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Urinary Incontinence in Young Nulliparous Women: The Effects of Different Levels of Physical Activity

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Every dream that you leave behind,

is a piece of your future that no longer exists

Steve Jobs

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A incontinência urinária de esforço (IUE) é a perda de urina que ocorre em sincronia com atividades que aumentam a pressão intra-abdominal. Este tipo de incontinência urinária (IU) é a mais comum e, recentemente, as maiores prevalências foram relatadas entre atletas femininas. Diversos fatores de risco clássicos como idade, obesidade e parto parecem ter relação direta com a IU, mas o papel da atividade física (AF) permanece controverso. Assim, esta tese teve por objetivo clarificar o papel de diferentes níveis de AF na frequência de IU, tal como analisar a morfologia e função dos músculos do pavimento pélvico (MPP). Assim, realizamos uma revisão da literatura, seguido por cinco estudos transversais com mulheres que não tinham os tradicionais fatores de risco de IU. Os sintomas de IU e a AF foram avaliados por questionários de auto-relato. Cada estudo teve testes estatísticos apropriados. Estudo I avaliou a frequência de IUE entre mulheres atletas e sua associação com as variáveis de treino. No Estudo II, avaliamos a influência dos diferentes níveis de AF em uma amostra de 386 mulheres. Estudo III também averiguou a IU em diferentes níveis de AF mas objetivamente medida por acelerómetros. Para avaliar se características estruturais e biomecânicas dos MPP podem influenciar a IU, realizamos o Estudo IV. Por fim, o Estudo V aferiu a anatomia e o deslocamento dos MPP após a prática de diferentes desportos a longo prazo utilizando imagens de ressonância e modelos 3D. Os resultados permitem concluir que existe uma alta frequência de IU em atletas, as quais possuem 2.53 vezes maior risco de desenvolver IU comparativamente as não atletas; ademais, o ranking das atletas e o volume de treino foram identificados como fatores de risco para IU, tal como o cenário oposto, o sedentarismo pareceu favorecer a IU. Os resultados também demonstram que cumprir as diretrizes de AF não é associado com a IU. Por fim, os resultados apoiam que diferentes morfologias dos MPP induzido pela AF recreativa de baixo ou alto-impacto, não promovem sintomas de IU.

PALAVRAS-CHAVE: PRESSÃO INTRA-ABDOMINAL; EXERCÍCIO; INCONTINÊNCIA URINÁRIA DE ESFORÇO; COMPORTAMENTO SEDENTÁRIO; MÚSCULOS DO PAVIMENTO PÉLVICO.

Abstract

Stress urinary incontinence (SUI) is the leakage of urine that occurs synchronously with activities that increase the intra-abdominal pressure. This dysfunction is the most common type of urinary incontinence (UI) and, recently, the highest prevalence were found in female athletes. Numerous classical risk factors such as aging, obesity, and childbirth appear to have direct relationships with UI, whereas the role of physical activity (PA) remains controversial. Thus, this thesis aimed to clarify the role of different PA levels in the frequency of UI, as well as to analyze the morphology and function of the pelvic floor muscles (PFM). Thus, we carried out a literature review, followed by five cross-sectional studies among women that did not present the traditional risk factors for UI. UI symptoms and PA were assessed via self-reported questionnaires. Each study was supported by appropriate statistical tests. Study I evaluated SUI frequency in female athletes and its associations with training variables. In Study II, we determined the influence of different PA levels on the UI frequency in a sample of 386 women. The Study III also investigated UI among different PA levels but, now, PA was objectively measured by accelerometers. To assess if structural and biomechanical characteristics of the PFM may influence UI, Study IV was performed. Finally, Study V evaluated the PFM anatomy and displacement after long-term practice of different sports using resonance imaging and 3D models. The results allowed concluding the existence of a high frequency of UI in athletes, that have a 2.53 times greater risk to develop UI comparatively to their peers non-athletes; moreover, the athletes' ranking and training volume were identified as risk factors for UI, as well as the opposite scenario, the sedentary behavior seems to favor UI development. The results also demonstrated that comply PA guidelines is not associated with the occurrence of UI. Finally, the results support the concept that differences in the PFM morphology induced by low or high-impact PA for recreational purposes, do not promote UI symptoms.

KEYWORDS: INTRA-ABDOMINAL PRESSURE; EXERCISE; STRESS URINARY INCONTINENCE; SEDENTARY BEHAVIOUR; PELVIC FLOOR MUSCLES.

List of Abbreviations

ACSM	American College of Sports Medicine
ANOVA	analysis of variance
AP	antero-posterior
BMI	body mass index
CG	continent group
FE	finite element
IAP	intra-abdominal pressure
ICI	International Consultation on Incontinence
ICIQ-UI-SF	International Consultation on Incontinence Questionnaire - Short Form
ICS	International Continence Society
IG	incontinent group
LH	levator hiatus
MOI	moment of inertia
MRI	magnetic resonance imaging
MUI	mixed urinary incontinence
MVPA	moderate-to-vigorous physical activity
PA	physical activity
PFM	pelvic floor muscles
PFMT	pelvic floor muscle training
POP	pelvic organ prolapse

PV	pubovisceral
RCTs	randomized controlled trails
SD	standard deviation
SPSS	statistical package for the social science
SUI	stress urinary incontinence
UI	urinary incontinence
UUI	urgency urinary incontinence

Chapter I

General Introduction

Introduction

Stress urinary incontinence (SUI) is the most common type of involuntary leakage of urine among women. It may result from a wide spectrum of varying degrees of disruption of normal anatomy and/or function of the pelvic floor muscles (PFM).This particular type of urinary incontinence (UI) occurs during the increase in intra-abdominal pressure (IAP) (Haylen et al., 2010). It is estimated that SUI affects around 40% of European women and a recent study showed that in Portugal 21.4% of women with age ≥40 years reported at least one episode of urinary leakage (Correia, Dinis, Rolo, & Lunet, 2009).

SUI has a considerable impact on those affected women, both physically and mentally. Without an identified specific etiology, several researches have investigated during the last century some personal characteristics associated with the development of SUI and have recognized that some factors such as the race (Hay-Smith et al., 2009), hormonal changes from ageing (Bresee et al., 2014), increase in IAP by obesity (Dursun et al., 2014) or by pregnancy (Dolan et al., 2004), and damage to the PFM during delivery (Gyhagen, Bullarbo, Nielsen, & Milsom, 2013) are the main and substantiated risk factors to develop SUI. Curiously, the highest prevalence of SUI is currently found in young, nulliparous and physically active women, who do not present any of those traditional risk factors (Eliasson, Larsson, & Mattsson, 2002). This relatively high rate of SUI in the young population reinforces the need for better understandings about the pathophysiology of SUI in order to efficiently prevent or treat this clinical condition. This information would be highly useful because the factors favoring the development of UI in nulliparous young women are still scarcely known.

Urinary continence is the result of a many-sided and fascinating co-ordination between both central (autonomic and somatic innervations) and peripheral (bladder, urethra, muscles and bony supporting structures) control mechanisms (Daneshgari & Moore, 2006). While awareness of risk factors for UI in young women is improving slowly, several studies have associated the development of SUI with morphological or functional alterations of the PFM,

rather than with other structural dysfunction (Bø, 2004; Kruger, Dietz, & Murphy, 2007). The PFM, the diaphragm, the *transverses abdominis* muscles and the low back spine are the main structures responsible for managing the IAP. While almost all of those structures that surround the abdominal cavity do not suffer gravitational loading, the PFM located in the caudal confinement of the pelvic cavity are more prone to IAP-induced downward compression that occurs during physical tasks done at work or at home using the trunk, (Sapsford, 2004). Therefore, since IAP increases with efforts, progressively higher IAP is expected with more intense and demanding exercises (Shaw et al., 2014). Importantly, in response to this, the PFM are lifted at contraction, closing the *urogenital hiatus* and maintaining urine continence.

Depending of the doses of physical activity (PA), two opposing consequences might be expected from strenuous exercise on the pelvic floor functioning: (1) PA may strengthen the PFM, or (2) PA may overload, stretch, and weaken these muscles (Bø, 2004). It is recognized that PFM co-activates with abdominal and other core muscles during voluntary exercise to maintain lumbo pelvic stability (Sapsford et al., 2001). To support this rationale, women who are regular practitioners of exercises should have strong and effective PFM and consequently should not present PFM dysfunction such as SUI. However, on the other hand, one should consider the limited capacity of neuromuscular adaptations when facing high IAP demands. Therefore, women can develop SUI (Nygaard, Hamad, & Shaw, 2013) resulting from rapid, sudden and frequent increase in IAP (Eliasson et al., 2002). Indeed, the excessive increase in IAP overloads the PFM pushing them down. So, the muscles and ligaments that support the pelvic floor and suspend the pelvic organs can be damaged by repeated and demanding physical exercise.

Until now, the association between PA and SUI has been controversial. While some authors related PA with extremely harmful consequences for PFM, (Eliasson et al., 2002; Nygaard, Thompson, Svengalis, & Albright, 1994), others reported no effects or even positive effects on PFM (Hannestad, Rortveit, Sandvik, & Hunskaar, 2000; A. H. Lee & Hirayama, 2012; Zhu, Lang, Wang,

Han, & Huang, 2008). Considering the consequences of PA on PFM, studies have demonstrated that female athletes have thicker PFM when compared to non-athletic controls (Kruger et al., 2007; Kruger, Murphy, & Heap, 2005), and furthermore have strong PFM contraction (Eliasson et al., 2002). However, interestingly enough, it seems to be consensual that women training high-impact sports (Eliasson et al., 2002) or those who compete for prolonged periods (Da Roza, Brandao, Mascarenhas, Jorge, & Duarte, 2014) are the ones with higher rates of UI. For instance, jumps can generate a maximum reaction force on the PFM of as much as 16 times the body weight (Hay, 1993), such as parachute jumping (Davis & Goodman, 1996), which may lead to SUI. Indeed, performing high training volumes along many years in the upright position can develop structural and/or functional changes in the PFM. It should be noted, however, that these assumptions about the negative effects of physical training on PFM are just supported by the highest frequency of SUI registered in athletes engaged with high-impact sports, and none of the studies has established any relationship between the characteristics of the performed training and the severity of UI.

More recently, research has focused on PFM fatigue (Ree, Nygaard, & Bo, 2007) or delayed reflex (Da Roza et al., 2014) to explain the involuntary loss of urine. Although some authors defend that PFM can be trained by synergic effect of PA, each female athlete might have a personal threshold of exercise intensity or training volume over which their PFM will not support repetitive impact (Eliasson, Nordlander, Larson, Hammarstrom, & Mattsson, 2005). Under normal circumstances, performing a rapid, strong, and well-timed PFM contraction seems to compress the urethra (Baessler, Miska, Draths, & Schuessler, 2005) to prevent its descent (Dietz, Steensma, & Vancaillie, 2003) and consequently to avoid urine leakage (Bø, 1995). Thus, the timing of a PFM contraction is an important factor to preserve urinary continence (Moore et al., 2013), which can be strictly related to the muscle spindles. They are the most important and specialized sensory receptors of length in skeletal muscle. In fact, muscle spindles help maintain muscle tone as they provide resistance to stretch

and are also involved in the stretch reflex (Dimitriou, 2014). However, to date, there is not enough scientific evidence to sustain these hypotheses.

Beyond this extreme condition associated with high impact exercises for competitive purposes, few studies have investigated the prevalence of SUI among young female non-athletes (Bø, Bratland-Sanda, & Sundgot-Borgen, 2011). Since moderate-to-vigorous PA is recommended as one of the greatest priorities to promote women's health (Maiese, 2002), and the majority of young women practice exercise for recreational purposes, it is of great importance to clarify the influence of regular PA on SUI (Shaw et al., 2014). Indeed, some studies have evaluated the impact of levels of PA on UI, but the results are inconclusive (Hannestad et al., 2000; A. H. Lee & Hirayama, 2012; Zhu et al., 2008). These confounding results are in part due to non-standardized methodologies used to determine the prevalence of UI, the wide age range of samples, the use of different definitions of exercise and its levels, the small sample sizes, the cultural variances of each population (which leads to incomparable studies) and the lack of age- and inactive- matched control, among others. Besides that, studies concerning UI and exercise have used subjective analysis with questionnaires to assess de PA level, which can lead also to a significant bias of the results. Since determining the amount of PA is essential to evaluate its effects on PFM, it should be done with an objective measure that enables to record from the inactive behavior until vigorous activity.

Apart from these, since the PFM strength is reported objectively using a vaginal pressure device (Knight et al, 1998), the stress forces that the PFM are submitted during increases of IAP (e.g. exercise) are not known. This limitation is mainly due to the PFM location - inside the pelvis (DeLancey, 1994) - which makes its very difficult to develop experimental work *in vivo*. Thus, building a computational model capable of reproducing the PFM behavior during raises in IAP could be a first step to understand the local effects of PA. Computational models allow visualizing the potential mechanisms causing PFM dysfunction from a biomechanical perspective (da Silva-Filho et al., 2010). Until now, important developments have enabled a better understand of childbirth and

female pelvic organ prolapse (Chen, Ashton-Miller, & DeLancey, 2009; Noakes, Bissett, Pullan, & Cheng, 2008; Parente, Natal Jorge, Mascarenhas, Fernandes, & Silva-Filho, 2010), but have not been used yet to understand the repercussions of PA on PFM. As the first step to build the 3D models is retrieving geometrical information from imaging, it is also possible to evaluate the PFM morphology among sport women and assess the biometric differences between continent and incontinent ones. Moreover, biomechanical simulation enables to evaluate PFM contraction and the consequent displacement. Assuming the hypothesis that women who undertake high-impact sports for a long period overload their PFM (Bø, 2004), it is expected that these forces cause some degree of muscle damage or weakening, which changes their biomechanical response regarding continence (Dietz & Shek, 2008) in the long-term.

Taking into consideration that the above-mentioned SUI in non-athletes is poorly reported, and that there is still lack of understanding on the role of exercise on the SUI, the present work aims to clarify these items. For that purpose, it is divided into six main sections. The first two are composed by an introduction and a theoretical background where the aspects concerning the prevalence and risk factors for UI, the influence of PA on the PFM as well as the studies concerning the treatment for SUI in young women who practice sports are analyzed. The third section, designed to achieve the main purpose, comprises five original studies, each one with different aims:

Study I, entitled “Volume of training and the ranking level are associated with the leakage of urine in young female trampolinists”, analyzed the association between training volume variables and athletic performance with the UI among female athletes contently submitted to rises in IAP.

In the study II, entitled “Urinary incontinence and levels of regular physical exercise in young women”, the frequency of UI for different PA levels was verified, especially for women that practice recreational activities.

The study III, entitled “Sedentary behavior is a risk factor to develop urinary incontinence in young women” investigated the PA levels and the inactive behavior measured by accelerometer, and their association with symptoms of UI.

The study IV, entitled “Football practice and urinary incontinence: relation between morphology, function and biomechanics”, analyzed the morphological and functional differences between incontinent and continent-matched female football players using biomechanical models.

In the study V, entitled “A pilot study for the analysis of long-term exercise on pelvic floor anatomy and function”, the changes in PFM anatomy and displacement at contraction over a 4-year period of different exercise practices were evaluated.

An integrated discussion of the results is presented in the fourth section. Finally, the fifth and sixth sections gather the main conclusions of this thesis and future works, respectively. At the end of each section, the supporting bibliographic references are presented.

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Chapter II

Theoretical Background

Review Article

Urinary Incontinence in Sport Women: from Risk Factors to Treatment –A Review

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Urinary Incontinence in Sport Women: from Risk Factors to Treatment – A Review

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Abstract: Although a variety of the health benefits have been attributed to regular physical activity, some studies suggested that strenuous exercise may be considered as an independent risk factor for the onset of urinary incontinence in young women. The aim of this article is to provide a review of the scientific literature concerning the role of physiotherapy in the prevention and treatment of urinary incontinence in sport women. Stress urinary incontinence is defined as a leakage of urine during elevated intra-abdominal pressure that can occur during exercise. This dysfunction may affect the quality of life, carrying negative implications on psychological, social and athletic performance. Pelvic floor muscle training has been shown to be an effective treatment in women in general population. However, few studies have been conducted showing the effects of the pelvic floor training in sportswomen. In addition, there are no randomized clinical trials studying this subject. Evidence suggests that stress urinary incontinency may be related to delays in pelvic floor muscles contraction in response to sudden increase of intra-abdominal pressure. Further research is necessary to determine the pelvic floor muscles function in women that perform physical activity with different levels of exigency.

Keywords: Athletes, high impact sports, intra-abdominal pressure, muscle training, pelvic floor muscles, physical exercise, physiotherapy, stress urinary incontinence.

INTRODUCTION

Physical exercise has been highlighted as a primary issue for prevention and therapeutic support of several chronic diseases and to provide numerous psychological benefits [1, 2]. Several studies report that regular exercise improves cardiovascular condition, physical endurance and work capacity [3, 4]. Moreover, it might also increase muscle mass and strength, reduce adiposity, improve physical appearance, neuromuscular co-ordination and cognitive function, thus generally improving the quality of life [5-7]. Hence, sedentary women are often advised to perform regular physical exercise. However, when strenuous, it may be considered as an independent risk factor for the onset of urinary incontinence (UI) [8, 9].

UI is defined by the International Continence Society (ICS) as "complaint of involuntary loss of urine" [10]. The pathophysiology of UI is multifactorial [11], and a wide range of risk factors have been identified. Older age, obesity, gynecological surgery, pregnancy and childbirth are considered to be the main risk factors in weakening the pelvic floor muscles (PFM) and development UI [12, 13]. Interestingly, most of the incontinent women who practices sports or athletes are nulliparous, young and do not have the classic risk factors for pelvic floor problems.

North American [14] and European [15, 16] epidemiological studies conducted with resident women, suggest that 10% to 40% of the studied population is affected by UI. In the late 80s, studies began to emerge relating UI with physical activity in female athletes and non athletes [17]. Recent studies suggest the existence of high incidence of UI in female athletes participating in long-term high impact sports, especially the incontinence that occurs during increases of intra-abdominal pressure (IAP), which is defined as stress UI [18]. The connection between sports activities and pelvic floor dysfunction in young women has been recently a target of attention by the medical community [8, 19-22]. Eliasson *et al.* [23] reported that 80% of nulliparous elite trampolinists, with mean age of 15 years, have involuntary loss of urine during trampoline training.

