipline (Hr / week)	7.88 ± 2.75	7.93 ± 3.93	7.84 ± 1.50
History of elite sport	19	5	14
Years training elite sport	8.31 ± 3.63	6.75 ± 2.87	8.83 ± 3.81
Hand Grip Preference (n)			
Left	3	1	2
Right	24	9	15
No Preference	6	4	2
Spin Side Preference (n)			
Clockwise	11	2	9
Counter-Clockwise	16	9	7
No preference	6	3	3
Splits Flexibility (n)			
Left leg front split is better	11	6	5
Right leg front split is better	15	4	11
Equal	7	4	3
Medical History in previous 12 months (n)			
Students who reported injuries	24	11	13
Injuries to the head, neck, trunk	9	1	8
Injuries to the arms	13	7	6
Injuries to the legs	11	4	7
Major Surgeries	9		
Recurrent Injuries	13	2	11

LBP characteristics are presented in Table 2. Fifty five percent of participants (n = 18) reported having LBP (Table 2). A total of 8 students were classified with chronic LBP (pain lasting >3 months) and 10 students were classified with acute LBP (pain lasting <3 months). The mean pain intensity was 4.45 ± 1.89 in participants with acute LBP and 4.63 ± 2.28 in participants with chronic LBP. The mean PCS scores was 10.63 ± 8.23.

Table 2 - LBP Characteristics ((mean + SD) or n)

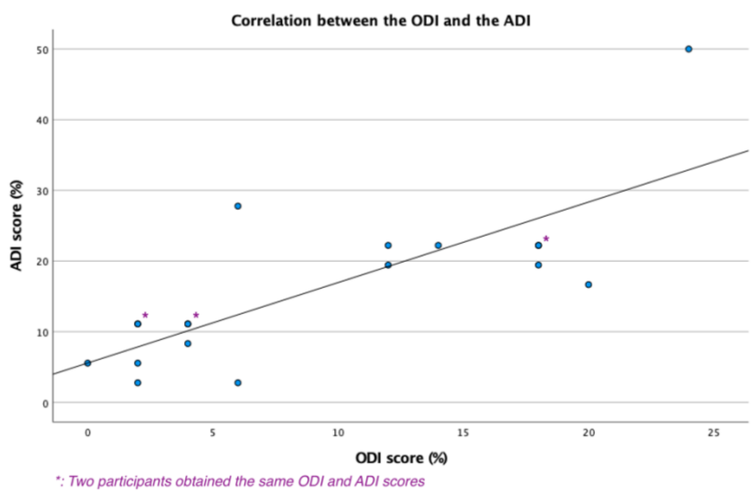
	All (n = 18)	Male (n = 7)	Female (n = 11)
LBP (n)			
Acute <3months	10	5	5
Chronic >3months	8	2	6
LBP duration in weeks			
Total	16.87 ± 36.73	4.87 ± 6.00	24.50 ± 45.90
Acute <3months	2.06 ± 1.62	1.42 ± 0.90	2.70 ± 2.02
Chronic >3months	35.38 ± 50.67	13.50 ± 2.12	42.67 ± 57.78
Pain Intensity (0-10 scale) for			
Total	4.53 ± 2.01	4.32 ± 1.26	4.66 ± 2.42
Acute <3months	4.45 ± 1.89	4.75 ± 1.25	4.15 ± 2.50
Chronic >3months	4.63 ± 2.28	3.25 ± 0.35	5.08 ± 2.49
Pain Intensity (0-100 scale)	45.28 ± 20.07	43.21 ± 12.64	46.59 ± 24.17
Questionnaires on LBP			
ODI scores %	9.33 ± 7.67	9.14 ± 6.82	9.45 ± 8.49
ADI scores %	16.20 ± 11.36	14.29 ± 7.25	17.42 ± 13.56
ODI interpretation results, No.			
Minimal Disability	17	7	10
Moderate Disability	1	0	1
Severe Disability	0	0	0
ADI interpretation results, No.			
Minimal Disability	12	5	7
Moderate Disability	5	2	3
Severe Disability	1	0	1
PCS Scores (/52)			
Total	10.63 ± 8.23	9.00 ± 7.70	11.58 ± 8.70
Acute <3months	8.80 ± 7.63	8.60 ± 7.50	9.00 ± 8.63
Chronic >3months	14.13 ± 8.20	10.00 ± 11.31	15.50 ± 7.71

For the ODI and the ADI, the mean scores were 9.33% ± 7.67 and 16.20% ± 11.36, respectively. Based on the ODI, 88.89% of the artists with LBP were classified with mild disability, 11.11% with moderate, and 0% with severe disability. In comparison, the scores from the ADI classified 66.67% of students with mild, 27.78% with moderate and 5.55% with severe disability. Overall, all participants were classified as low catastrophizers as all PSC scores were below 30 (ranged from 1 to 28).

Associations between the pain intensity (NPRS), ODI and ADI

There was a significant positive correlation between ODI and ADI r=0.77 [95% CI: 0.53, 0.92; p<0.001] (Figure 1). Pain intensity was positively correlated with ADI r=0.52 [95% CI: 0.01, 0.84; p=0.03) but not with ODI r=0.29 [95% CI: -0.27, 0.75; p=0.25].

Figure 1 – Correlation between the ODI and ADI. *Scatter plot with best fit line of the correlation between the ODI and ADI scores*



Associations between the mean pain duration, ODI and ADI

There was no significant correlation between the ODI and mean pain duration (r=0.326, p=0.186) or between ADI and mean pain duration (r=0.179, p=0.477).

Associations between the PSC, pain intensity (NPRS), pain duration, ODI and ADI.

The PCS scores were significantly correlated with the NPRS (r=0.710; p<0.001) and the ADI (r=0.506; p=0.032). However, there was no correlation between the PCS and ODI scores (p=0.088) or between PCS and pain duration (r=0.07, p=0.79).

PRELIMINARY DISCUSSION

To our knowledge, this is the first study to investigate the prevalence of LBP in circus artists. Over half of our student sample (55%) reported LBP. From the students with LBP, only one reported having had their first episode of LBP in the previous 3-months prior to this study. All other artists with a history of LBP had either multiple episodes of acute LBP, or chronic LBP (> 3months). Our findings were in accordance with the available literature suggesting that the spine is a frequently injured location in circus artists.[1,9,11,12]

LBP-related disability was assessed using both the ADI and ODI questionnaires. While the ODI was originally designed to asses disability related to daily activities in the general population, the ADI was specifically designed to assess LBP-related disability in athletes of all ages and disciplines. [55–57] Furthermore, the ADI was preferred over the MFS as the MFS was designed specifically for young athletes ranging from 12-22 years old; [56,57,68] this age range is not representative of our circus student sample. While the MFS is a very short questionnaire containing 5 only questions, the ADI has 12 questions about pain disability during movement and training as well as daily activity, providing a broader and more detailed assessment of LBP-related disability.[56,68] In accordance with a previous study in athletes,[56] we found a significant correlation between the ADI and ODI scores. However, the level of disability (e.g., mild, moderate, severe) were classified differently depending on the questionnaire used. With the ODI, all circus artists in our sample, except for one, were classified as having mild disability (e.g., 88.8%) as opposed to the 66.6% with the ADI. In a previous study with professional ballet dancers, all performing artists with LBP were also classified as having mild disability when using the ODI.[42] Noormohammadpour et al. concluded that the ADI can more precisely assess the severity of LBP in athletes in comparison to the ODI as it was primarily designed for the general population.[56] Consequently, the ODI is likely unable to assess the full daily effects of LBP-related disability in professional artists or elite athletes. Of note, while the reliability and validity of the ADI has been established, the ICC for the question related to sexual activity was not calculated in Noormohmmadpour et al's study due to the low response rate and nature of a sensitive topic in Iranian culture.[56] In our study, however, all artists answered this question.