It is widely accepted that UI adversely affect the quality of life, carrying significant negative implications on psychological, social, physical and economic domains, on personal and sexual relationships [24] and even decrease athletic performance [25]. In addition, during the past decade, the annual direct costs related to UI were calculated to be nearly $20 billion in the United States of America [26]. Since the UI is a global concern, several randomized controlled trails (RCTs) and systematic reviews have concluded that pelvic floor muscle training (PFMT) is an effective therapy for UI in the general population. In this sense, the purpose of this article is to provide a review of the scientific literature concerning the role of physiotherapy in the prevention and/or treatment of UI in sport women, exploring the connection between sports, prevalence and the risk factors to develop urinary incontinence.

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URINARY INCONTINENCE IN SPORT WOMEN

There are three principal types of UI: (1) the urge urinary incontinence (UUI), defined as involuntary loss of urine associated with a sudden and strong desire to void (urgency); (2) the stress urinary incontinence (SUI), that is defined by the ICS as a leakage of urine during elevated intra-abdominal pressure (coughing, sneezing, or exercising); and (3) the mixed urinary incontinence (MUI), that is the complaint of involuntary leakage associated with the urgency and also with exertion, effort, sneezing or coughing [10, 27].

The mechanism of continence is formed by the complex coordination between bladder, urethra, PFM and the supporting ligaments. Briefly, to maintain urinary continence the urethral closure pressure must be greater than bladder pressure, both at rest and during increases in IAP to retain urine in the bladder [28]. Studies demonstrate that in continent women, increases in IAP are preceded by a rise in urethral pressure produced by contraction of the PFM, assisting in the continence [29]. Although no single factor completely explains stress incontinence etiology in fitness women, heavy training could produce a rapid or unexpected increase in IAP which may explain episodes of SUI.

Prevalence and Risk Factors

Nowadays, the SUI represents a large-scale public health concern affecting 26% of women in the community aged 30-59, being considered the most common type of UI [30]. Furthermore, is often regarded as an inevitable part of the aging process with prevalence increasing to 25-40% at 65 years age group [31, 32]. Interestingly, when observed among female elite athletes the prevalence of SUI can achieve rates of 80%. Thyssen *et al.* [33] interviewed elite athletes (with a mean age of 22.8 years) in 8 different sports, including ballet, and found that 51.9% of them had experienced urine loss, 43% while participating in their sport and 42% during daily life. A similar prevalence was found in a study performed by Jácome *et al.* [34] in which UI was experienced by 41.5% of the athletes with the highest rates found in women who practiced high impact sports such trampoline (80%) [23]. According to these findings, a systematic review of Bø *et al*. [19] revealed that the highest prevalence of UI during sports involved high-impact activities such as trampoline, gymnastics and ball games. Other study, analyzing women involved in 12 different sports demonstrated that the SUI was more frequent in hockey and volleyball players than the others sports [21]. Table **1** shows the prevalence of UI in women who practice physical activity.

It is known that only a minority of women become elite athletes. Most women then tend to practice regular physical activity as a key in weight maintenance and obesity prevention or just because they enjoy exercising. Accordingly, a previous study has examined the relation between moderate physical

Table 1. Prevalence of Urinary Incontinence in Sports Women

Author	Year	Design	Subjects	N	Mean Age (Years)	Prevalence of UI	Assessment
Nygaard *et al.*[a]	1990	Cross-sectional	Female volunteers	326	38.5	47%	Questionnaires
Nygaard *et al.*[b]	1994	Cross-sectional	Nulliparous, elite college varsity female athletes	144	19.9	28%	Questionnaires
Nygaard *et al.*[c]	1997	Retrospective and cross-sectional	Former female Olympians in High impact vs. Low impact	104	High impact 46.2 vs low impact 42.4	High impact: 35.8% Low impact: 4.5%	Questionnaires
Bø & Borgen[d]	2001	Cross-sectional; Case control	Elite athletes vs non-athletes	1146	15-39	Athletes: 41% vs. non-athletes 39%	Questionnaire and a clinical interview
Thyssen *et al.*[e]	2002	Cross-sectional	Athletes in eight different sports, including ballet	291	22.8	51.9%	Questionnaire
Eliasson *et al.*[f]	2002	Cross-sectional	Female elite trampolinists	35	15	80%	Questionnaire and Pad test during trampoline (n=18)
Eliasson *et al.*[g]	2005	Observational	Nulliparous women from nine maternity clinic	665	28	High impact 44% Low impact: 30% No activity: 35%	Questionnaire
Eliasson *et al.*[h]	2005	Cross-sectional	Former trampolinists	305	21	Leakage during trampoline training: 45%	Questionnaire
Cayle, *et al.*[i]	2006	Cross-sectional	Elite athletes vs. control group	583	18-35	Elite athletes: 28% Controls: 10%	Questionnaire
Bø *et al.*[j]	2011	Cross-sectional	Fitness instructor	685	32.7	26.3%	Questionnaire
Jácome *et al.*[k]	2011	Cross-sectional	Female athletes	106	24	41.5%	Questionnaire
Fozzatti *et al.*[l]	2012	Prospective comparative	Women who attend gyms vs. who did not attend gyms	488	20-45	Attended gyms: 24.6% Did not attend gyms: 14.3%	Questionnaire

[a][35]; [b][36]; [c][37]; [d][38]; [e][33]; [f][23]; [g][13]; [h][39]; [i][40]; [j][41]; [k][34]; [l][42].

activity and UI in middle-age women. Authors found that moderate exercise is associated with lower risk of developing later SUI [43], and the role of exercise in weight maintenance may explain this association. These findings support the hypothesis that moderate exercise is beneficial to the general health. However, some evidence also supports the contrary, as a recent study in which 488 nulliparous women of normal weight were interviewed, and there was a high prevalence of UI symptoms found in women who frequent the gym, independent of the type of physical activity performed. Considering the total number of women interviewed, reports of urine loss was 39.4%, between the women who attend gyms 14.3% answered loss urine during the exercises, while 57.4% reported emptying the bladder as prevention before starting the exercises [42]. Nygaard *et al.* [36] also found a 28% prevalence of exercise induced SUI in college athletes. Therefore, there is little knowledge about the effects of the exercise in long term to the PFM.

When comparing female athletes with general women, a study found that the athletes had a UI prevalence of 28% while the control subjects only had 9.8% with p=0.001 [40]. Other study, evaluating the prevalence of SUI in 679 women of fertile age that practices recreational sports activity showed that 14.9% of the women reported UI. Additionally, the authors found a higher rate of incontinence in women participating in basketball (16.6%), athletics (15%), and tennis or squash (11%) [44]. Curiously, Bø *et al.* [41] conducting a study among a group of fitness instructors, including yoga and Pilates, reported a prevalence of UI similar to the general population, suggesting that general exercise does not seem to protect against UI [32] So, the exercise could be likely to unmask the symptoms of SUI during exercise, which would not had been revealed if the women were sedentary.

Because of PFM position and considering that sports women have more repetitive events of increased IAP during exercise than the sedentary ones, SUI may be therefore the most frequent form of UI. In addition, Hay [45] reported that the maximum vertical ground reaction forces during landing in long jumps can reach 16 times the athlete's body weight. Some studies support the theory that high-impact sports can lead to SUI by an isolated traumatic event sports such as parachute jumping [46]. Opposed to this, Nygaard [37] analyzed former elite athletes that practice high impact sports when younger in a retrospective study that lasted 16 years. The study divided the former athletes into 2 groups: 1) swimming, low-impact group and; 2) gymnastics and track and field, high-impact group. The author discovered that the practice of high-impact sports did not predispose the athletes to develop UI in older ages. In addition, Bø & Borgen [47] found similar results - they do not demonstrated significant differences between former athletes and controls in the prevalence of UI later in their life. However, it seems to be a consensus regarding the fact that there is no current evidence that strenuous exercise causes UI [32].

At the present, pregnancy and birth are considered the main risk factors for developing pelvic problems that result in pelvic organ prolapse and UI, mainly due to neuromuscular injury in the PFM and ischemic damage in the bladder outlet and urethra [48]. Beyond all the obstetric complications, SUI is also associated with the delivery mode where the forceps-assisted in vaginal delivery may be an additional risk [49]. Until now, there are few researches that had studied morphological changes in the PFM due to the high impact sports and their influence on the delivery mode. Nevertheless, they suggest that the athletes that are submitted a repeated PFM activation develops as a consequence of the sport a muscle hypertrophy, thus hindering the second stage of labor. Authors have reported that some women undergoing high-impact intense training have had unexpected difficulties during delivery, which may be attributable to changes in PFM structure or function [50].

Nonetheless, advancing age, white race, and obesity were very strong factors associated with persistent UI [51]. Sampselle *et al.* [52] demonstrated that bone mass index constituted an important risk for urine loss severity with the increase of 5% probability for leakage of urine. Incidence of new-onset SUI was related to obesity in longitudinal cohort studies [53], supporting a causal relationship. The mechanism by which weight gain and obesity contribute to or worsen SUI has been associated to a constant increase in IAP and stress in the pelvic cavity, causing chronic strain, stretching, and weakening of muscles and nerves. Weight loss was associated to a decrease in symptoms of UI and morbidity following gynecological surgery [54]. Therefore, because obesity is a potential modifiable risk factor for SUI, weight loss through moderate physical exercise may be an effective treatment. So it is necessary to encourage women to practice physical activity.

Another concern with the athletes is the hormonal factor, once decreased levels of estrogen in female athletes with amenorrhea have been associated with reduction in bone mass [55]. Some female athletes involved in sports activities have weight problems, and may have a present or past history of eating disorder. In this context one may encounter the female athletic triad, which refers to amenorrhea, osteoporosis and disordered eating [56]. Several studies have shown that eating disorders such as anorexia nervosa were associated with increased risk of all urinary symptoms [38, 57]. Bø & Borgen [38], in 2001, evaluated the prevalence of SUI and UUI in female athletes analyzing the possible association between UI and eating disorders. The authors found a significantly higher frequency of SUI and UUI in eating disordered athletes compared with healthy athlete (49.5% vs. 38.8% and 20% vs. 15%, with p=0.003 and p=0.048, respectively). Nonetheless, further research into eating disorders and their effects on the PFM is warranted.

Physiopathology

There are two opposing hypotheses about the influence of sports on the pelvic floor. The first states that female athletes have strong pelvic floor muscles; the opposite one defends that female athletes may overload, stretch and weaken their pelvic floor [19]. The first one suggests that any physical activity that increases IAP will lead to a pre-contraction of the PFM and consequently the PFM will be also trained [58]. Therefore, the sport women should be more "protected" from the pelvic floor disorders than the sedentary ones. The second hypothesis, however, indicates changes in PFM collagen content [36] or PFM fatigue-

induced by strenuous physical activity [59], or even that the connective tissue might be chronically damaged due to repeated increases in abdominal pressure [60]. In fact, as a consequence of constant IAP, due to the great forces involved in practicing high impact sports, it might be expected that the athletes progressively develop structural or functional alterations in PFM.

Surprisingly, the athletes' PFM seem to be strong enough to prevent urine leakage [23]. Furthermore, the same occurrence seems to happen with sport and physical education students [58, 61]. Bø *et al.* [58] did not find any difference in PFM pressure during voluntary contraction in continent (14.3 cmH_2O) and in incontinent (16.2 cmH_2O) groups. In the same way, Da Roza *et al.* [61] had evaluated vaginal resting pressure and maximal voluntary contraction pressure in 43 nulliparous sports students (mean age 21±4 years). The authors did not find significant differences in the manometric measurements between the continent and incontinent groups.

Kruger *et al.* [62] in 2005 analyzed the PFM morphology between women who have participated in long-term, high impact and high intensity sport/exercise and women who have not. The authors found significant differences in the cross-sectional area and width (measured in the line of the anal canal) of the PFM between the athletic group and the control ones. Curiously, both variables were greater in the women that practice high impact sports than in control group, with 106±46.05 mm^2 vs. 86.4±28.02 mm^2 and 0.89±0.08 cm vs. 0.67±0.15 cm, respectively. These data, added to the findings of a good PFM strength, suggests that urine leakage in sportswomen with SUI may be due to altered muscle responsiveness to mechanical stimulus. Contrary to these results, in 2013, Borin *et al.* [63] found differences in perineal pressure of volleyball (p=0.009) and basketball players (p=0.039) compared with non athletes.

Probably, such difficulty in quickly contracting the PFM may be related to differences in predominant muscle fiber type [64] or with a tolerance to stretch of muscle spindles within PFM that further generates a delayed reflex response [65, 66]. Indeed, the repeated and frequent overstretching of PFM could have a negative impact on intrafusal fibers, which may be related to delays in force contraction rather than PFM weakness. Nevertheless, despite the exponential increase of published studies over the last decade (Fig. **1**), further studies are needed to support these findings.

ROLE OF THE PHYSIOTHERAPY

Concerning young fitness women, the loss of urine can lead to the abandonment of physical activities and to inactivity [19, 44], which can result in obesity, muscle weakness and postural problems. Nygaard *et al.*, [35] reported that 20% of young women exercisers stopped because of urine leakage. These facts motivate the need to contribute to an effort to apply prevention strategies in young women.

PFMT was reported for the first time by Dr. Arnold Kegel in 1948 and since that time "Kegel exercises" have become a common term to designate the exercises performed to treat pelvic floor dysfunctions [67]. Nowadays, Level 1 grade evidence has shown that PFMT is effective in preventing and treating for SUI. It is also recommended as first-line treatment for UI in young, middle-aged, and elderly women [32, 68-70]. Thus, it is essential that physiotherapists conduct an effective PFM rehabilitation. A correct PFM contraction is characterized by two main components: squeeze around pelvic openings and inward (cranial) lift, elevating the pelvic plate [65].

Recently, Henderson *et al.* [71], in a cross-sectional study with 779 women, assessed the ability that women with or without pelvic floor dysfunction have to contract their PFM after a brief verbal cue. The authors found that the PFM contraction was done correctly on first attempt in 85.5%, 83.4%, 68.6% and 85.8% of women with POP, SUI, both POP and SUI, and neither POP nor SUI, respectively (p=0.01 between POP and SUI vs. neither POP nor SUI). However, and interestingly, Bump *et al.* [72] found that, although contracting correctly, only 50% of a population of continent and incontinent women were able to voluntarily contract the PFM with enough force to increase urethral

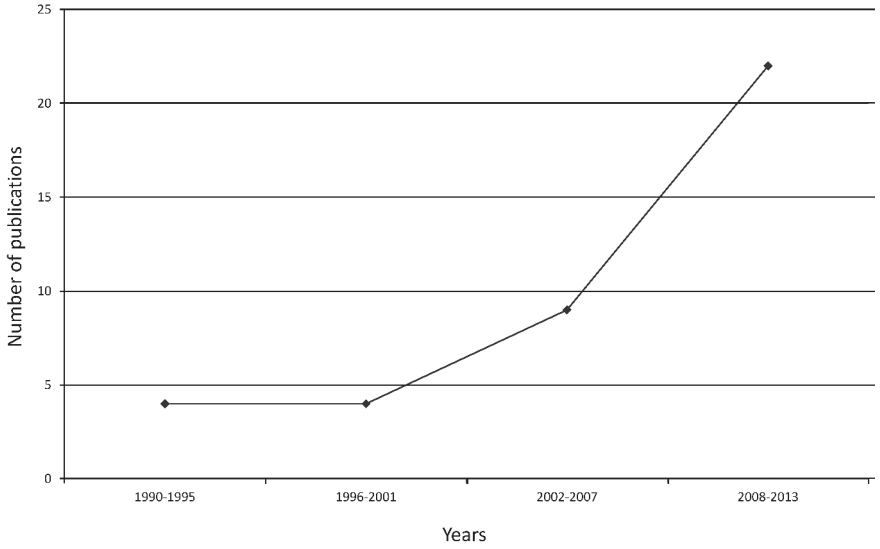


Fig. (1). Number of publications found concerning pelvic floor muscles in sports women.

pressure. Therefore, the physiotherapists should continue to teach patients to perform a correct contraction using visual observation and vaginal palpation - that are useful and easy method applied in clinical practices.

The training of the PFM is defined as repetitive and selective voluntary contraction and relaxation of PFM. Studies suggest that there are three biological rationale to carry the PFMT [25]. The first one suggests that a strong and correct PFM contraction, prior to and during effort, will prevent urine loss. After this, through PFMT, the muscles would be stronger, and that it may facilitate more effective automatic motor unit firing of the PFM. This would improve bladder neck support, which enables it to resist to downward forces during rises in IAP [73]. Last but not least, the third theory suggests that PFMT has implications in the co-ordination of muscle activity, since during the rehabilitation the PFM improves indirectly through abdominal muscle usage [74]. Hence, an increasing tone and co-contraction of PFM and abdominal muscles is expected in continent women during increased impact from physical activity [25].

Work done by Miller *et al.* [74] has shown 98% effectiveness in urine leakage reduction during cough if women perform a pre-contraction before rises in IAP (also called "knack" contraction). However, it is improbable that athletes or sportswomen undertake a voluntary PFM pre-contraction in every increase in IAP. The main purpose of the rehabilitation protocol was to train and strengthen the PFM up to a point where these muscles could unconsciously contract during any increase in IAP [19]. In order to bring light on differences in PFM contractile capacity between continent and incontinent women, that may better explain urine leakage, Madill *et al.* [66], in 2010, studied the patterns of PFM activity during coughing. Their findings suggest that urine loss in women with SUI may be related with the delay in force generation rather than PFM weakness. These findings support the theory that PFMT for SUI may work primarily by improving motor control [25] by teaching women with SUI more effective motor patterns and training the PFM to contract more quickly [66].

In addition, the same group performed an observational pre-post test study in 2013, during a 12-week PFM rehabilitation program in older women. The authors found that the improvements in preventing urine leakage were produced along with improvements in PFM co-ordination, suggesting that PFMT can change the PFM activation patterns employed by incontinent women at the same time as the exercise program decreases their incontinence symptoms [75]. However, the underlying mechanism by which PFM rehabilitation reduces urine leakage is not fully understood yet [75].