Our results revealed a significant positive correlation between ADI and NPRS, but no correlation was found with the ODI. This finding also corroborate with Noormohmmadpour et al's study.[56] On average, the NPRS scores in our sample of circus artists was 1 point higher on the 0-10 scale as compared to professional ballet dancers with similar population characteristics.[42] The correlation between NPRS (e.g. pain intensity) and ADI suggests that both daily activities was well as training activities likely influence LBP-related disability in athletes. Furthermore, the ADI and NPRS were positively correlated with PCS scores, suggesting that artists with higher pain catastrophizing thoughts also reported higher pain intensity and LBP-related disability. Although artists with chronic LBP generally had higher PCS scores, there was no correlation with pain duration. We are not aware of any previous studies that have assessed PCS scores in performing artists with LBP. While the NPRS and ADI measure perceived pain and disability level, the cross-sectional nature of this study does not allow to establish a causal relationship between pain, disability and catastrophizing. Overall, our findings suggest that the ADI is likely a better tool to assess LBP-related disability in performing artists and that healthcare providers and researchers should consider screening for pain catastrophizing to increase personalized patient care, prevention and treatment plans.

Limitations

Despite the high prevalence of LBP in our sample, the sample size was too small to establish potential risk factors such as certain disciplines or years training circus as be potential risk or preventive factors towards LBP. Our findings provide preliminary information in LBP in this population; however, we are unable to establish the incidence of LBP in circus artists due to the nature of this exploratory study and voluntary basis for participation which may have insighted more students with LBP or interested in LBP to participate.

PRELIMINARY CONCLUSION

Our findings provide novel insights regarding the high prevalence of LBP in student circus artists. In our sample, 55% of circus students had a history of LBP, with 55.5% reporting acute and 44.5% reported chronic LBP. Despite the strong correlation between ODI and ADI scores, our findings suggest that the ADI may be a better tool to assess LBP-related disability in performing artists. Future studies in artists should consider screening for pain catastrophizing as our findings revealed significant positive correlations between LBP intensity and related disability with PCS scores.

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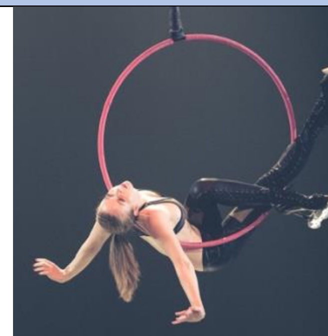
CHAPTER 5 – APPENDIXES

APPENDIX A – Circus Disciplines

Circus Discipline	Description	Visual
Aerial Acrobatics		
Aerial Hoop	Circular aerial apparatus made of metal in varying diameters that is attached at one or two points.	
Straps	Two thin parallel straps along which the artist rolls and unrolls using their wrists and arms to execute rises, falls and aerial acrobatics.	
Corde Lisse (rope)	Vertical cotton rope stranded or braided of 3-to-5-centimetre diameter.	
Silks	Two fabric panels created by a folding a large length of fabric over a hooking device.	

Swinging Trapeze	A trapeze suspended at a great height (min. range of 14 meters).	
Cloud Swing	A slack rope attached at both ends to form a swing around 6 metres long. As it swings back and forth, the artist performs holds, turns and other aerial acrobatics.	
Static Trapeze	A simple trapeze hung at various heights upon which one or two artists execute moves without no swing from the trapeze. The Static Trapeze employed by two acrobats has the carrier that attaches themself to the trapeze with bent knees and the carrier can hold or propel the flyer to perform various aerial acrobatics.	
Dance Trapeze	A trapeze with both ropes attached on a single point.	

Russian Cradle	The apparatus composed of gantries secured on the ground with a platform. At the platform level, the catcher is attached at the waist and propels the flyer or flyers into the air to execute aerial acrobatics.	 

Floor acrobatics		
Chinese Hoops	An acrobat dives through a set of wooden or metal hoops of varying diameters balancing one on top of the other on the ground.	
Chinese Pole	One or several vertical metal posts fixed into the ground and around 3-to-9 metres in height.	
Russian Bar	Two carriers support a flexible bar on their shoulder or arms and a flyer stands upright and performs on the bar.	
Trampoline	Discipline from gymnastics often used in combination with other acrobatic discipline to propel the flyer to greater heights.	