A controlled study by McLean *et al.* [76] using ultrasound images showed a significant reduce in urethral mobility during coughing and an increase in the cross-sectional area of the urethra after 12-week PFM training. This study suggests that the Physiotherapist-supervised PFMT is effective to reduce bladder neck motion during coughing. Other study [77], that also evaluated the role of the PFMT in women with UI, performed a training program in three hundred and seventy-two women (mean age 52.3 years) suffering from urinary symptoms. The training was performed during three or more months (mean was 9.9 months) and consisted in practices of three sets per day of contraction and relaxing of PFM. The authors concluded that PFMT was an effective intervention for improve urinary symptoms and the quality of life.

PFMT is often combined with biofeedback to help women learn how to contract the PFM or to improve training performance. A Cochrane systematic review [78] reported that the biofeedback may provide benefit in addition to the PFMT in women with UI. However, this review contended that these findings may be confounded by a difference in PFMT programs, e.g. dosage of training, the degree of contact with the health professionals or the heterogeneity in the inclusion criteria. Accordingly, a recent RCT using the same PFMT program in two groups showed that PFMT, with or without biofeedback, increased the strength of the PFM, decreased the number of leakages episodes and improved the quality of life in both groups. However the study did not found significant difference after 12 weeks of training between the groups [79]. The ICI demonstrated that the trials suggested that treatment effect might be greater in SUI women who tended to be younger (in their 40s and 50s) and participated in a supervised PFMT program for at least three months [32]. Furthermore, women who had higher contact with the health professionals and who received regular (e.g. weekly) supervision were more likely to report improvement than women doing PFMT with little or no supervision [80].

A search of PubMed and Scopus did not reveal any randomized controlled trials of PFMT in young nulliparous sportswomen or female elite athletes. Only two recent studies reported results from the effect of PFMT on sportswomen [70, 81]. The first published study was a case study addressing the outcome of a 4-month treatment for UI in 3 female volleyball players. The results indicated that an individualized PFM rehabilitation program including biofeedback, functional electrical stimulation, and PFMT with and without vaginal cones could reduce UI [81]. The other was a pre-post test pilot study with seven female sport students that reported SUI. After 8 weeks of PFMT, the outcomes demonstrated a significant improvement in vaginal resting pressure, frequency and amount of leakage [70].

Currently, there are still questions on the effectiveness of PFMT in long-term outcome. In a systematic review, Bø and Hilde [82] demonstrated evidence of muscle strength loss from weeks 12 to 31 after cessation of training, both to the elderly and younger group. However, no study has evaluated how many contractions women need to perform to maintain PFM strength after cessation of organized training [82]. Certainly, more research is needed in this area.

CONCLUSIONS

The literature shows that the prevalence of SUI in young female sportswomen is high, especially in women practicing high-impact sports. Furthermore, SUI may be a barrier for their participation in sports events due to emotional implications. The pathophysiology of UI is multifactorial. Evidence suggests that SUI may be related to delays in PFM contraction. There are no randomized clinical trials reporting the effects of PFMT in sportswomen. Further research is

necessary to determine the pelvic floor muscles function in women that perform physical activity.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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ABBREVIATIONS

IAP	=	Intra-Abdominal Pressure
ICS	=	International Continence Society
MUI	=	Mixed Urinary Incontinence
PFM	=	Pelvic Floor Muscles
PFMT	=	Pelvic Floor Muscle Training
RCTs	=	Randomized Controlled Trails
SUI	=	Stress Urinary Incontinence
UI	=	Urinary Incontinence
UUI	=	Urge Urinary Incontinence

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Chapter III

Original Articles

Study I

Volume of Training and the Ranking Level are Associated with the Leakage of Urine in Young Female Trampolinists

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Clinical Journal of Sport Medicine [Epub ahead of print]

Volume of Training and the Ranking Level Are Associated With the Leakage of Urine in Young Female Trampolinists

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Objectives: The aim of this study was to investigate in young nulliparous female trampolinists the hypothetical associations between the level of athletic performance and the volume of training with urine leakage.

Design: Cross-sectional cohort study.

Setting: Professional trampolinists.

Participants: Twenty-two female athletes participating in a trampoline national championship were included in this study.

Assessment of Risk Factors: The associations for player-related performance variables were evaluated using Spearman rank correlation and Kruskal–Wallis H test verified the differences between the tertiles.

Main Outcome Measures: Rate of urinary incontinence (UI) among young athletes and the relationship with the athletic performance. Screening was performed through a questionnaire. This included the demographic sample characterization, the assessment of training volume, and the athletes' ranking in the championship. Additionally, it included the International Consultation on Incontinence Questionnaire Short-Form (ICIQ-UI-SF) to assess the leakage.

Results: About 72.7% of the participants reported that they experienced urine leakage during trampoline practice and described that the episodes of leakage started after the beginning of the trampoline. Significant associations between the athletic performance and the training volume were observed with the severity of incontinence. Dividing the sample in tertiles of training volume, it was observed that the third tertile was the one with greatest impact of incontinence on their quality of life (ICIQ score).

Conclusions: The results confirm a high frequency of UI in young trampolinists and reveal a clear identification of the athletes' ranking and the training volume as risk factors to develop and worsen urine loss.

Clinical Relevance: Special attention from team physicians and trainers is required for this athletes' problem that is often hidden by shame. In addition, female athletes practicing high-impact sports should be informed about the risk to develop pelvic floor muscles dysfunction and should be encouraged to seek help from health professionals to minimize or even eliminate the urine incontinence.

Key Words: pelvic floor muscles, stress urinary incontinence, intra-abdominal pressure, pelvic floor disorders, athletes

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INTRODUCTION

Urinary incontinence (UI) is a clinical condition affecting up to 50% of women during the course of their lives, with a higher prevalence in adulthood.[1] This involuntary leakage of urine has a multifactorial etiopathogenesis and negatively affects the quality of life of millions of women.[2] Aging, pregnancy, and vaginal delivery are currently considered the most common risk factors to develop UI.[3–5] However, in the last decade, several studies have documented stress urinary incontinence (SUI) as a common problem among nulliparous young women,[6–9] especially in those practicing high-impact sports.[10,11] Indeed, a national wide Danish research reported that 51.9% of the studied female athletes had experienced urine loss while participating in their sport activities or during daily life situations.[6] Moreover, in a population of nulliparous elite athletes (mean age of 19.9 years), Nygaard et al[12] stated that the women who practiced gymnastics and basketball had the highest rates of SUI, with 67% and 66%, respectively. In the same way, Eliasson et al[10] reported the highest prevalence rate of UI (80%) in 15-year-old female trampolinists.

This involuntary urine leakage occurs during effort (sports activities), sneezing, or coughing, that is, during conditions of increased intra-abdominal pressure.[13] Therefore, this type of UI raises the possibility about the dysfunction of striated periurethral and pelvic floor muscles (PFM) in young athletes, which well functioning is determinant to maintain urinary continence during enhanced abdominal pressure.[14] Indeed, it is suggested that training for high-impact sports may cause direct damage to the PFM and consequently contribute to the development of SUI.[15] Although some authors propose the existence of morphological changes of

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Ethics approval: Research Ethics Committee of the Faculty of Sports from the University of Porto, Porto, Portugal.

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the PFM in young women as a result of sports activities,[6,10] others suggest PFM fatigue, induced by strenuous physical activity,[16] or even changes in PFM collagen content[12] to explain the involuntary urine leakage that occurs during enhanced abdominal pressure in athletes. In fact, as a consequence of their hardly training programs, especially in high-impact sports, it might be expected that these athletes progressively develop structural or functional alterations in the PFM that are constantly submitted to great forces. It should be noted, however, that these assumptions about the negative effects of physical training on PFM are just supported by the highest frequency of SUI registered in athletes engaged with high-impact sports, and none of these studies have established any relationship between the characteristics of the performed training and the severity of the disorder.

Assuming the hypothetical negative repercussions of repeated overload on the PFM induced by training, in athletes practicing high-impact sports, an association between the severity of UI and the training volume, as well as the athletic performance, would be expected. Furthermore, if PFM dysfunction is in fact the result of a high-demand training process, the emerging of SUI should always arise after the athlete has started her sports practice and not before. Consequently, the aim of this study was to investigate the occurrence of those hypothetical associations, using young nulliparous female trampolinists as a standard of athletes who are frequently submitted to rises in intra-abdominal pressure during their sport practice.

MATERIALS AND METHODS

Participants

This cross-sectional study was conducted during a trampoline Portuguese national championship in May 2012. The athletes belonging to the elite and non-elite categories were invited to participate in this study. From a total of 24 females, 22 agreed to participate. Based on the equation to estimate the sample size in prevalence studies,[17] on the prevalence of UI reported in previous studies ranging from 68% to 80%,[9,10] and using 95% confidence level, a sample size of 22 athletes were allowed within a 19–percentage point margin of error.

All participants were informed about the objectives and procedures and were elucidated of any doubt before giving their written informed consent. The Research Ethics Committee of the Faculty of Sports from the University of Porto, Portugal, approved the study.

Methods

A questionnaire containing 2 sections was used to characterize the participants, their sport activity, and to evaluate the SUI symptoms. The first part of the questionnaire contained items to characterize some anthropometric and demographic variables [age, height, weight, body mass index (BMI), age of menarche, constipation and cough symptoms, race/ethnicity, education level, and the moment when the SUI emerged in their life], as well as the trampoline training features (hours of exercise training per week and years of trampoline training). The second section of the questionnaire was composed by the International Consultation on Incontinence Questionnaire Short-Form (ICIQ-UI-SF)[18] (Appendix). The ICIQ-UI-SF was divided into 4 parts: (1) frequency (never, once a week or less often, 2 or 3 times week, once a day, several times a day, or all the time), (2) amount of leakage (small, moderate, or large), and (3) overall impact of UI [ranging between 0 (not interfere) and 10 (a great deal)]. A fourth item included 8 questions related to symptoms determining the type of UI. Summing the first 3 items, a value between 0 and 21 is obtained (ICIQ score), with greater values indicating increased severity. All symptoms were defined according to the standardization of terminology proposed by the ICS.[13] All data remained confidential.

At the end of the championship, the elite athletes were classified and ranked according to their performance by using the judges' scores. The athletes' ranking was established to verify the correlations between performance and estimated urine leakage, based on the hypothesis that the athletes with better scores are those who went through more strenuous trainings.

Statistical Analysis

Mean value, SD, and range were used to describe the results. Normality of distribution was tested with Shapiro–Wilk test. The sample was distributed in tertiles based on the amount of training volume (hours of training per week × years of training). To verify the differences between the tertiles, the Kruskal–Wallis H test was used. Spearman rank correlation test was applied to test correlations among variables. Values with $P \leq 0.05$ were considered statistically significant. All analyses were performed using SPSS version 20.0 for windows (SPSS, Inc, Chicago, Illinois).

RESULTS

The Table presents the main characteristics of the sample. None of the 22 trampolinists presented constipation symptoms or chronic cough problems. Regarding the frequency of physical training, 6 women trained 3 to 4 times per week, whereas the majority (n = 16) trained 5 to 6 times per week. Moreover, on average, the athletes trained 2 hours a day (range, 1 hour and 30 minutes to 3 hours per day).

Sixteen (72.7%) of the 22 women reported involuntary leakage during trampoline practice, and 3 of them reported urine loss also during coughing and sneezing. All incontinent

TABLE. Main Characteristics of the Sample (n = 22)

	Mean ± SD	Range
Age (y)	18.1 ± 3.4	14-25
Weight (kg)	55.0 ± 4.9	49.0-70.0
BMI (kg/h^2)	20.4 ± 1.3	18.2-23.9
Age of menarche (y)	12.7 ± 1.2	11-16
Hours of training/wk	11.3 ± 2.7	6-15
Duration of training (y)	11.0 ± 2.9	5-17
Age when started the trampoline training	7.1 ± 2.9	2-13

Data are presented as mean ± SD and range.

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women stated that the episodes of urine leakage have started only after they begin trampoline training. Regarding the frequency of involuntary urine loss, half of the incontinent trampolinists reported its occurrence once a week or less often, 6 athletes stated losses ranging from once a day until to 2 or 3 times a week, and only 2 women have mentioned urine leakage several times a day. The amount of urine loss was self-classified as moderate in the majority of cases (93.7%), and only 1 athlete reported loss of a small amount. The self-reported overall impact of UI in the quality of life was registered as "not interfere" or interfering "mildly" by 68.8% of the incontinent athletes. One may note that only 1 athlete reported that the loss of urine had a great extend in her daily life. Additionally, these 16 women who referred to have urine leakage had longer training volume (P = 0.02), duration of training (P = 0.005), and late menarche (P = 0.04) when compared with the continent ones.

Regarding the associations among variables, we found a strong and positive correlation between the years of training and the ICIQ score (r = 0.611; P = 0.003). Moreover, the years of training had a positive correlation with the frequency and with the estimated amount of urine leakage (r = 0.469; P = 0.023 and r = 0.575; P = 0.005, respectively). The training volume, that is, the accumulated hours of training per week during their sport lifetime (years), also showed a positive correlation with the ICIQ score (r = 0.629; P = 0.002; Figure 1A), with the frequency (r = 0.430; P = 0.044) and with the estimated volume of urine loss (r = 0.502; P = 0.025). Interestingly, we found that the elite athletes' ranking in the championship had an association with the ICIQ score (Figure 1B), with frequency and with the estimated volume of urine loss (r = 0.573, P = 0.005; r = 0.454, P = 0.034; and r = 0.675, P = 0.001, respectively).

The elite athletes' ICIQ score distribution according to the tertiles of training volume is shown in Figure 2. A significant difference was observed between the first and the second (P = 0.015) and between the first and the third (P = 0.003) tertiles.

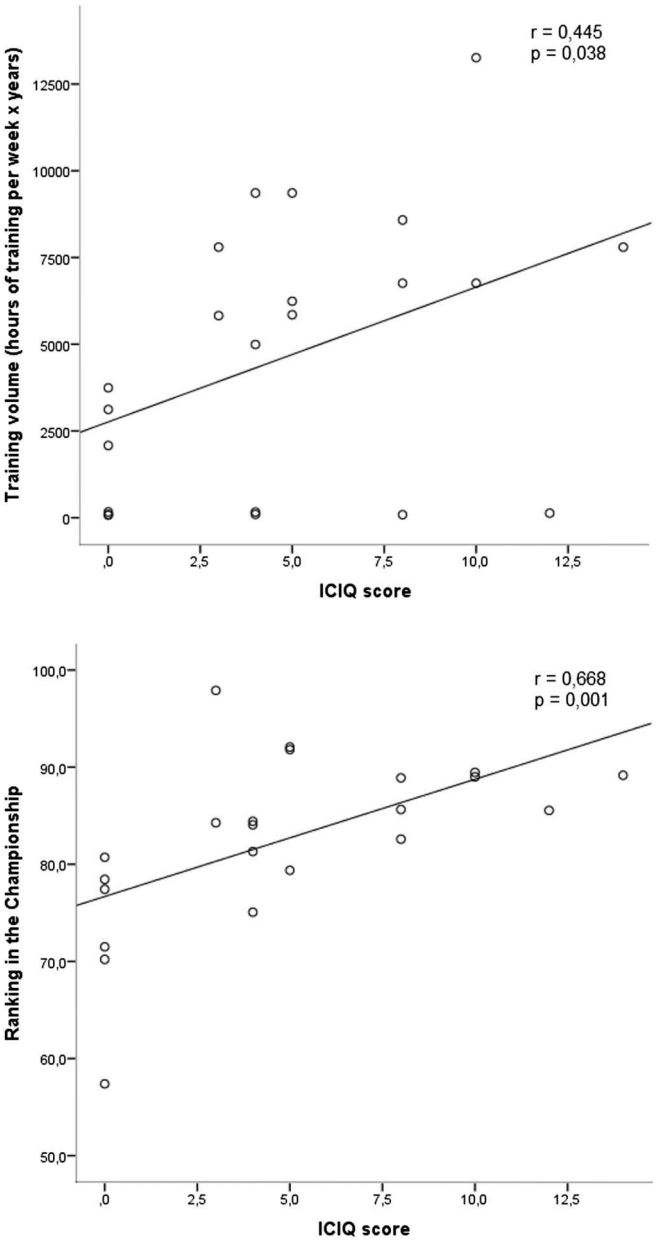


FIGURE 1. Correlations between variables: training volume and ICIQ score (A), and ranking in the championship and ICIQ score (B).

DISCUSSION

This study found a high frequency of SUI in young female trampolinists. Although others have already described a higher frequency of SUI in high-impact sports,[8,10,12,15] to the best of our knowledge, no previous studies have assessed the association between the training volume or the level of athletic performance (ranking) with the occurrence and severity of SUI. It must be emphasized that the chosen modality to perform this study was based on a statement of the International Gymnastics Federation that defines the trampoline practice as a "high, continuous rhythmic feet to feet and feet to back, front or seat rotational jumping elements, without hesitation or intermediate straight bounces."[19] Also, the results of Thyssen et al[6] suggesting that jumping is the activity most likely to provoke urine leakage. Therefore, as the trampoline training is characterized by a succession of jumps and acrobatic movements into the air, the athletes experience huge increases in intra-abdominal pressure that imply great forces to the PFM. We may note that only young and nulliparous athletes were studied to eliminate potential bias.[20] Moreover, BMI, constipation symptoms or chronic cough problems, which are known to enhance the risk to develop UI,[4,9,21] were also controlled in our study (Table).

According to the self-questionnaire applied, our results show that athletes with higher training volumes reported also refer a more severe incontinence (Figure 2A), with a higher frequency of loss and greater estimated amount of urine leakage. In the same way, Eliasson et al[10] compared athletes with and without urine leakage, and their results have shown that in the first group, the participants were older and had higher duration and training frequency. Similarly, we found that the group of incontinent had a higher volume (P = 0.022) and years (P = 0.005) of training as well as age of menarche

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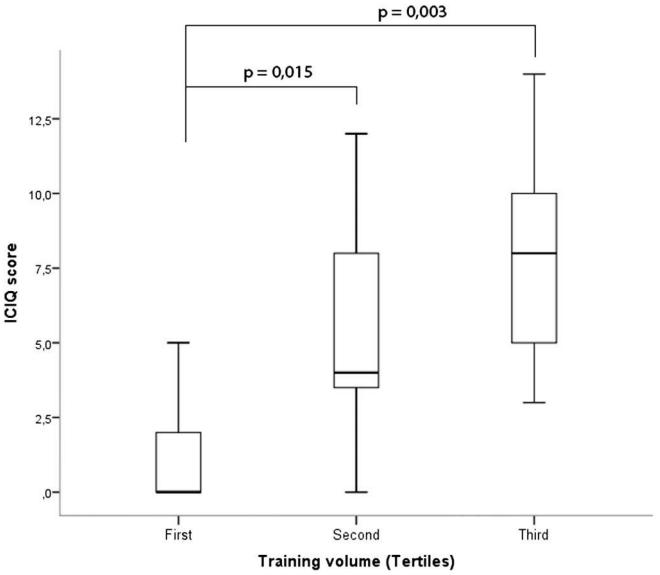


FIGURE 2. The training volume divided in tertiles relative to ICIQ score (boxplot). Significant difference between the first and the second ($P = 0.015$) tertiles and between the first and the third ($P = 0.003$) tertiles.

($P = 0.042$). Furthermore, in our study, the association between the ranking in the national championship and the urine loss was also observed (Figure 1B). These findings support the suggestion that athletes with higher scores in trampoline practice would be also those submitted to higher impact forces onto PFM due to more years and hours per week of training, and consequently those with more "leakage times" and with an increased severity of the urine loss. Interestingly, the athletes of our sample considered that the loss of urine only "slightly" affects their daily lives despite the high volume of trampoline training. Possibly, the athletes use strategies to prevent or reduce the occurrence of urine loss such as anticipated urination or the restriction of liquid intake before the practicing, as reported in other studies.[22]

At the moment, the cause of SUI in young nulliparous athletes remains unclear. Despite its multifactorial nature, the relevance of PFM contraction to promote urethral closure for maintaining continence is widely recognized.[23] As mentioned, previous studies suggested morphologic changes and/or PFM fatigue and/or changes in collagen concentration[6,10,16] as a possible causes to develop SUI.[12] Surprisingly, several studies have been demonstrated that athletes' PFM seem to be strong enough to prevent urine leakage.[8,10] Furthermore, Bø et al[24] measured PFM function in sport and physical education students, with and without UI, and did not find any difference in PFM strength. These data support the concept that urine loss might not be due to morphologic changes or fatigue of PFM, but instead it might be a consequence of altered muscle responsiveness to mechanical stimulus. Considering its fiber type composition, PFM have the ability to maintain the basal tonus (by recruiting slow twitch muscle fibers) and to develop rapid contractions preceding an abrupt rise of the intra-abdominal pressure (mainly with the recruitment of fast twitch muscle fibers).[25] This response to the rise of intra-abdominal pressure is due to distension of muscle spindles within PFM that further generates a cocontraction of the PFM.[26] In this sense, it might be speculated that this demand to the PFM could have a negative impact on intrafusal fibers, diminishing their responsiveness to stretching, which may results in a delay to PFM contraction. Nevertheless, additional studies are required to support this hypothesis.

When dividing the sample in tertiles by training volume (Figure 2), another important result to consider is that athletes with higher training volumes felt more embarrassment and discomfort with urine leakage. Evidently, the athletes with greater training volume (hours of training per week × years of training) reported more years experiencing urine leakage and consequently they can consider it more severe. This finding may demonstrate that female athletes can be more concerned with the loss of urine over the years, and this could be a factor leading to the abandonment of sports practice.

One disadvantage of this study is related with the possibility of a type II error mainly due to dimension of the sample population, which could be larger. However, according to the estimation of the sample size, this study had an adequate number of subjects to study the prevalence of UI among trampolinists. Second, despite the ICIQ-SF-UI questionnaire assesses the symptoms subjectively, it is validated and is considered a robust means of evaluating UI. In further studies, objective measurements to evaluate the incontinence symptoms and the level of physical activity should be performed. Embarrassment and lack of knowledge about UI may be additional factors to contribute to underreporting of the real symptoms.

CONCLUSIONS

This study shows a high frequency of SUI in young trampolinists, clearly identifying the athletes' ranking and the training volume as risk factors to the emergence and severity of SUI. The results support the theory of the harmful chronic effects of high-demand physical training in the PFM function.

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APPENDIX INTERNATIONAL CONSULTATION ON INCONTINENCE QUESTIONNAIRE

Urinary Incontinence - Short Form

How often do you leak urine? *(tick one box)*

Never	☐	0
About once a week or less often	☐	1
2 or 3 times week	☐	2
About once a day	☐	3
Several times a day	☐	4
All the time	☐	5

Think how much urine do you usually leak *(tick one box)*

None	☐	0
A small amount	☐	2
A moderate amount	☐	4
A large amount	☐	6

Overall, how much does leaking urine interfere with your everyday life? *(Please ring a number between 0 (not at all) and 10 (a great deal)*.

0	1	2	3	4	5	6	7	8	9	10
Not at all										A great deal

When does urine leak? *(Please tick all that apply to you)*

Never	☐
Loss urine before reaching the toilet	☐
Loss of urine during coughing/sneezing	☐
Loss of urine when asleep	☐
Loss of urine during physical activity	☐
Loss of urine after finishing urinating and are dressed	☐
Loss of urine for no obvious reason	☐
Loss of urine all the time	☐

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Study II

Urinary Incontinence and Levels of Regular Physical Exercise in Young Women

Accepted for publication in

International Journal of Sports Medicine

International Journal of Sports Medicine
Thieme

Urinary incontinence and levels of regular physical exercise in young women

Journal:	*International Journal of Sports Medicine*
Manuscript ID:	IJSM-10-2014-4487-cs.R2
Manuscript Type:	Clinical Sciences
Key word:	Pelvic floor muscles, Stress urinary incontinence, Intra-abdominal pressure, Training volume, Nulliparous

Abstract: The purpose of this study was to determine the influence of different levels of regular physical exercise on the frequency of urinary incontinence in young nulliparous women from the northern region of Portugal. Participants (n=386) self-reported demographic variables, frequency, and time spent practicing organized exercise per week, as well as completed the International Consultation on Incontinence Questionnaire-Short Form. The level of exercise was calculated based on the time (in minutes) usually spent per week in organized exercise. 19.9% of Portuguese nulliparous women reported incontinence symptoms. Considering the distribution of urinary incontinence among the different quartiles of organized exercise, women from the 4thquartile (those who train for competitive purposes) demonstrated highest relative frequency (p=0.000) and a 2.53 greater relative risk to develop (95% CIs,1.3–2.7) incontinence compared to women from the 1stquartile (inactive). Women who practice exercise for recreational purposes (2nd and 3rdquartiles) did not show significant differences in prevalence of and relative risk of developing urinary incontinence compared to women from the 1stquartile. The results showed that women participating in organized exercise involving high volume training for competition are potentially at risk of developing urinary incontinence, though organized exercise undertaken without the intent to compete seems to be safe for maintaining urinary continence.

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Title: Urinary incontinence and levels of regular physical exercise in young women

Abstract

The purpose of this study was to determine the influence of different levels of regular physical exercise on the frequency of urinary incontinence in young nulliparous women from the northern region of Portugal. Participants (*n*=386) self-reported demographic variables, frequency, and time spent practicing organized exercise per week, as well as completed the International Consultation on Incontinence Questionnaire-Short Form. The level of exercise was calculated based on the time (in minutes) usually spent per week in organized exercise. 19.9% of Portuguese nulliparous women reported incontinence symptoms. Considering the distribution of urinary incontinence among the different quartiles of organized exercise, women from the 4thquartile (those who train for competitive purposes) demonstrated highest relative frequency (*p*=0.000) and a 2.53 greater relative risk to develop (95% CIs,1.3–2.7) incontinence compared to women from the 1stquartile (inactive). Women who practice exercise for recreational purposes (2nd and 3rdquartiles) did not show significant differences in prevalence of and relative risk of developing urinary incontinence compared to women from the 1stquartile. The results showed that women participating in organized exercise involving high volume training for competition are potentially at risk of developing urinary incontinence, though organized exercise undertaken without the intent to compete seems to be safe for maintaining urinary continence.

Keywords: Pelvic floor muscles; Stress urinary incontinence; Intra-abdominal pressure; Training volume; Nulliparous

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Introduction

There is incontrovertible evidence that regular physical activity is associated with advantageous health outcomes [17]. The benefits of being physically active are numerous and include the prevention of several chronic diseases and consequently reduced risk of premature death [27]. Furthermore, a graded linear relationship seems to exist between an individual's volume of exercise and health status, such that the most physically active subjects are those at the lowest risk of mortality [27]. However, as with any drug, the dosage makes the poison, and a safe upper limit of the volume of exercise performed potentially exists, beyond which the adverse effects exceed the benefits and thereby favor the occurrence of harmful consequences for, among others, metabolic, immune, cardiovascular, osteo-articular, and skeletal muscular function [14,21].

While the advantageous and harmful dose-dependent effects of exercise are relatively well understood in several organs and tissues, the repercussions of different levels of physical exercise on the pelvic floor muscles (PFM) remain unclear. It is known that many daily body movements using the trunk and/or limbs are frequently associated with increased intra-abdominal pressure (IAP), which results in an inertial force of the abdominal contents in a cranial-to-caudal direction, with the greatest pressure upon the PFM [2]. When intense and repeated over time, such increased IAP may adversely affect the supporting structures of the PFM with harmful consequences to its function. If these forces exceed urethral closure pressure, then urine loss due to stress urinary incontinence (UI) may occur. This condition is particularly prevalent in some elite athletes who are regularly exposed to sudden increases in IAP [7,15] yet do not evidence any other UI risk factors, such as increased body mass index (BMI), diabetes, chronic pelvic pain, constipation, pregnancy, vaginal delivery, or pelvic floor surgery [24,28]. A recent study showed that 72.7% of female trampolinists in Portugal experienced urine leakage during exercise and described training volume as a risk factor to developing UI [7]. However, beyond these extreme conditions associated with high impact exercise for competitive purposes, few studies have investigated among non-athletes the prevalence of UI in young women while considering the different levels of exercise, including inactivity. At the same time, studies linking exercise and UI have presented contradictory or inconclusive results [4,12,16,26]. For instance, while some authors have reported an inverse association between the prevalence of UI and

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regular PA [5,9,12,16,28], other studies have found a direct relationship between general exercise and prevalence of UI [3,4,19], or even the absence of difference between physically active and sedentary women [6]. These conflicting results may be explained by several factors, such as insufficient sample size, the different methodologies used to determine the prevalence of UI, the wide age range of samples, the use of different definitions of exercise and its levels, and the cultural variances of each population, among others. Accordingly, using an adequate sample size for which all of these biased factors were controlled for, the purpose of the present study was to determine the influence of different levels of regular exercise on the frequency of UI in young nulliparous women from Northern Portugal.

Materials and Methods

Women with ages ranged from 14 to 33 years were randomly selected from the student population of high schools and universities from the region of Oporto, Portugal. The presence of traditional risk factors of UI, such as a BMI higher than 30 kg/m^2 and any history of diabetes mellitus, chronic pelvic pain, pregnancy or pelvic floor surgery, were exclusion criteria. Results from a previous study reporting a prevalence of 9.8% in the general population of women aged from 18 to 35 years[6] were used to estimate the minimum sample size required for the present study. Assuming a UI rate of 9.8% and using a confidence level of 95% within an allowable margin of error of d = 0.03[1], a minimal sample size of 377 women was required[1]. The study was approved by the Ethics Committee of the Hospital de São João-Porto (CES-120-13) and was conducted in accordance with the Declaration of Helsinki and followed the international standards [13]. All participants—or for minors, their parents—gave written, informed consent.

UI was defined according to the standards recommended by the International Continence Society [15] as any leakage or involuntary loss of urine. Leak or urine loss caused by increased IAP in situations such as sneezing, coughing, lifting, or exercising were considered to be stress UI. By contrast, urgency UI was defined either as an urgency to urinate but an inability to reach the toilet before leaking, or else having a strong, sudden urge to urinate without advance warning. Mixed UI symptoms were defined as a combination of the previous two conditions.

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The Portuguese version of the International Consultation on Incontinence Questionnaire: Short Form (ICIQ-SF) was used to assess symptoms of UI [25]. The total score was calculated using the sum of all items, which ranged from 0 to 21 in which the highest score signified the most severe condition.

In the present study, an additional set of 13 items was used to assess demographic characteristics, medical and obstetric history, and athletic tendencies. For athletic tendencies, women reported the frequency of regular participation in each activity per week (number of occasions) and the length of each exercise session (duration of occasions). Women's weekly exposure to organized sporting activities was calculated as a product of the frequency of their participation per week by the duration of each session (min/week), in which organized sport refers to activities regularly held by a school, club, gym, or other organization.

Based on their amount of exercise practiced per week, women were distributed in quartiles as follows:

- The 1st quartile (range of 0–30 min of exercise/week, with a mean ± *SD* of 5.01 ± 4.7 min/week) included women who do not exercise regularly, though some may do so sporadically. Based on the criteria of the American College of Sports Medicine (ACSM)[18], these women are considered physically inactive since none perform 30 min/day of exercise 5 days/week.
- The 2nd quartile (range of 31–180 min of exercise/week, with a mean ± *SD* of 149.5 ± 33.5 min/week) included women who engage in a moderate amount of organized exercise each week. In this quartile, 52.2% of women complied with ACSM guidelines[18].
- The 3rd quartile (range of 181–420 min of exercise/week, with a mean ± *SD* of 305.5 ± 63.9 min/week) comprised women who are sport science students, all of whom complied with ACSM recommendations[18].
- The 4th quartile (ranging 421–2,940 min of exercise/week, with a mean ± *SD* of 757.6 ± 404.8 min/week) included women who practice regularly high volumes of physical training per week for competitive purposes. All women belonged to different sport disciplines (e.g., trampoline, soccer, handball, swimming, volleyball, track and field, and martial arts), all of which complied with ACSM recommendations[18].

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Statistical analysis

Results are presented as relative frequencies in means and standard deviations. The Kruskal–Wallis one-way ANOVA test was used to compare sociodemographic data (age, BMI, and age at menarche) and total ICIQ-SF score among the quartiles. The chi-squared test was used to compare the relative distribution of UI type among the quartiles, as well as to investigate the associations among UI and constipation, capacity to stop the urine flow, and irregular menstruation variables. The relative risk (RR) and the corresponding 95% confidence intervals (CIs) of developing any UI among the quartiles were estimated, using the 1st quartile as a reference group. All data were analyzed using SPSS version 20.0 for Windows (SPSS Inc., Chicago, IL, USA), and p values ≤0.05 were considered to be significant.

Results

The present cross-sectional study was conducted from May to December 2013 with 399 young nulliparous women. From the 399 women initially selected, 396 (99.2%) fully completed the questionnaire. Of these women, four had had pregnancy, three had undergone pelvic surgery, and three had BMIs higher than 30 kg/h^2, which produced a final sample of 386 women (96.7% of women eligible). The overall mean age was 21.4 ± 3.3 (range 14–33) years, and the mean BMI was 21.6 ± 2.5 (range 15.4–28.5)kg/m^2. Most women (83.9%) were university students (n = 324), while the rest (16.1%) were high-school students (n = 62).

The overall self-reported relative frequency of UI in the sample was 19.9% (77 of 386). Among women who reported experiencing UI, the prevalence of stress, urgency, and mixed UI were 49.4% (n = 38), 22.1% (n = 17), and 28.6% (n = 22), respectively. The mean ICIQ-SF scores for overall, stress, urgency, and mixed UI were 5.4 ± 2.6 (range of 2–14), 5.8 ± 2.7 (range of 3–14), 4.6 ± 1.9 (range of 2–9), and 5.3 ± 2.8 (range of 3–13), respectively. In all, 3.7% (n = 13) of women declared an inability to stop their urine flow. No significant associations were found between UI and constipation (p = 0.446) or irregular menstruation (p = 0.955) problems.

According to self-reported time of exercise practiced per week, no significant differences in age (p = 0.126), BMI (p = 0.887), and age at menarche (p = 0.523) were found between the quartiles (see Table 1). Results demonstrated that the 4th quartile exhibited a higher frequency of incontinent

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women (p = 0.000). Regarding the RR for UI among the quartiles, it was found that women from the 4th quartile had a 2.53 greater risk (95% CIs, 1.3–2.7) than those from the 1st quartile (reference group) to have UI. The RR for the 2nd and 3rd quartiles were 0.80 (95% CIs, 0.867–1.079) and 1.10 (95% CIs, 0.912–1.136), respectively.

The frequency of UI symptoms, the amount of urine loss, and the mean ICIQ-SF score for each quartile are presented in Table 1. Of women with UI, most reported urinary leakage once a week or less, and the amount of leakage was generally small for all groups. Regarding the type of UI, the 4th quartile was the most affected by stress UI (70.3%) compared to 1st (p = 0.046) and 2nd (p = 0.033) quartiles. The relative frequency of urgency, stress, and mixed UI among the quartiles appears in Figure 1.

Women who trained for competitive purposes (4th quartile) had the least ability to stop their urine flow during micturition compared with women of the 1st quartile, who demonstrate inactive behavior (p = 0.011).

Discussion

The present study clearly shows that the high prevalence of UI observed in our sample is closely associated with the high volume of physical training performed per week for competitive purposes. Yet, in contrast to women from the 4th quartile, our data also show that being physically active, as women from 2nd and 3rd quartiles are, does not enhance the risk of developing UI.

Regarding the 1st, 2nd, and 3rd quartiles, the frequencies of UI were very similar and consistent with those described by Cayle *et al*, who assessed UI in the general female population and found a UI prevalence of 9.87% in physically active women and 9.84% in sedentary women [6]. Our results show similar prevalence of 15.6% and 11.6% for physically active (3rd and 2nd quartiles, respectively) and of 14.5% for inactive (1st quartile) women. These prevalence rates are consistent with those of a large Australian investigation of young, nulligravid women of the same age (16–30 years), in which the authors found a UI rate of 12.6% among those who were physically active [20]. Thus, since statistical differences in UI frequency between the 1st, 2nd, and 3th quartiles were not found, our findings clearly support the consensus that women should be encouraged to practice organized exercise and follow ACSM recommendations [18] in order to reap the benefits of exercise [27].