Korean board	A rocking board where two acrobats stand on each end and are catapulted in turn. Artists take off and land on a hard static surface resembling a seesaw.	
Hand to Hand	Two or more acrobats on the ground including a carrier that carries the flyer on the hands or the head. The two forms of Hand to Hand are: - Static (the carrier and flyer perform only moves involving strength and balance with no great need to move through space.) - Dynamic (the carrier provides the propulsion to the flyer, who performs different acrobatic jumps landing on the shoulders of the partner, another carrier, or the ground.)	
Contortion	A contortionist performs exaggerated positions with extreme stretching, flexing and bending of the arms and legs. It includes back-bending, front-bending and dislocation.	
Equilibrium		
Tight Wire	A metal cable suspended horizontally between two mounts generally performed at a low height, unlike High Wire, which is performed at a great height.	
Slack Wire	Related to the Tight Wire, the difference is the slack tension of the cable or rope causing the line to curve between the mounts. The acrobat moves along the wire and by rocking.	

Hand Balancing	Acrobat executes various moves and acrobatics while balancing on the hands or head. This may be performed on the ground or on some apparatus. The main apparatus used is canes (metal rods set at varying heights and capped by blocks for the hands)	
Cyr Wheel	A simple metal circle in which the acrobat moves and executes acrobatic moves.	
Bicycle	Perform acrobatic movements on a moving or static bicycle.	
Manipulation		
Clowning Art		

APPENDIX B - Online Questionnaire (English Version)

Welcome!

You are being invited to complete this survey to participate in this circus research on circus artists and low back pain. If there is anything you do not understand, or if you want more information, please contact and ask the researcher.

Section A: Demographics

General background and training information

A1. ID CODE

A2. Age (in years)

A3. Sex:

This question is not mandatory.

- Male ☐
- Female ☐
- Intersexed ☐
- Other ☐

A4. Program Year of DEC/DEE:

- Preparatory Year ☐
- Year 1 ☐
- Year 2 ☐
- Year 3 ☐

A5. Ethnicity:

- White/Caucasian ☐
- Hispanic or Latino ☐
- Black or African American ☐
- American Indian or Alaskan Native ☐
- Asian or Pacific Islander ☐
- Prefer not to answer ☐

A6. How many years have you been training circus?

A7. Are you a generalist (2-3 disiciplines in different families) or a specialist (one main discipline)?

Circus families are floor acrobatics, aerial acrobatics, equilibrium, manipulation and clowning skills.

- Generalist ☐
- Specialist ☐

A8. What is your main circus discipline?

- Aerial Hoop ☐
- Straps ☐
- Silks ☐
- Corde Lisse ☐
- Cloud Swing ☐
- Dance Trapeze ☐
- Swinging Trapeze ☐
- Hand Balancing ☐
- Cyr Wheel ☐
- Juggling ☐
- Clowning ☐
- Hula Hoop ☐
- Hoop Diving ☐
- Hand to hand FLYER ☐
- Hand to hand PORTER ☐
- Contorsion ☐
- Chinese Pole ☐
- Other ☐

Other

A9. How many years you have trained in your main discipline?

A10. How many hours do you train your main discipline in a week?

A11. What other circus disciplines do you train in?

Please specify how many years you have trained in each discipline and how many hours you train each discipline in a week.

You do not need to check your main discipline for this question.

- Aerial Hoop ☐
- Straps ☐
- Silks ☐
- Corde Lisse ☐
- Cloud Swing ☐
- Dance Trapeze ☐
- Swinging Trapeze ☐
- Hand Balancing ☐
- Cyr Wheel ☐
- Juggling ☐
- Clowning ☐
- Hula Hoop ☐
- Hoop Diving ☐
- Hand to Hand FLYER ☐
- Hand to Hand PORTER ☐
- Contortion ☐
- Chinese Pole ☐
- Other ☐

Other ____________________

A12. Do you have a history of elite training in any other sport prior to doing circus arts?

If you have trained a sport, please specify how many years you had practiced this sport.

- None ☐
- Gymnastics ☐
- Dance ☐
- Figure Skating ☐
- Synchronized Swimming ☐
- Martial Arts ☐
- Other ☐

Other

Section B: Laterality

B1. What is your preferred hand grip?

- Left Hand ☐
- Right Hand ☐
- No Preference ☐

B2. What is your preferred spinning side?