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The 4th quartile presented a higher frequency of urine loss than the other quartiles. To explain, scientific literature has shown that women training for competitive purposes have a higher frequency of UI than non-athletic controls [6]. Though causes of UI in young women remain unclear, investigations have indicated sudden rises in IAP [10] or the impact from ground reaction forces [26] as primary risk factors. As a consequence, delay between stimulus and PFM contraction can also explain urine loss among athletes [7], which may be associated with athletes' higher tolerance for stretching muscle spindles. Since the muscles spindles help maintain a constant muscle length, increases in IAP will distend these muscles within the PFM, leading to an automatic response of PFM contraction, but the timing of PFM contraction may occur after the leakage of urine. Similarly, the present study found that women from the 4th quartile were 2.53 times more likely to have UI than inactive women (1st quartile), perhaps since increased IAP pushes the pelvic floor downward to prompt such a continuous overload that could often overstretch the PFM and consequently have a negative impact on intrafusal fibers [7,8]. However, additional studies using objective methods to measure the levels of exercise (e.g., accelerometry) are needed to elucidate exercise's other associations with UI.

The present study showed an overall UI frequency of 19.9% for its sample, as well as that stress UI was the most common type of UI (49.4%) reported. It should be noted that the 4th quartile (comprised of athletes) had significantly higher frequencies of UI, which thereby overestimated the UI frequency in the general population. Moreover, women in the 4th quartile evidenced a lesser ability to stop their urine flow (p = 0.011) than inactive women (1st quartile). The capacity to stop urination during micturition can be considered to be a low-cost, non-invasive method [23] to detect dysfunctional PFM [22]. Such weakened ability reported by the 4th quartile might be a consequence of altered muscle responsiveness to continuous mechanical stimuli, which supports the theory that such an inability can be associated with decreased neuromuscular activity[11] or with a tolerance to stretch muscle spindles in PFM that consequently generates a delayed reflex response [7,8].

This study is part of our ongoing effort to better understand UI among young nulliparous women. It also represents the first report of the RR of UI among different levels of organized exercise compared to inactivity in women. As most other epidemiological studies, we did not use urodynamic

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equipment to determine the pathophysiologic basis of incontinence; therefore, some misclassification of the different types of UI may have occurred. Despite this limitation, we used the ICIQ-SF, which is a robust measurement tool with which to assess symptoms of incontinence. Moreover, the sample size used in the present study was calculated in order to ensure that the power analysis was not compromised.

Conclusion

This study shows an overall UI prevalence of 19.9% among young, nulliparous women in Portugal, though the group of competitive athletes significantly overestimates this rate. Young women should be encouraged to practice organized exercise and to follow ACSM recommendations in order to reap the health benefits of exercise without being afraid of developing UI, since women who performed exercise for recreational purposes did not evidence any increase in relative risk. Women training for competitive purposes showed a 2.53 times greater risk of increased prevalence of UI than women demonstrating inactive behavior. These results could be used to raise awareness and to alert young women— especially athletes—of the need to establish preventive strategies for UI.

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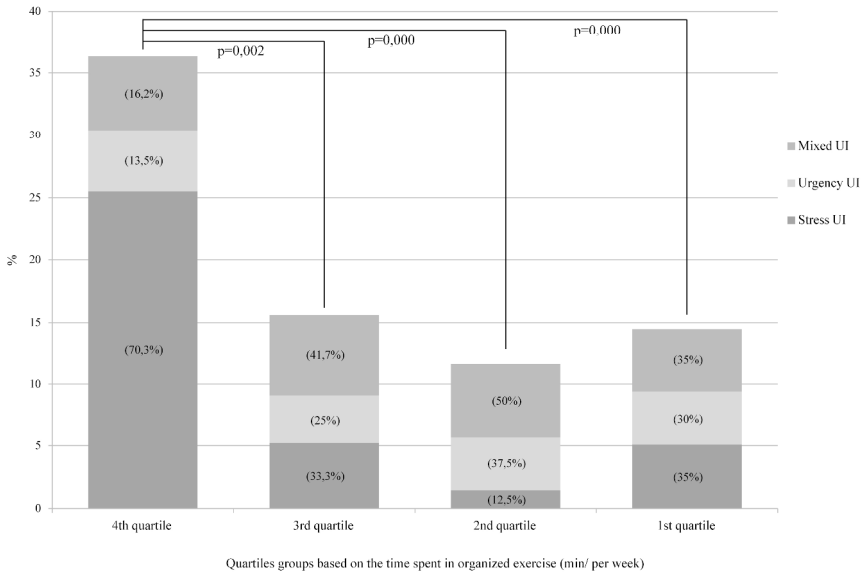
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Relative frequency and type of UI according to the quartiles of exercise per week. Significant difference between the 4th and 3rd quartiles (p = 0.002), 4th and 2nd quartiles (p = 0.000) and 4th and 1st quartiles (p = 0.000)
297x209mm (300 x 300 DPI)

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Table 1: Sample characteristics, frequency of urinary incontinence symptoms, amount of urine leakage, and International Consultation on Incontinence Questionnaire total score of women affected by urinary incontinence according to quartiles of exercise practiced per week.

Characteristic	1st quartile	2nd quartile	3rd quartile	4th quartile	*p*
Age (years)	21.3 ± 2.3	21.7 ± 3.4	21.2 ± 3.2	20.8 ± 4.1	0.126
BMI (kg/h^2)	21.8 ± 2.7	21.6 ± 2.4	21.5 ± 2.3	21.3 ± 2.2	0.887
Age at menarche (years)	12.8 ± 1.5	12.6 ± 1.4	12.5 ± 1.5	12.7 ± 1.1	0.523
UI symptoms					
Frequency (%)					0.104
Weekly or less	85	100	83.3	64.9	
Twice or three times weekly	0	0	8.3	13.5	
Daily	15	0	8.3	13.5	
Always	0	0	0	8.1	
Amount (%)					0.344
Small	100	100	100	91.9	
Moderate	0	0	0	8.1	
Large	-	-	-	-	
Total ICIQ score	5.1 ± 2.3	3.6 ± 0.9	5.6 ± 2.8	5.9 ± 2.8	0.079

BMI: Body mass index; ICIQ: International Consultation on Incontinence Questionnaire; UI: Urinary incontinence

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Study III

Sedentary Behavior is a Risk Factor to Develop Urinary Incontinence in Young Women

Submitted for publication in

Journal of Sports Sciences



SEDENTARY BEHAVIOR IS A RISK FACTOR TO DEVELOP URINARY INCONTINENCE IN YOUNG WOMEN

Journal:	*Journal of Sports Sciences*
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Manuscript Type:	Original Manuscript
Keywords:	Accelerometer, Exercise, Inactivity, Pelvic floor muscles, Urinary incontinence
Note: The following files were submitted by the author for peer review, but cannot be converted to PDF. You must view these files (e.g. movies) online.	
Figure 1.vsd	

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SEDENTARY BEHAVIOR IS A RISK FACTOR TO DEVELOP URINARY INCONTINENCE IN YOUNG WOMEN

Running head: Sedentary behavior and loss of urine

Keywords: Accelerometer, Exercise, Inactivity, Pelvic floor muscles, Urinary incontinence.

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Abstract

The physical activity guidelines suggest a minimum of 150 minutes weekly of moderate-to-vigorous exercise to obtain health benefits. However, vigorous exercise has been associated with urinary incontinence. No previous study correlated urinary incontinence with the levels of physical activity using an objective measure. Thus, the present study investigated the association between different levels of physical activity measured by accelerometer with urinary incontinence symptoms among young women. Eighty one women underwent the International Consultation on Incontinence Questionnaire-Short Form and used the accelerometer during 7 consecutive days. Twenty(24.7%) women self-reported symptoms of incontinence. No association was observed between reach the exercise recommendations with urinary incontinence(p=0.335;OR=0.571, 95% CIs:0.182-1.797). Incontinent women evidenced longer daily periods of sedentary time when compared to the continent ones(p=0.019). Spearman correlation showed significant association between frequency, amount and severity of urine leakage with inactivity(r=0.455; r=0.456 and r=0.456, respectively), as well as an inverse association between amount and severity of urine loss with light activity(r=-0.456 and r=-0.433, respectively). In conclusion, the severity of incontinence had a positive association with the inactivity and was negatively associated with the time spent in light exercise. Our results point out to the relevance of discouraging the inactivity, while promoting the guidelines for exercise practice.

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Introduction

Evidence has emerged suggesting high demanding physical activity (PA) as a risk factor to develop functional alterations on pelvic floor muscles (PFM), as a result of the repetitive increase of the intra-abdominal pressure(Bø, 2004; Mens, Hoek van Dijke, Pool-Goudzwaard, van der Hulst, & Stam, 2006). In fact, many studies have investigated the association between high levels of PA and the development of urinary incontinence (UI)(Jacome, Oliveira, Marques, & Sa-Couto, 2011), and there seems to be consensual that women training for competitive purposes were the ones more prone to develop UI (Da Roza, Brandao, Mascarenhas, Jorge, & Duarte, 2014; Nygaard, Thompson, Svengalis, & Albright, 1994). At the same time, it is well-recognized that moderate-to-vigorous PA is recommended by international health associations as one of the greatest priorities to promote women's health (Maiese, 2002). However, until now, studies relating PA with UI used the most common approach to measure PA level, i.e., the self-reported questionnaires. The estimation of PA frequency and duration is a cognitive challenge because questionnaires use a limited number of questions to assess a specific behavior that can lead to a significant bias (Sallis & Saelens, 2000) of the results. Accordingly, the use of accelerometers, which measure movement intensity, or other objective measure, may help to overcome some of these challenges (Troiano et al., 2008). Another advantage of the use of accelerometer is that, besides measuring the PA, it also creates the possibility to assess the inactivity behavior, which is associated with distinctive health outcomes. So far, no previous studies have investigated the effect of objectively measured PA levels on UI symptoms. In this context, the purpose of this study was to investigate the symptoms of UI in young females among different levels of PA measured by accelerometers.

Methods

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This was a cross-sectional cohort study carried out with women living in Oporto, Portugal. The ethical committee of Centro Hospital de São João-EPE (code: CES-120-13) approved the study and all women gave written consent form. Women were randomly recruited from local Universities and data were collected over a 9-month period from September 2013 to May 2014. Inclusion criteria were to be 18-39 years old, to be nulliparous and eumenorrheic. It is noted that in order to eliminate potential bias (Milsom, Altman, & Lapitan, 2009) in the current analysis, women were considered ineligible if they had had previous or ongoing pregnancy, they had prior pelvic surgery, their body mass index (BMI) were ≥ 30 kg/m^2 or age were ≥ 40 years, and they had history of diabetes mellitus or chronic pelvic pain. Ninety-one women underwent a questionnaire comprising both demographic characteristics and the International Consultation on Incontinence Questionnaire - Short Form (ICIQ-SF). Moreover, all of them agreed to use the PA monitor. In order not to compromise the power of analysis, the overall sample size was calculated using a confidence level of 95% within an allowable margin of error of d = 0.07 and assuming a UI rate of 9.8%, which is a UI prevalence in physically-active women aged 18 to 35 years (Caylet et al., 2006), therefore a minimal sample size of 69 women would be required (Arya, Antonisamy, & Kumar, 2012).

The ICIQ-SF included four items pertaining the (1) frequency and (2) amount of leakage, the (3) overall impact of UI in quality-of-life and (4) eight questions related to symptoms that help to define the type of UI. For the first three questions, the participants rated their answers on a Likert scale, according to which the maximum scores (corresponding to the greatest severity), were 5, 6 and 10 respectively. The ICIQ-SF score is calculated using the sum of these three items, which can range from 0 to 21, and the highest score was considered the more severity of the condition. Importantly,

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the first question of the ICIQ-SF was used to define the woman as continent or incontinent.

PA measurement

The level of PA was determined by using the accelerometer GT1M from Actigraph (Actigraph®, LLC; Ft. Walton Beach, FL). This lightweight, biaxial monitor is a small portable accelerometer that measures and records vertical acceleration as "counts" of the body, and translates motion into activity scores. Studies have proved to be a technically reliable instrument, both within and across monitors (Rothney, Apker, Song, & Chen, 2008), and to be valid for quantifying activity levels in laboratory and field settings (Trost, McIver, & Pate, 2005). Women were asked to use the accelerometer over the right hip on an elasticized belt for 7 consecutive days. Participants were instructed to maintain their usual routine of activities and remove the device when swimming, bathing and sleeping. A diary to log relevant information in wearing the device was provided.

Accelerometer data was recorded in 5-s sampling periods (epochs) and then aggregated in 60-s epochs for analysis. A minimum recording of 8h per day was the criteria to accept daily PA data as valid. Individual records were only accepted for analysis if at least 5 days were successfully assessed. Assuming that the monitor was not worn, nonwear time was defined as at least 60 consecutive minutes of zero activity intensity counts. Activity levels were based in mean count.min^{-1}.Each minute of wear time during the monitoring period was classified into sedentary (0–99 counts); light (100–2019 counts); moderate (2020-5998 counts); vigorous (≥ 5999); or moderate-to-vigorous (MVPA) (≥ 2020 counts) PA, according to cut points reported in previous validation study (Troiano et al., 2008). All data were processed with Actilife version v6.10.2. The outcome variable was calculated by dividing the sum of activity counts for a

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valid day by the number of minutes of wear time in that day across all valid days (Troiano et al., 2008).

From the ninety-one women initially selected, 10 participants were excluded from the final analysis (Figure 1). The reason for exclusion were due to human error during use (n=4), no compliances with the PA criteria (n=3) and malfunctions with monitor (n=3).

****Figure 1 near here****

Statistical analysis

All analyses were computed using IBM SPSS Statistics (version 21) for Windows (SPSS® Inc., an IBM Company, Chicago, IL, USA) with the significance level set at $p<0.05$. Descriptive statistics (mean and standard deviation for continuous variables and relative and absolute frequencies for categorical variables) were calculated for all outcome measurements. Comparison of age, age of menarch, weight, BMI and PA levels between continent and incontinent groups was performed using Mann-Whitney U test. To describe the adherence to PA recommendations, daily MVPA time was used to create a dichotomous variable to differentiate those with sufficient activity to meet the recommended accumulated amount of ≥30 min/day of MVPA (Nelson et al., 2007) from those who did not. The Pearson Chi-square test of independence was performed to examine the relation between UI and the compliance of the PA recommendations' levels. Furthermore, the odds ratios (ORs) and 95% confidence intervals (CIs) between PA recommendation and the presence or absence of UI were estimated. Spearman correlations were used to examine associations of PA levels and UI variables.

Results

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Mean participant's age was 24.4±4.2 (range 19-34) years and the mean of BMI was 21.5±1.9 (range 16.7-26.5) kg/m^2. From the participants, 20 women (24.7%) self-reported UI symptoms and among of them 14 (70%) meet the recommended PA, while 6 (30%) did not. Regarding the continent group, 49 (80.3%) women meet the criteria of PA and 12 (19.7%) did not (Figure 1). Among incontinent women, most of them reported stress UI (n=11), mainly during PA, four presented symptoms of urgency UI and five mixed UI (Table 1). Pearson chi-squared test showed no association between UI with the compliance of the PA recommendations' levels (p=0.335; OR=0.571, 95% CI: 0.182-1.797).

****Table 1 near here****

Table 2 shows the distribution of the demographic characteristics (age, weight, BMI and age of menarch) and PA levels of continent and incontinent groups. The incontinent group showed higher minutes of sedentary PA per day when compared to the continent women (p=0.019), while time spent in light, moderate, vigorous, MVPA or count.min^{-1} levels have similar values. Spearman correlation analysis between PA levels and UI variables from ICIQ-SF questionnaire are shown in Table 3. Significant associations were found between sedentary behavior with frequency and amount of urine leakage, and also with the severity of UI (ICIQ-SF score). Furthermore, time spent in light PA evidenced a significant negative correlation with the amount of leakage and with ICIQ-SF score.

****Table 2 near here****

****Table 3 near here****

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Discussion

The present study shows that meeting the PA recommendations was not associated with the UI symptoms; incontinent women spent more time in sedentary behavior than the continent ones; and the severity of UI had a positive association with the sedentary behavior and was negatively associated with the time spent in light PA in our sample of young nulliparous females.

So far, this was the first study reporting the association between objective measurements and UI symptoms. The advantage of using objective PA measurements that it overcomes biases associated with self-reports, which include an overestimation of PA levels and underestimation of sedentary time (Troiano et al., 2008). In this context, the accelerometer became established as a research reliable tool for the objective PA measurement (Hendelman, Miller, Baggett, Debold, & Freedson, 2000). Our results demonstrated that almost 80% (63/81) of the women reached the PA recommendations and, in addition, were not found associations between meet the PA recommendations and UI symptoms (p=0.335). Indeed, the Centers for Disease Control and Prevention and the American College of Sports Medicine recommend, since 1995, an accumulation of at least 30 minutes of moderate-intensity activities five days a week to obtain substantial health benefits. Consistent with this, our findings suggest that women should follow the PA recommendations to reach the health benefits associated with the exercise, and not avoid MVPA for fear of developing UI.

Recent studies with objectively measured sedentary time data have shown that prolonged time in sedentary behavior is a cardiometabolic risk factor (Bankoski et al., 2011) and is positively associated with higher mortality rates (Koster et al., 2012) independent of MVPA. Interestingly, the results of the present study demonstrate that the time spent in sedentary behavior is positively associated with the frequency, amount

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and with the severity of UI symptoms. In addition, our results also show that incontinent women have higher minutes spent in sedentary behavior than the continent ones. Despite growing evidence from epidemiological studies that sedentary behavior is a health risk factor for several chronic diseases, there is still a lack of evidence about the physiological responses of the PFM to sedentary behavior (inactivity physiology). We speculate that women with extreme behavior regarding PA – inactive women vs. athletes (Da Roza et al., 2014) – would be more prone to develop pelvic floor disorders as a consequence of opposite factors.

Incontinence may have a negative impact on physical, emotional and social health in women's life, and can lead a handicap to PA (Brown & Miller, 2001). However and in contrast, studies also demonstrated that the urine loss did not restrict the activities or diminish the self-esteem (Fultz & Herzog, 2001) since only a few women reported that they avoided sporting activities because of urine leakage (Brown & Miller, 2001). Our results demonstrated that among the 20 incontinent women, most of them (n=15) reach the PA recommendations and only few ones consider the leakage as a severe (n=4) or as a great extend (n=1) problem on their quality-of-life. So, based on this we suggest that, in our study, the incontinent women did not reduce their daily activities due to UI. The results also demonstrated a negative association between light PA and UI variables. A theoretical model evidences a physiological synergistic relationship between PFM and abdominal muscles (mainly the *transverses abdominis*) (Sapsford, 2004; Sapsford & Hodges, 2001). This association indicates that an increase in PFM activity occurs in response to isometric contractions of the abdominal muscles during normal trunk activities, which can improve the vaginal squeezing pressure contributing for urinary continence (Sapsford et al., 2001). The negative correlation found in the present study between light PA with the amount of leakage and the ICIQ-SF score may support the fact that light exercise can have a protective effect on the PFM through this synergy

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effect. Nevertheless, more research is warranted into the mechanisms underlying the effect of sedentary behavior and light PA on the PFM.

This study presents some limitations. Firstly, we used a self-reported measure of UI symptoms. Nevertheless, the ICIQ-SF questionnaire is a validated instrument and it is specific to assess UI symptoms. This is a cross-sectional data set, which may increase the risk of reverse causation. An important strength of our study was that PA levels were measured objectively by means of accelerometry.

Conclusions

In conclusion, reach the PA guidelines recommendations was not associated with UI. The results showed that incontinent women spend more minutes of sedentary behavior per day than the continent women. Furthermore, sedentary behavior was positively associated with the frequency and amount of urine leakage and also with the UI severity, which could be considered a novel risk factor for UI. Considering our results, it seems important to promote actions that can both reduce the sedentary behavior and promote the guidelines for PA in the young female population.

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Table 1: Type of urinary incontinence among nulliparous women (ICIQ-SF), n=20. Multiple answers possible.

	N
Loss of urine during coughing/sneezing	3 /20
Loss of urine during physical activity	11 /20
Loss urine before reaching the toilet	6 /20
Loss of urine after finishing urinating and are dressed	1 /20
Loss of urine for no obvious reason	2 /20
Loss of urine when asleep	0
Loss of urine all the time	0

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Table 2: Participant demographics and physical activity characteristics (n = 81).

Variable	*Continent (n=61)*	*Incontinent (n=20)*	*p*[1]
Age (years)	24.9±4.5	22.7±3.1	0.079
Age of menarch (years)	12.7±1.3	12.9±1.1	0.751
Weight (Kg)	58.8±7.1	56.2±5.5	0.194
BMI (m/Kg^2)	21.6±1.9	20.9±1.8	0.176
PA levels			
$Count \cdot min^{-1}$	298.3±139.2	236.2±88.8	0.151
Sedentary (min/day)	880.9±260.6	1045.6±88.8	0.019*
Light (min/day)	267.5±100.0	241.6±86.8	0.408
Moderate (min/day)	46.3±23.6	43.6±21.8	0.697
Vigorous (min/day)	3.8±8.1	3.4±6.2	0.142
MVPA (min/day)	50.1±26.1	47.0±22.4	0.930

BMI: body mass index; PA: physical activity; MVPA: moderate-to-vigorous physical activity

[1] Analysis by Mann-Whitney *U* test

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Table 3: Spearman correlation coefficients between physical activity levels and urinary incontinence variables (n=20).

Variable	Sedentary PA (min/day)	Light PA (min/day)	Moderate PA (min/day)	Vigorous PA (min/day)	MVPA (min/day)	Count. min^{-1}
Frequency of leakage	0.455*	-0.411	0.232	-0.319	0.140	-0.179
Amount of leakage	0.456*	-0.456*	-0.348	0.041	-0.295	-0.214
Impact on QOL	0.348	-0.331	0.183	-0.042	0.120	-0.078
ICIQ-SF score	0.456*	-0.443*	0.134	-0.077	0.082	-0.130

PA: Physical activity; QOL: Quality of life

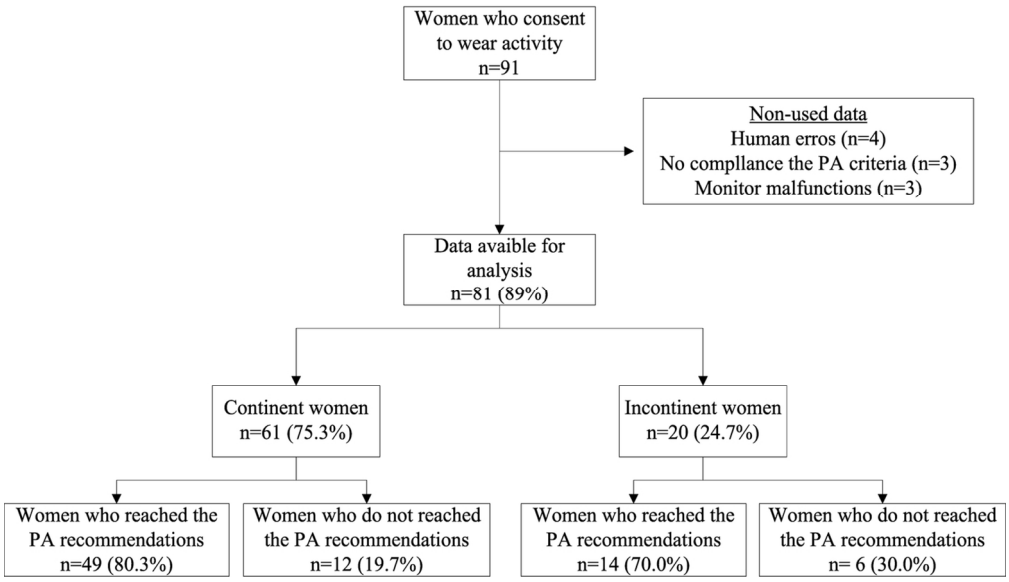
* $p<0.05$

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Legends

Figure 1: Flow diagram of the data included in the study. The eighty-one women in the final sample were divided according to continence status and physical activity parameters.

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Flow diagram of the data included in the study. The eighty-one women in the final sample were divided according to continence status and physical activity parameters.
119x68mm (300 x 300 DPI)

For Review Only

Study IV

Football Practice and Urinary Incontinence: Relation between Morphology, Function and Biomechanics

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Title: Football practice and urinary incontinence: relation between morphology, function and biomechanics

Running Head: football practice and urinary incontinence

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Word Count: 2540

Keywords: athletes; finite element method; magnetic resonance imaging; sports practice; stress urinary incontinence

Abstract

Current evidence points to a high prevalence of urinary incontinence among female athletes. In this context, this study aims to assess if structural and biomechanical characteristics of the pubovisceral muscles may lead to urine leakage. Clinical and demographic data were collected, as well as pelvic Magnetic Resonance Imaging. Furthermore, computational models were built to verify if they were able to reproduce similar biomechanical pubovisceral muscle response as the one measured by dynamic imaging during active contraction by means of the percent error. Comparing to the continent ones (n=7), incontinent athletes (n=5) had thicker pubovisceral muscles at the level of the midvagina ($p=0.019$ and $p=0.028$ for the right and left sides, respectively). However, there were no differences neither in the strength of contraction in the Oxford Scale or in the displacement of the pelvic floor muscles during simulation of voluntary contraction, which suggests that urine leakage may be related with alterations in the intrafusal fibers than just the result of thicker muscles. Additionally, we found similar values of displacement retrieved from dynamic images and numerical models (6.42 ± 0.36mm vs. 6.10 ± 0.47mm; $p=0.130$), with a percent error ranging from 1.47% to 17.20%. However, further refinements in the mechanical properties of the striated skeletal fibers of the pelvic floor muscles and the inclusion of pelvic organs, fascia and ligaments would reproduce more realistically the pelvic cavity.

1. Introduction

Urinary incontinence (UI) [1] is traditionally regarded in the literature as a problem affecting older multiparous women due to its relation with ageing, pregnancy and vaginal delivery [2]. However, a high prevalence of UI, mainly stress UI (SUI) [3, 4], has been observed in young nulliparous female athletes [5, 6], which can be explained by the marked increase in intra-abdominal pressure (IAP) [7] during exercise. Accordingly, as a consequence of high and recurrent pressure upon the pelvic floor muscles, bladder and urethra, SUI is prevalent in high-impact activities such as trampoline, gymnastics and some ball games [6]. On one hand, the repeated increase in IAP may lead to a continuous pre-contraction and strengthening of the pelvic floor muscles during training [7]. However, there is enough evidence to state that intense training may also have the effect of overloading and stretching the pelvic floor [6, 8], which potentially explains the development of structural and/or functional changes that lead to SUI [6].

Assuming the hypothesis that women who undertake high-impact sports for a long period overload their pelvic floor [6], it is expected that these forces cause some degree of muscle damage or weakening, which changes their biomechanical response regarding continence and organ support [9] in the long-term. During the increase in IAP, the pubovisceral muscle closes the *urogenital hiatus* widening through a strong postero-anterior contraction to maintain the continence and to resist the downward movement of the organs.

As *in vivo* experimental work is very difficult to undertake in this field, biomechanical models have been applied to better understand the role and the mechanical behavior of the pelvic structures in the development of UI and genital prolapse, such as the muscles and ligaments [10]. As for example, Chen et al. evaluated the changes in material properties of the

pelvic floor muscles, uterine ligaments and fascia to explain cystocele formation and apical descent, which are possible findings in pelvic floor dysfunction [11, 12].

SUI is not fully understood [6], and diagnosis often relies on imaging methods such as ultrasound and Magnetic Resonance Imaging (MRI) in the clinical setting to evaluate muscle damage or (ab)normal contraction [13, 14]. As our purpose was to gather knowledge of the anatomy and function of the pelvic floor muscles in female football players, in both a clinical and biomechanical perspectives, we aimed to assess if numerical models were able to reproduce similar muscle biomechanical response. To this end, and in order to investigate if there were differences between continent and incontinent athletes, we produced numerical models from their MRI data. Furthermore, we simulated pelvic floor muscles contraction to compare postero-anterior muscle displacement with the results from additional dynamic sagittal images. This biomechanical analysis is part of current work to further validate the model, which will be used to assess the effect of IAP loading on the pelvic floor muscles induced by different types of exercise. This will enable to estimate local stress values along the pelvic cavity.

2. Materials and methods

2.1 Participants

This was a cross-sectional pilot study conducted between November 2012 and March 2013 in the region of Porto, Portugal. Inclusion criteria included: to be a federated athlete for at least 7 years, eumenorrheic, nulliparous, to be between 18-25 years old and to have a body mass index (BMI) between 19-30Kg/m^2. Women were ineligible if they had undergone pelvic surgery, previous pregnancy, pelvic organ prolapse or chronic constipation. The Research Ethics Committee of the Centro Hospitalar de São João-EPE, Porto, Portugal (code: CES10/2010) gave full approval to this study.

Women took the International Consultation on Incontinence Questionnaire-Short Form survey (ICIQ-SF). The ICIQ-SF [15] is a simple and brief questionnaire developed by the International Continence Society (ICS), translated and validated for the Portuguese language [16]. The first question in the survey determines the presence or absence of UI, and it also includes eight questions to determine the type of UI (urgency, stress or mixed UI). Additionally, women were asked if the urine leakage episodes begun before or after starting the training, and also if they were able to stop the urine flow during micturation. Further demographic characteristics were collected (age, BMI, age of menarche and years of sport practice).

A final convenience sample of 5 incontinent (IG, incontinent group) and 7 continent (CG, continent group) athletes was selected from football Clubs.

2.2 Clinical evaluation

The 12 participants underwent clinical examination with the same gynecologist. During the evaluation, the contraction of the pelvic floor muscles contraction was assessed by digital examination of the vagina using the five-point Oxford Grading Scale: 0, no contraction; 1, flicker; 2, weak; 3, moderate; 4, good; and 5, strong. This was performed in a crook lying position, using two distal phalanges inside the vaginal *introitus*. Participants were asked to contract with the maximum perceived effort and to hold the contraction at least 2-3 sec. Three consecutive squeezes were recorded with a 10-sec interval between efforts [17], and the best was registered. Co-contraction of the gluteal, hip adductor or rectus abdominal muscles was discouraged through previous instruction to ensure a valid measurement. Only contractions with simultaneous observable inward movement of the perineum were considered valid [18].

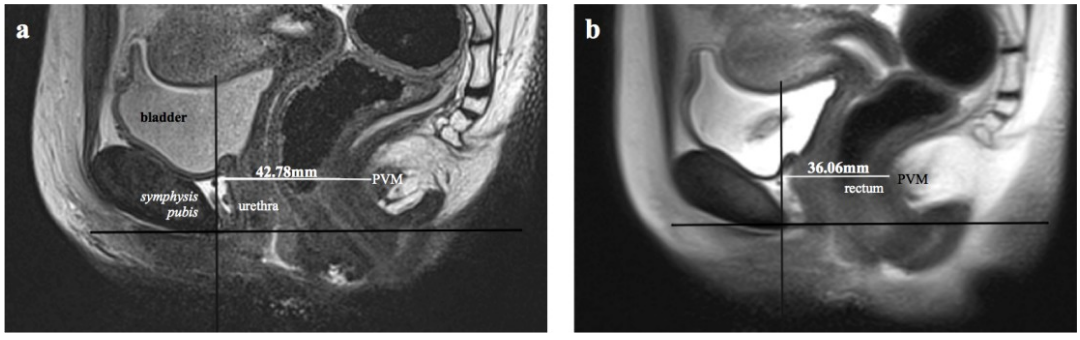
2.3 Image analysis

The participants were scanned for pelvic MRI in the supine position. Static multiplanar T2-w high-resolution and sagittal dynamic images at maximal voluntary contraction were

acquired using a 3.0T scanner. An experienced radiologist reviewed the datasets, and no pathological findings were described. Axial images were used to measure the pubovisceral muscle thickness at the level of the midvagina and the canal anal (right and left sides) (Figure 2a and 2d). To carry out the measurements, the slice closer to the plane of minimal hiatal dimensions was used. This plane is defined as the minimal antero-posterior (AP) diameter of the *urogenital hiatus*, from the postero-inferior margin of the *symphysis pubis* to the anterior margin of the pubovisceral muscle [19], where it defines the anorectal angle [20].

Figure 1 shows sagittal images from a continent 19-year old athlete, acquired at rest (a) and during contraction (b) of the pelvic floor muscles. The black lines are horizontal and vertical axes placed in the inferior and posterior border of the symphysis pubis. The white line demonstrates the distance between the vertical axis and the pubovisceral muscle. The difference in muscle position between rest and contraction was registered as being its postero-anterior displacement. This pulls the rectum, the urethra and the bladder anteriorly towards the *symphysis pubis* as seen in Figure 1, which reduces the *urogenital hiatus* length and width.

Figure 1: Magnetic Resonance images of the same continent woman at rest (a) and during maximal voluntary contraction (b) (PVM=pubovisceral muscle).



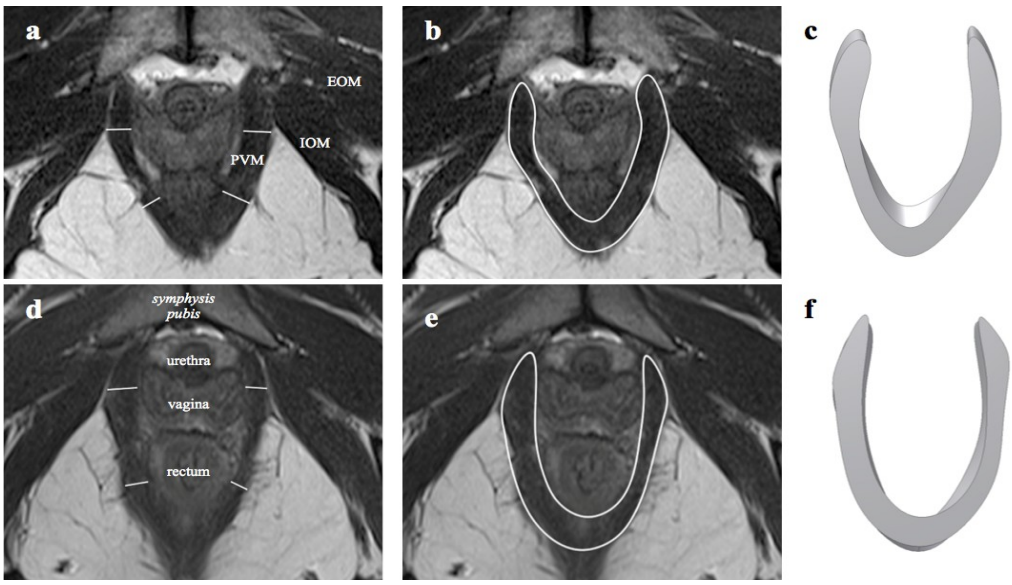
Numerical simulation

To build the biomechanical models based on the Finite Element Method, the pubovisceral muscle was identified between the pelvic organs and the obturator muscles throughout the axial images. It was manually segmented (Figure 2b and 2e) by using a contour spline in the Inventor® software (Autodesk, San Raphael, CA, USA) [21] to

create a 3D solid model, see Figure 2c and 2f. After this manual procedure, the geometrical model of the muscle and the finite element mesh (with tetrahedral elements – C3D4) were created using the Abaqus® software version 6.12 (Dassault Systèmes Simulia Corp., Providence, RI, USA). The number and volume of elements in the meshes varied among the subjects due to the individual differences in muscle geometry. Mean values were Mean values were 121.113 and 19.115.80mm^3, ranging from (61.768 - 232.930) and (9.324.46 - 29.934.68mm^3), respectively.

Boundary conditions play a central role in the simulation results, because they may change the biomechanical response and the displacement values depending on the anatomical location of muscle attachments. To simulate the pubovisceral muscle contraction, boundary conditions were imposed to incorporate the existence of the surrounding structures. The nodes corresponding to the insertion of the pubovisceral muscle in the symphysis pubis were considered zero-displacement nodes. Those portions attached to the arcus tendineous levator ani in the medial surface of the internal obturator muscle (which prevent lateral movement in the x-direction) and the tip of the coccyx (which is known to have some degree of vertical mobility) were constrained to move in the z-axis.

Figure 2: Axial images of a continent (upper row) and incontinent woman (lower row). The pubovisceral muscle (PVM) was identified, and its thickness (right and left sides) was measured at the level of the midvagina and the canal anal (a and d). Individual 3D solid models of the muscles were created via manual segmentation of the geometry (b and e) by using a contour spline (c and f) (EOM=external obturator muscle; IOM=internal obturator muscle; PVM=pubovisceral muscle).