- I don't spin ☐
- Clockwise ☐
- Counter-clockwise ☐
- No preference ☐

B3. **Are both your splits equal in flexibility?**

Yes, both are equal ☐

No, my left front leg is better ☐

No, my right front leg is better ☐

Section C: Injury History

C1. **IN THE PAST YEAR, have you had an injury(ies) to your head, neck or trunk (e.g. ribs, spine)?**

******An injury is defined as any injury requiring treatment******

Yes ☐

No ☐

C2. **HEAD, NECK & TRUNK:**

Briefly describe the injury(ies) and the exact location of the injury (e.g. location & side of the body injured).

******An injury is defined as any injury requiring treatment******

C3. **IN THE PAST YEAR, have you had an injury(ies) to your arms (eg. shoulder, elbow, wrist)?**

******An injury is defined as any injury requiring treatment******

Yes ☐

No ☐

C4. **ARMS:**

Briefly describe the injury(ies) and the exact location of the injury (eg. location & side of the body injured).

******An injury is defined as any injury requiring treatment******

C5. **IN THE PAST YEAR, Have you had an injury(ies) to your legs (eg. hip, thigh, groin, knee, ankle, shin, foot)?**

******An injury is defined as any injury requiring treatment******

Yes ☐

No ☐

C6. **LEGS:**

Briefly describe the injury(ies) and the exact location of the injury (eg. location & side of the body injured).

******An injury is defined as any injury requiring treatment******

C7. **Do you have a recurrent injury(ies)?**

If yes, what are your recurrent injury(ies)?

No ☐

Yes ☐

C8. **Have you had any major surgeries?**

If yes, what was/were the major surgery(-ies)?

No ☐

Yes ☐

C9. **Are you currently taking any prescribed medication?**

If yes, please specify the medication.

No ☐

Yes ☐

C10. **Have you ever been told you have a "twist in the spine" or scoliosis?**

If yes, please specify what you have been told.

No ☐

Yes ☐

Section D: Low Back Pain

D1. **Have you had pain in your lower back in the past 4 WEEKS?**

Yes ☐

No ☐

D2. How long did it last (in weeks)?

D3. Was this your first episode of low back pain?

Yes ☐

No ☐

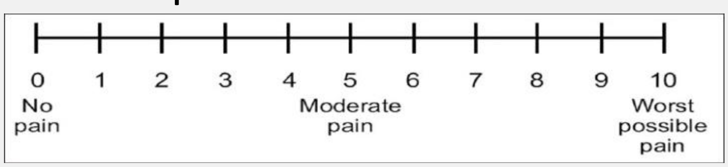
D4. Where was the pain located?

Centered ☐

Left Side ☐

Right Side ☐

D5. How severe was your low back pain on a scale of 0 to 10?



D6. Have you had pain in your lower back in the past 3 months?

Yes ☐

No ☐

D7. How long did it last (in weeks)?

D8. Was this your first episode of low back pain?

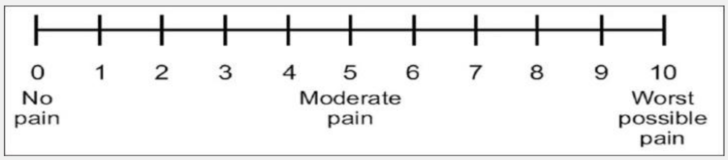
Yes ☐

No ☐

D9. Where was the pain located?

- Centered ☐
- Left Side ☐
- Right Side ☐

D10. How severe was your low back pain on a scale of 0 to 10?



Section E: Low Back Pain - Oswestry Disability Index

This questionnaire has been designed to give us information as to how your back or leg pain is affecting your ability to manage in everyday life. Please answer by checking ONE box in each section for the statement which best applies to you. We realise you may consider that two or more statements in any one section apply but please just shade out the spot that indicates the statement which most clearly describes your problem.

E1. Section 1 - Pain intensity

- I have no pain at the moment ☐
- The pain is very mild at the moment ☐
- The pain is moderate at the moment ☐
- The pain is fairly severe at the moment ☐
- The pain is very severe at the moment ☐
- The pain is the worst imaginable at the moment ☐

E2. Personal care (washing, dressing etc)

- I can look after myself normally without causing extra pain ☐
- I can look after myself normally but it causes extra pain ☐
- It is painful to look after myself and I am slow and careful ☐
- I need some help but manage most of my personal care ☐
- I need help every day in most aspects of self-care ☐
- I do not get dressed, I wash with difficulty and stay in bed ☐

E3. Section 3 – Lifting

- I have no pain at the moment ☐
- I can lift heavy weights without extra pain I can lift heavy weights but it gives extra pain ☐
- Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently placed Eg. On a table ☐
- Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned ☐
- I can lift very light weights ☐
- I cannot lift or carry anything at all ☐

E4. Section 4 – Walking

- Pain does not prevent me walking any distance ☐
- Pain prevents me from walking more than 1 mile ☐
- Pain prevents me from walking more than 1/2 mile ☐
- Pain prevents me from walking more than 100 yards ☐
- I can only walk using a stick or crutches ☐
- I am in bed most of the time ☐

E5. Section 5 – Sitting

- I can sit in any chair as long as I like ☐
- I can only sit in my favourite chair as long as I like ☐
- Pain prevents me sitting more than one hour ☐
- Pain prevents me from sitting more than 30 minutes ☐
- Pain prevents me from sitting more than 10 minutes ☐
- Pain prevents me from sitting at all ☐

E6. Section 6 – Standing

- I can stand as long as I want without extra pain ☐
- I can stand as long as I want but it gives me extra pain ☐
- Pain prevents me from standing more than 1 hour ☐
- Pain prevents me from standing more than 30 minutes ☐
- Pain prevents me from standing more than 10 minutes ☐
- Pain prevents me from standing at all ☐

E7. Section 7 – Sleeping

- My sleep is never disturbed by pain ☐
- My sleep is occasionally disturbed by pain ☐
- Because of pain I have less than 6 hours sleep ☐
- Because of pain I have less than 4 hours sleep ☐
- Because of pain I have less than 2 hours sleep ☐
- Pain prevents me from sleeping at all ☐

E8. Section 8 – Sex life (if applicable)

- My sex life is normal and causes no extra pain ☐
- My sex life is normal but causes some extra pain ☐
- My sex life is nearly normal but is very painful ☐
- My sex life is severely restricted by pain ☐
- My sex life is nearly absent because of pain ☐
- Pain prevents any sex life at all ☐

E9. Section 9 – Social life

- My social life is normal and gives me no extra pain ☐
- My social life is normal but increases the degree of pain ☐
- Pain has no significant effect on my social life apart from limiting my more energetic interests eg, sport ☐
- Pain has restricted my social life and I do not go out as often ☐
- Pain has restricted my social life to my home ☐
- I have no social life because of pain ☐

E10. Section 10 – Travelling

- I can travel anywhere without pain ☐
- I can travel anywhere but it gives me extra pain ☐
- Pain is bad but I manage journeys over two hours ☐
- Pain restricts me to journeys of less than one hour ☐
- Pain restricts me to short necessary journeys under 30 minutes ☐
- Pain prevents me from travelling except to receive treatment ☐

Section F: Athletes Disability Index Questionnaire

This Questionnaire is Designed to Assess How Low Back Pain is Affecting Your Circus Training and Daily Activities. Please Read the Following Questions Carefully and Choose the Option That Best Describes Your Current Situation.

This Questionnaire is Designed to Assess How Low Back Pain is Affecting Your Circus Training and Daily Activities. Please Read the Following Questions Carefully and Choose the Option That Best Describes Your Current Situation.