In order to obtain an approximation of the muscle fiber directions, which is an important parameter for the constitutive model, it was assumed that muscles have an isotropic behavior, defined by Yeoh [22]. It was also implicit that the direction of the muscle fibers is coincident with the direction of the maximal principal stress lines when the pelvic floor is deformed by the weight from the pelvic organs at rest. For this purpose, a uniform pressure of $1x10^{-3}$ MPa was applied to the inner surface of the pubovisceral muscle. The parameters C10 = 0.003 N/mm^2, C20 = 0.002 N/mm^2 and C30 = 0.001 N/mm^2 were obtained from the experimental work of Janda et al. [23].

In this work it is assumed that the muscles are a highly hydrated tissue and, consequently, a quasi-incompressible behavior was attributed. The constitutive equation adopted for the muscle 3D behavior is a modified form of the incompressible, transversely isotropic, hyperelastic model proposed by Humphrey and Yin (1987) for cardiac tissues [24].

The strain energy per unit volume of the reference configuration can be written using the equation:

$$U = U_I\left(\bar{I}_1^C\right) + U_J\left(J\right) + U_f\left(\bar{\lambda}_f, \alpha\right) \tag{1}$$

U_I is the strain energy stored in the isotropic matrix embedding the muscle fibers, defined as (Eq.2) :

$$U_I = c\left[e^{b\left(\bar{I}_1^C - 3\right)} - 1\right], \tag{2}$$

where c = 0.0185 N / mm^2; b = 1.173.

In Eq. (1) U_J is responsible for ensuring the incompressibility condition (where D = 0.0001 mm^2 / N), and is defined by Eq. (3) as:

$$U_J = \frac{1}{D}\left(J-1\right)^2, \tag{3}$$

U_f is the strain energy stored in each muscle fiber, that includes a passive elastic part and an active part due to the contraction. The parameters used in the model for passive elastic behavior U_{pas}, given by Eq. (4) were A = 0.028 N / mm^2; a = 0.0625.

$$U_{pas} = A\left\{\exp\left[a\left(\bar{\lambda}_f - 3\right)^2\right] - 1\right\} \tag{4}$$

where $\bar{\lambda}_f$ represents the fiber stretch ratio in the direction N of the undeformed fiber. When $\bar{\lambda}_f > 1$, otherwise we consider the strain energy to be zero, assuming that the fibres offer no resistance to compression. The active part U_{act} is given by [25]:

$$U_{act} = \alpha\, T_0^M \int_1^{\bar{\lambda}_f} 1 - 4\left(\bar{\lambda}_f - 1\right)^2 \mathrm{d}\,\bar{\lambda}_f \tag{5}$$

where α is the activation level, ranging from 0 to 1. When $0.5 < \bar{\lambda}_f < 1.5$, U_{act} is larger than 0, for other values of $\bar{\lambda}_f$ the muscle produces no force and, therefore, the strain energy is zero. The constant T_0^M is the maximum tension produced by the muscle at resting length $\left(\bar{\lambda}_f = 1\right)$. For the active muscle contraction, the parameter T_0^M was = 6.82×10^{-7} MPa.

The magnitude and the postero-anterior displacements were assessed in the numerical simulation and the IG and CG were compared. As a means to evaluate the numerical model, the postero-anterior displacements were compared with the results from dynamic MRI for all the athletes. This displacement in the midsagittal plane was chosen as it enables to better visualize the upward and inward movement of the pelvic floor muscles without motion artifacts during the scanning. The percent error was also calculated for every case (displacement numerical simulation – displacement dynamic image) / displacement dynamic image * 100).

3. Statistical analysis

All analyses were computed using IBM SPSS Statistics (version 21). Descriptive statistics (mean, standard deviation for the continuous variables) were calculated. Mann-Whitney *U* test was used to compare the continent and incontinent groups. The differences between the displacements found in the numerical simulation and in the MR images were verified using the *Wilcoxon* test. The percent error between the displacements achieved in the numerical simulation and in dynamic images displacements for each athlete was calculated to determine the precision of the modeling. $P<0.05$ was considered statistically significant.

4. Results

Characteristics of the incontinent and continent athletes are presented on Table 1. Results are shown as mean ± SD.

Table 1: Demographic characteristics and years of football practice for the two groups.

Variable	IG (n=7)	CG (n=5)	*P*
age (years)	22.4±6.5	21.0±5.29	0.120
BMI (kg/m^2)	21.1±1.95	22.6±2.33	0.291
age of menarche	12.6±1.3	12.7±1.2	0.438
years of sports practice	10.6±4.1	9.4±1.9	0.620

BMI: Body Mass Index; CG: Continence Group; IG: Incontinent Group.

Comparison between the Oxford Grading Scale scores and morphological measures of pubovisceral muscle for the 2 groups is presented on Table 2. All the incontinent athletes self-reported SUI; furthermore, for all of them the episodes of urine leakage started after the beginning of football practice. We may note that our sample is homogeneous, meaning that it is comprised of young and nulliparous athletes who practice the same physical activity for a similar period of time. Furthermore, our results were not affected by known risk factors associated to UI such as increased age or high BMI [6] (Table 1) that could lead to potential bias. Results also demonstrated that women from the IG have significant thicker muscles at level of midvagina when compared to the continent ones (Table 2).

Table 2: Oxford Grading Scale and measurements of the pubovisceral muscle from the Magnetic Resonance images in women with and without urinary incontinence.

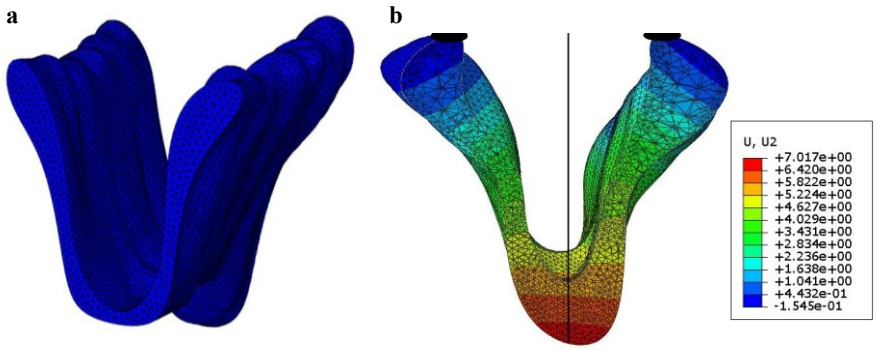
Variable	IG (n=7)	CG (n=5)	*P*
Oxford Grading Scale	4.1±1.8	4.3±1.2	0.541
thickness MidVa mm (left)	7.6±1.3	5.6±0.7	0.028*
thickness MidVa mm (right)	8.6±2.1	5.3±1.4	0.019*
thickness AC mm (left)	6.4±2.0	6.4±1.4	0.935
thickness AC mm (right)	6.4±2.3	6.2±1.8	0.935

AC: anal canal; CG: Continence Group; IG: Incontinent Group; MidVa: midvagina; mm: millimeters

The output for postero-anterior displacement (U2) was retrieved from the numerical simulation (Figure 3) and compared with the measurements performed in the dynamic MRI.

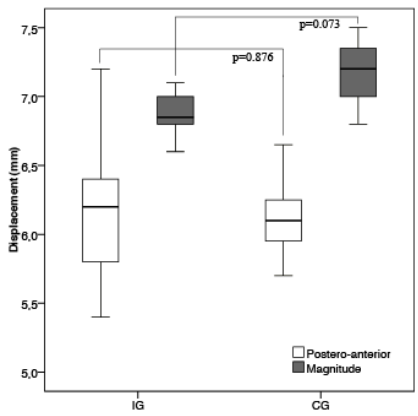
The results were similar (6.10±0.47mm vs. 6.42±0.36mm; p=0.130), and the percent error varied between 1.47% and 17.20%.

Figure 3: Numerical simulation model of the pubovisceral muscle of an incontinent young athlete at rest (a) and during contraction (b). The displacement resulting from PFM contraction is presented in millimeters. Black dots represent the upper margins where muscle attaches the *symphysis pubis*, and the black line denotes the axis of postero-anterior displacement of the pubovisceral muscle during contraction.



The comparison between postero-anterior and magnitude displacement outputs for both groups is shown in the boxplot (Figure 4). There was no statistical difference between the IG and CG (6.2±0.68mm vs. 6.1±0.31mm; p=0.876 and 6.9±0.19mm vs. 7.2±0.25mm; p=0.073, respectively).

Figure 4: Postero-anterior and magnitude displacements differences between both groups in numerical simulation.



5. Discussion

To our knowledge, this is the first study simulating active contraction of the pelvic floor muscles among young female athletes. The morphological measurements suggest that the incontinent women have thicker muscles at the level of midvagina when compared to the continent ones. Despite that, there were no differences either in the Oxford Scale or in the displacement on the biomechanical simulation between groups. Additionally, we found similar values of displacement in MRI vs. finite element method which means that the models were actually able to reproduce the pubovisceral muscle contraction.

Previous studies from Kruger et al. [26, 27] have already described thicker pelvic floor muscles in female athletes when compared with non-athlete controls, in the range of what was obtained in the present study. As our sample includes women practicing football for similar number of years, we suppose that the overload and stretch to the pelvic floor muscles may be comparable. Since athletes have thicker muscles and both groups presented strong and similar values on the Oxford Scale and in muscle displacement during contraction, we suggest that SUI may be associated with a decreased response or delayed reaction of the pubovisceral muscle rather than just the result of morphology and strength. As the pubovisceral and the *sphinter urethrae* muscles (that closes the urethra during the increase in IAP to prevent micturition) are part of the pelvic diaphragm [28], perhaps the pubovisceral muscle is thicker in incontinent athletes to try to counteract a decreased responsiveness of the *sphinter urethrae*.

Additionally, as in other muscles in the human body, the pelvic floor muscle are composed by striated skeletal fibers that act by means of passive and active forces at rest and also during voluntary contraction [29]. Theoretically, thicker muscles should have higher tension-generating capacity, as the number, length and cross-sectional area of the extrafusal fibers may be incremented. Curiously, similar mean values on the Oxford Scale were obtained

by both groups, suggesting that muscular strength, i.e., the maximal voluntary contraction [30], was not compromised. Accordingly, the similar values of displacement that we found for the two groups may indicate that thicker muscles of the incontinent athletes do not always reflect better function, since the stretch imposed by the exercise may deform the intrafusal fibers. Given that SUI in exercising women and athletes is not fully understood, our results suggest that the pelvic floor muscles may have a delayed response in result of many years of sports practice. As mentioned by Eliasson et al. [31], there is probably a personal threshold of intensity or training volume over which the pelvic floor muscles will not to support repetitive impact.

The magnitude of the force generated by skeletal striated muscle is related with the velocity of muscle shortening, the length of the fibers when stimulated and the period of time since the stimulus. On the biomechanical perspective, the constitutive model usually applied to pelvic floor muscle contraction is derived from experimental work of Humphrey et al. [24], which applies mechanical properties of cardiac muscle fibers, such as its length at rest or the maximum tension at rest ($T_0^M = 6.82\times10^{-7}$ MPa). However, it may not represent muscle responsiveness to continuous mechanical stimulus or the effect of neuromuscular activity loss. Moreover, there is no experimental evidence that the skeletal striated muscle fibers of the pelvic floor have the same mechanical properties of cardiac tissue. Future work is needed to address this important topic.

This study presents some limitations. Firstly, the model did not include the pelvic organs and connective tissue, which would be more realistic of the female pelvic cavity. However, a baseline pressure was applied in the inner surface of the muscle in order to mimic the presence of the organs. Secondly, as reported above, some assumptions and simplifications on the modeling were presumed. Finally, there is lack of experimental evidence of pelvic muscles properties in young incontinent athletes.

6. Conclusion

In conclusion, the numerical models showed similar displacement when compared with the dynamic MR images. Interestingly, despite the incontinent athletes showed thicker muscles at the level of midvagina, no significant differences were found in muscle strength or in the displacement at maximal voluntary contraction when compared with the continent ones. Accordingly, maybe pubovisceral muscle thickness is not the only ingredient to prevent urinary incontinence.

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Conflict of interest statement

There is no conflict of interest. Thuane Da Roza is currently receiving a research fund grant from the “Programa Ciências Sem Fronteiras – CNPq – Brasil”. For the remaining authors none were declared.

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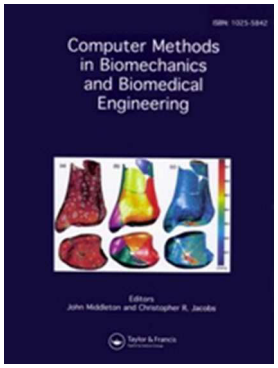
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Study V

A Pilot Study for the Analysis of Long-Term Exercise on Pelvic Floor Anatomy and Function

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Original

A pilot study for the analysis of long-term exercise on pelvic floor anatomy and function

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Intensive physical exercise has been suggested as being a risk factor for developing pelvic floor disorders. The main goal of this pilot study was to determine whether high-impact sports can modify pelvic floor muscles morphology in the long-term, and also if these changes alter its function when compared to low-impact sports. Two young, asymptomatic and nulliparous women of similar age were selected. One practiced low-impact exercise (Pilates) for 4 years while the other practiced high-impact sports (gym). Both were evaluated in 2008 and 2012 by using clinical examination, self-assessment questionnaires and magnetic resonance imaging. Tridimensional finite element models were built for both periods in order to simulate the pelvic floor contraction as a means to assist on clinical evaluation. In 2012, the woman who practiced Pilates evidenced an increase in pelvic muscles thickness and a decrease in levator hiatus dimensions, while the gym practitioner had the opposite alterations. However, and despite these differences, continence and organ position was maintained through correct contraction. Results from numerical simulations were similar to the findings in dynamic magnetic resonance images. In this sense, one can consider the finite element method as an adequate tool to simulate pelvic floor muscles contraction and which can, therefore, be useful as a non-invasive evaluation method.

Keywords: Pelvic floor muscles, sports, biomechanics, urinary incontinence.

1. Introduction

The International Continence Society has standardized the nomenclature which defines stress urinary incontinence (SUI) as the involuntary loss of urine during elevated abdominal pressure (Haylen et al. 2010). SUI approximately affects 50% of the middle-aged women on situations such as sneezing, coughing and/or sports activities (Minassian et al. 2003). Currently, the highest rates of SUI were found among young women who practice high-impact sports (Eliasson et al. 2002). Its symptoms have a major impact on different aspects of the womens well being, which negatively affects their quality of life and may lead to inactivity (Gasquet et al. 2006; Hay-Smith et al. 2009). Indeed, authors found that incontinent women change their daily routines and spend less time with friends than continent ones (Jarvis et al. 1980).

Female continence may be seen as a biomechanical issue. The pelvic floor muscles (PFM) are of utmost importance for urinary continence along with the pelvic fascia and ligaments (Madill

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et al. 2010). Although the etiology of SUI has not yet been completely understood, the most popular current theory indicates that it frequently involves damage of the PFM, namely to the pubovisceral (PV) muscle, which forms a sling around the rectum and vagina to promote the levator hiatus (LH) closure (Kearney et al. 2006). The PFM have the ability to support the pelvic organs by contracting in an upward direction in order to prevent urine leakage (Bø et al. 1990) during rises in intra-abdominal pressure (IAP). Consequently, when the PFM are impaired, there is a weakening of the pelvic organs support and, consequently, the dimension of the LH may widen.

Previous studies have shown that wide LH and weakened PFM are associated with the recurrence and progression of SUI (Vakili et al. 2005; Ghafar et al. 2013). Recently, a new biomechanical concept based on the moment of inertia (MOI) of the cross-sectional PFM area was proposed so as to measure the bending or deflection characteristics of the PFM with LH measures through Magnetic Resonance Imaging (MRI). The idea is that the thinner the muscle and the wider the LH, the lower the resistance to deform the cross-sectional PFM area there will be (Brandao et al. 2013).

Nowadays, most young women try to keep fit by going to gyms and taking part of fitness programs. However they do not take special precautions to protect their PFM. A recent study found that women who attend the gym have a high prevalence of urinary incontinence symptoms, regardless of the type of physical activity that they perform (Fozzatti et al. 2012).

Recently, Pilates has gained popularity and acceptance within the fitness community. This mind-body fitness program incorporates the use of special equipment into movement routines designed to enhance flexibility, strength and coordination through low-impact exercises (Newell et al. 2012). Nevertheless, Bø et al. (2011) showed that urinary incontinence is prevalent among female fitness instructors, including yoga and Pilates teachers. Therefore, it is still difficult to reach conclusions as to any of these training methods when it comes to assess their impact on PFMs health.

Taking into account the hypothetical repercussions of high-impact vs. low-impact sports on the PFM, the main goal of this pilot study was to determine if there are any long-term effects of going to the gym vs. doing Pilates exercises to the pelvic floor morphology, and to verify if distinct morphologies reflect differences in PFM function.

2. Materials and Methods

2.1 *Participants*

The present pilot study was a prospective and comparative study, approved by the Ethics Committee of the Centro Hospitalar São João-EPE, Porto. Two young, asymptomatic and nulliparous women with similar age were selected. Both participants were evaluated in 2008 and in 2012 using clinical examination, self-assessment questionnaires and pelvic MRI.

2.2 *Gym and Pilates exercises*

Until 2008, both women were sedentary, but for the following 4 consecutive years, volunteers A and B performed regular Pilates and gym sessions, respectively. Volunteer A (25 years) had 1h Pilates classes twice a week, headed by a Pilates certified instructor. The exercises consisted of Pilates soil type exercises, sometimes, using a Swiss ball. The class used the traditional principles of Pilates, performing the exercises slowly, with smooth movements. Exercises were performed with breath coordination. There was special care so as to perform most of these movements in conjunction with PFM contractions (Wells et al. 2012).

On the other hand, volunteer B (22 years) went to the gym to perform localized exercises, e.g. sit-ups, bodybuilding and exercises with weight bearing. Furthermore, she was actively involved in body combat classes. These exercises were inspired by mixed martial arts, using a variety of muscle groups to perform fast movements with leaps both in the vertical and onward directions (Rixon et

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al. 2006).

This study defines regular physical activity as that performed every week, for a minimum period of 3 months, without missing classes/training sessions for more than 2 consecutive weeks. It is important to state that neither women had had any prior experience with formal PFM training, Pilates or Yoga exercises.