F1. Low Back Pain:

- I have no pain. ☐
- I have mild pain. ☐
- I have moderate pain. ☐
- I have severe pain. ☐

F2. Stretching exercises

- I can perform all stretching exercises without any back pain. ☐
- I can perform all stretching exercises but some of them are painful. ☐
- I cannot perform some stretching exercises because of my back pain. ☐
- I cannot perform any stretching exercises because of my back pain. ☐

F3. Strengthening/weight training exercises

- I perform all strength/resistance exercises without pain. ☐
- I can perform all strength/resistance exercises but some with pain. ☐
- There are some strength/resistance exercises I can't perform due to back pain. ☐
- I have completely quit strength/resistance exercises because of pain. ☐

F4. Your sport-specific moves or skills

- I perform all drills without any pain or restriction. ☐
- I perform all drills, but I feel some pain. ☐
- I cannot perform some of my drills because of pain. ☐
- I cannot perform any sport-specific drills. ☐

F5. Movement involving back rotations or change of direction

- I have no problem rotating my back or changing direction. ☐

I can perform back rotation and direction changing activities but some with pain. ☐

I am restricted in rotating my back and/or changing direction due to pain. ☐

I cannot perform rotational back movements or change direction because of pain. ☐

F6. Sitting

I can sit on any chair (surface) for as long as required. ☐

I can sit as long as required but I experience some pain. ☐

I have to leave the chair earlier than required because of pain. ☐

I can only sit for a short while because of pain. ☐

F7. Walking

I can walk on level and sloped surfaces, as well as stairs ☐

I can only walk on level surfaces without experiencing pain. ☐

My walking duration or speed has been affected by pain. ☐

The pain has severely limited my ability to walk. ☐

F8. Sleep

I have no pain or restrictions while sleeping. ☐

I can sleep without pain if I position myself in a certain way(s). ☐

I sleep less than before because of the pain. ☐

My sleep has been totally disrupted. ☐

F9. Personal care (putting on socks and shoes, going to the bathroom)

I can perform all personal-care activities without pain. ☐

I am capable of performing them, but they sometimes cause pain. ☐

I cannot perform some of my personal care due to pain. ☐

I need assistance for almost all personal care activities. ☐

F10. Fear of causing pain or damaging the back

- I have no fear of pain while performing sports activities/exercises. ☐
- I perform my training despite the fear of pain. ☐
- Fear of pain prevents me from performing some activities/movements. ☐
- Fear of pain has made me stop performing sports activities/exercises. ☐

F11. Leisure activities

- I perform my leisure activities without any pain. ☐
- Despite some pain, I do all of my leisure activities. ☐
- I avoid some recreational activities due to pain. ☐
- I avoid almost all recreational activities due to pain. ☐

F12. Sexual Activity

- I do not experience any back pain or limitations during sexual activity. ☐
- I have maintained my sexual activity but I do experience some back pain. ☐
- I have had to reduce sexual activity due to pain. ☐
- I completely refrain from sexual activity because of the back pain. ☐

Section G: Pain Catastrophizing Scale

G1. **We are interested in the types of thoughts and feelings that you have when you are in pain. Listed below are 13 statements describing different thoughts and feelings that may be associated with pain. Using the following scale, please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.**

0 – not at all 1 – to a slight degree 2 – to a moderate degree 3 – to a great degree 4 – all the time

When I'm in pain ...

	0 - not at all	1 – to a slight degree	2 – to a moderate degree	3 – to a great degree	4 – all the time
I worry all the time about whether the pain will end.	☐	☐	☐	☐	☐
I feel I can't go on.	☐	☐	☐	☐	☐
It's terrible and I think it's never going to get any better.	☐	☐	☐	☐	☐
It's awful and I feel that it overwhelms me.	☐	☐	☐	☐	☐
I feel I can't stand it anymore.	☐	☐	☐	☐	☐
I become afraid that the pain will get worse.	☐	☐	☐	☐	☐
I keep thinking of other painful events.	☐	☐	☐	☐	☐
I anxiously want the pain to go away.	☐	☐	☐	☐	☐

	0 - not at all	1 – to a slight degree	moderate degree	3 – to a great degree	4 – all the time
I can't seem to keep it out of my mind.	☐	☐	☐	☐	☐
I keep thinking about how much it hurts.	☐	☐	☐	☐	☐
I keep thinking about how badly I want the pain to stop.	☐	☐	☐	☐	☐
There's nothing I can do to reduce the intensity of the pain.	☐	☐	☐	☐	☐
I wonder whether something serious may happen.	☐	☐	☐	☐	☐

Section H: End of Survey

H1. **Thank you very much for participating!**

Is there any more information you would like to share with us that might help us?

Thank you very much for participating!