2.3 *Clinical examinations and Questionnaires assessment*

The clinical evaluations were performed at Centro Hospitalar São João-EPE. In the crook-lying position, volunteers were taught to contract their PFM with maximum perceived effort, and to hold the contraction for 2-3 s. Their ability to contract was measured by using the modified Oxford Grading Scale through digital examination (two fingers) and by observing the inward movement of the perineum during contraction. Co-contraction of the gluteal, hip adductor or rectus abdominal muscles was discouraged in previous instructions.

Afterwards, both volunteers filled in self-assessment questionnaires consisting of socio-demographic data, exercise habits and by "International Consultation on Incontinence Questionnaire-Short Form-ICIQ-SF", which assesses urinary incontinence symptoms (Tamanini et al. 2004).

2.4 *MR images and Measurements*

Axial 3-mm T2-weighted MR images of the pelvis were carried out by using a 3 tesla scanner. The images were acquired at rest in the supine position, along the puborectal line. This plane is defined as the minimal anterior-to-posterior (AP) diameter of the LH, from the posteroinferior margin of the symphysis pubis to the anterior margin of the PV muscle, where it defines the anorectal angle (Dietz and Shek 2009; Kruger et al. 2010). Using the same reference line, a dynamic acquisition was carried out at rest and during maximal voluntary contraction.

The image datasets acquired at rest were analyzed in the manufacturer workstation at a later stage. To carry out the measurements, the axial slice closer to the plane of minimal hiatal dimensions was used. The PV muscle thickness (right and left sides) and hiatal AP diameter and lateral diameter (Figure 1) were assessed. The variation in hiatal lateral dimensions (on the level of the midvagina) from at rest to contraction was measured by its relative variation percentage [(rest-contraction)/rest x100]. This was used as an indirect measure of the contraction ability through LH closure.

2.5 *CAD software and Finite element method*

The software Inventor (Autodesk, San Raphael, CA, USA) was used to draw and calculate the MOI and the cross-sectional area of the PV muscle using the plane of minimal dimensions. To build the four biomechanical models (volunteers A and B, both 2008 and 2012 datasets) all the images that included the PV muscle were manually segmented by using a contour spline (Figure 2a), as in previous work (Brandao et al. 2013). After this manual procedure, the geometrical model of the PV muscle (Figure 2b) and the FE mesh (with tetrahedral elements) were created (Figure 2c). The passive part of the muscle was considered a homogeneous and hyperelastic material.

To simulate muscle attachments, boundary conditions were placed on the upper margins of the muscle, where it connects with the pubic bone and the arcus tendineous levator ani. As the tip of the coccyx is an important insertion point, with some degree of mobility, the movement of the FE nodes in the AP direction was constrained. Finally, in order to obtain an anatomical-based approximation of the complex muscle fiber directions, which is a parameter for the constitutive model, the methodology used by d'Aulignac et al. (2005) and Parente et al. (2008) was followed. A uniform pressure of $1x10^{-3}$MPa was applied (it reproduces the IAP) to the inner surface of the PV

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muscle. The resultant maximum principal stress lines for each finite element were assumed to be coincident with the direction of the muscles fibers. Subsequently, while maintaining the pressure, muscle activation up to 100% was performed, following the methodology applied by Saleme et al. (2011).

The constitutive equation adopted in this work is a modified form of the incompressible transversely isotropic hyperelastic model proposed by Martins et al. (1998), which in turn is based on the work of Humphrey and Yin (1987). The modifications made by Martins, in Humphrey's model, had the purpose of making it qualitatively and quantitatively compatible with the passive and active longitudinal behavior of the PFM (Saleme et al. 2011).

The numerical simulation was made using the implicit version of the commercial software ABAQUS version 6.12 (Dassault Systmes Simulia Corp., Providence, RI, USA). After simulating PFM contraction, the relative variation percentage of the hiatal dimensions (at the level of midvagina) was assessed in the FE model. The measures of contraction for 2008 and 2012 were compared for the two volunteers by using the numerical results with the dynamic MRI.

3. Results

After 4 years of Pilates exercises, volunteer A evidenced an increase in PV thickness, area and MOI, as well as a decrease in both AP and lateral diameters of the LH. In contrast, volunteer B demonstrated a decrease or no change in these variables (Table 1). Despite the morphological differences found on the PFM between the participants, both remained continent and with unchanged PFM function.

Figure 3 shows the results of the relative variation percentage of the LH lateral dimension assessed by both the FE model and a dynamic MRI. The magnitude of the measurements was similar. The results showed a relative displacement of 7.82% and 9.81% in dynamic MRI vs. 7.75% and 9.76% in FE model, for volunteer A in 2008 and 2012, respectively. For volunteer B, the results were 6.8% and 7.02% in dynamic MRI vs. 6.07% and 7.2% in FE model. In this work, the FE method was used to conduct a biomechanical study of the PFM.

Both women finished 4 years of regular physical activity, without being absent for more than 2 consecutive weeks. During this 4-year period the participants maintained a normal body mass index (24.2 and 24.6 kg/m^2 for volunteer A vs. 21.5 and 22.3 kg/m^2, for volunteer B, for 2008 and 2012, respectively), never experienced pelvic problems, were never pregnant nor did they complain about loss of urine.

Regarding the Oxford scale, both women performed correct and reproducible contractions of the PFM. In 2008, their performance was classified as 4 (good contraction). In 2012, volunteer A improved to 5, while no change was observed for volunteer B. There was no clinical or imaging evidence of a pathological organ descent or even levator ani muscle lesion or dennervation.

4. Discussion

This study investigated the long-term effects of two different sports (high- vs. low-impact) on PFM morphology and functions through dynamic and static MRI and presented a methodology based on the FE method as a biomechanical tool to understand this complex structure. The results show that the participant performing regular Pilates for 4 years improved PFM contraction, the PV muscle thickness area, MOI, and decreased LH diameters when compared with the woman who attended a gym. These findings support the results from other studies which showed that Pilates exercise programs can strength the PFM (Savage 2005; Culligan et al. 2010).

The biomechanical simulation allows modeling pelvic structures and to indirectly quantify their mechanical behavior under any theoretical conditions (da Silva-Filho et al. 2010). Furthermore, the medical community is beginning to acknowledge the relevance of numerical simulation methods as

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an additional tool to the medical knowledge of the pathophysiology of the pelvic cavity (Petros 2007). In these FE models, the displacements obtained for the numerical simulation of 100% muscle contraction was similar to the MRI findings (Figure 3), thus showing that this methodology is adequate to simulate PFM contraction.

Nowadays, different forms of aerobic dance have been introduced as an effective and fun way to control body weight at the gyms e.g. body-combat (Rixon et al. 2006). These exercises include small and frequent jumps that therefore increase the IAP, and consequently put pressure into the PFM. In contrast, as Pilates comprises movement routines designed to enhance flexibility, strength, and coordination through low-impact exercises (Newell et al. 2012), many Pilates instructors believe that their methods can produce significant improvement in pelvic floor strength. This may eventually lead to a widespread use of Pilates-based exercise programs to treat and prevent pelvic floor dysfunction (Culligan et al. 2010).

In the last decade, the highest prevalence of SUI was found in athletes that heavily overload their pelvic floor (Nygaard et al. 1994; Thyssen et al. 2002). Studies have reported that high-impact sports may cause direct damage to the PFM (Jiang et al. 2004) or to the connective tissue, and therefore may play a role in urinary incontinence (Nygaard et al. 1994). Others indicate that morphological changes of the PFM might be the result of sports activities (Eliasson et al. 2002; Thyssen et al. 2002). However, until now, no study has verified the long-term consequences of exercise on the PFM morphology and function.

Pelvic floor disorders have been related to a wider LH and also to a more circular morphology, since the width and area of the hiatus strongly correlates with pelvic organ descent (Dietz and Shek 2009). Interestingly, this study showed that despite morphological differences between the participants, none of the young women showed SUI or prolapse symptoms. These results support the concept that urinary incontinence in young women might not be due to morphologic changes of PFM, but a consequence of altered muscle responsiveness to mechanical stimulus instead. Perhaps, high demand of pressure upon the pelvic floor could alter the responsiveness on intrafusal fibers (stretch receptors), which may results in a delay of PFM contraction.

Regarding a biomechanical perspective, the woman who attended a gym showed a decrease in the MOI of almost 30%, probably associated to a smaller PV muscle area and a wider LH (Brandao et al. 2013), resulting from constant rises in abdominal pressure. Several studies demonstrate the direct association between PV muscle thinning and defects with the increase of LH and prolapse diagnosis (Ansquer et al. 2006). Therefore, this study supports the hypothesis that high-impact sports may cause changes in LH and/or in the PFM function in a long-term, and might contribute to a high prevalence of PFM dysfunction such as SUI (Eliasson et al. 2002; Thyssen et al. 2002) and increase the risk of urogenital prolapse.

On the other hand, the woman who practiced Pilates evidenced a decrease in the hiatus diameters and an increase in PV thickness and MOI parameters, and these changes are most probably induced by the Pilates practice, as the PFM contraction is constantly performed.

To the authors best knowledge, longitudinal studies reporting the effects of Pilates and gym exercises on PFM in young nulliparous are quite rare in the literature. A former study showed that females who practiced Pilates were more efficient in recruiting their PFM and in stabilizing the pelvic area when compared to those who did not perform Pilates (Bernardo 2007). However, it is important to notice that this improvement will be noticed if the woman is able to correctly contract their PFM. Importantly, the present results do not emphasize the use of the Pilates method to prevent or treat pelvic floor dysfunctions. For this purpose, PFM training is the most relevant non-surgical treatment for pelvic floor disorders, with level A of evidence (Bø et al. 2007).

In the present study, the FE model has shown to be useful to quantitatively predict the effect of maximal voluntary contraction in the PFM. As the results from computational model were very close to the dynamic MR images, the FE simulation may be used as a non-invasive method when the Oxford Scale or the dynamic MR images cannot be performed. Some limitations must be considered. Firstly, this is a study-case work with a limited number of subjects. Secondly, there was no control over the frequency of the exercise performed by the participants. Another

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limitation of the study is the lack of a control group, so as to test possible differences induced by a sedentary lifestyle. In addition, the presented model also lacks some structures (such as the perineal body, organs, ligaments), which could affect some of the numeric values. Finally, larger randomized trials designed to determine the consequences of exercise programs in PFM during a long-term are required.

5. Conclusions

The present study demonstrated a negative long-term effect of high-impact exercise on the PFM and LH morphology in young nulliparous women. The results suggest that women who perform high-impact exercises should be more aware of their PFM and seek orientation to strengthen these muscles. In addition, despite PFM morphology differing between the 2 women, there were no changes in the PFM function.

The computer modeling approach in this study has proved to be able to represent the PFM contraction and to have the ability to improve our knowledge of the mechanisms of PFM function in the future, thus avoiding the use of dynamic MRI. Further research on this topic should be performed.

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Table 1: Measures of levator hiatus diameters (cm), pubovisceral muscle area (mm^2), thickness (cm) and moment of inertia (mm^4). The differences (Diff) between the two moments are also recorded.

Variables	Vol.A (2008)	Vol.A (2012)	Diff. (%)	Vol.B (2008)	Vol.B (2012)	Diff. (%)
AP diam.	5.7	4.9	-0.7 (13.0)	4.0	4.6	+0.6 (14.2)
Lateral diam.	2.5	2.1	-0.3 (14.0)	2.9	3.4	+0.6 (19.7)
Area	726.6	771.6	+45.0 (6.2)	276.3	239.3	-23,1 (13.4)
Thick (right)	0.5	0.8	+0.3 (57.6)	0.3	0.3	-0.01 (3.8)
Thick (left)	0.9	1.2	+0.3 (35.6)	0.4	0.4	-0.001 (0.2)
MOI	175716.1	206975.5	+31259.5 (17.8)	44627.4	32389.4	-12238.1(27.4)

AP (anteroposterior); diam. (diameter); Thick (thickness); MOI (moment of inertia).

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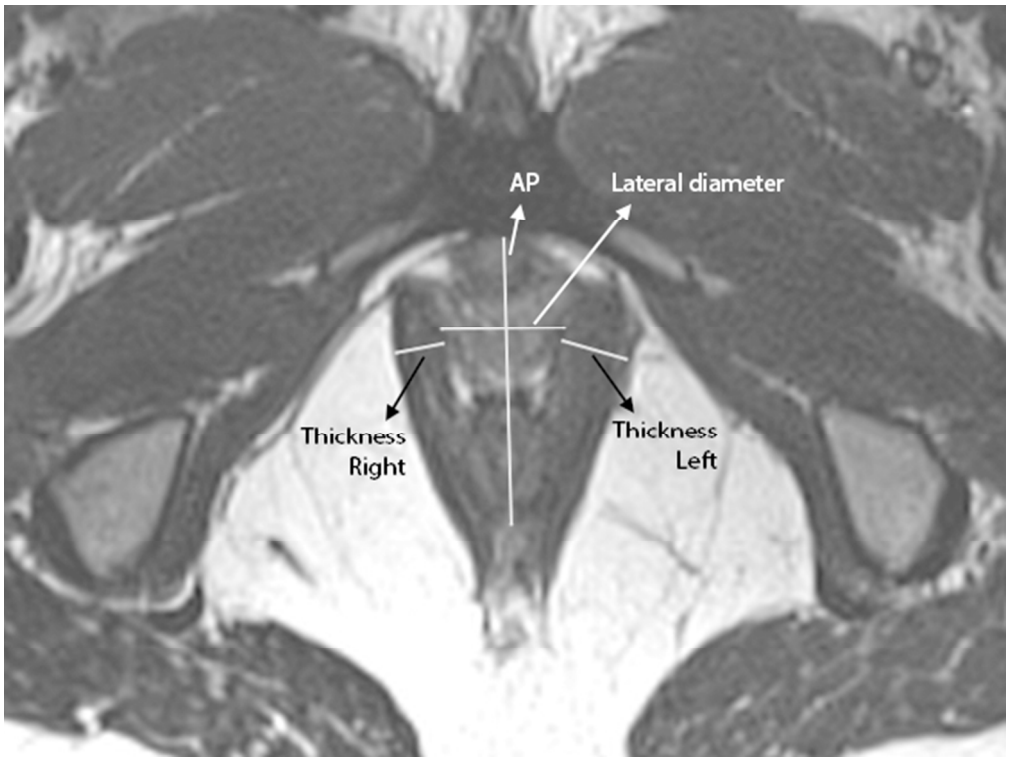


Figure 1: Morphological measures on the axial static MR images. Anterior-to-posterior (AP) and lateral dimensions (at the level of midvagina) of the levator hiatus were carried out (white arrows), and pubovisceral muscle thickness measures (left and right - black arrows) were taken.
55x41mm (300 x 300 DPI)

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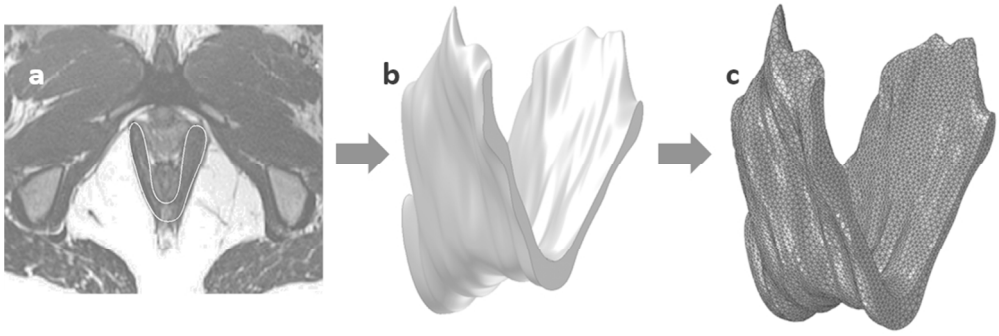


Figure 2: Steps for building the biomechanical model of the pubovisceral muscle. The manual segmentation of the muscles ´contour was performed by using the Inventor software (a). Afterward, a 3D computational model (b) and the finite element mesh were generated (c).
93x32mm (300 x 300 DPI)

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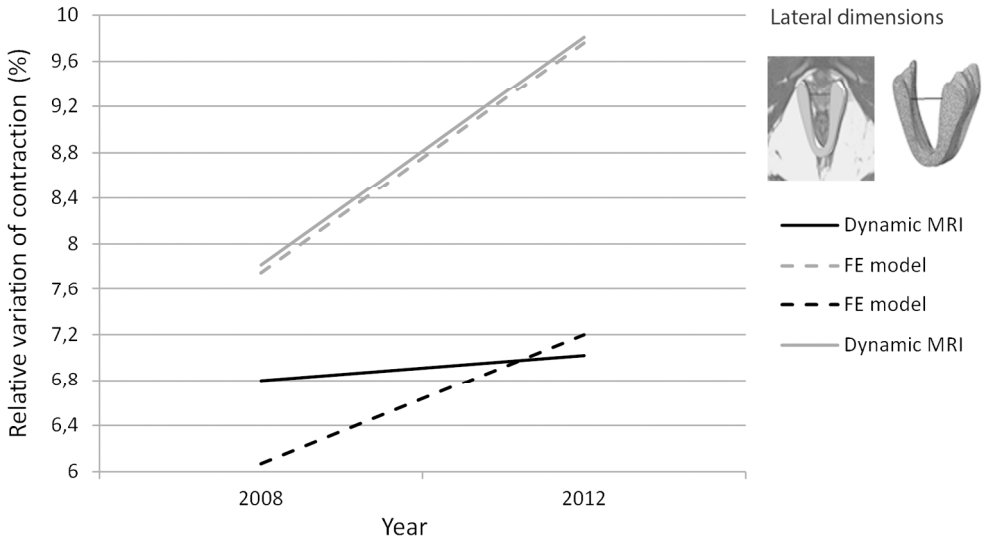


Figure 3: Results obtained from dynamic MR images and finite element model regarding the relative variation of pubovisceral muscle contraction (%) in the lateral dimension. The grey color line represents results from Volunteer A while the black color lines show Volunteer B.
159x93mm (300 x 300 DPI)

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Chapter IV

Integrated Discussion

Integrated Discussion

The original studies presented in this thesis corroborate the high prevalence of SUI among female athletes practicing high-impact sports described in the literature. Moreover, while the results suggested that organized exercise undertaken for recreational purposes seems to be safe against the urine leakage, the time spent in inactivity was significantly associated with the occurrence of UI symptoms. Finally, the obtained results also revealed that a change in the PFM's morphology is not necessarily associated with the occurrence of UI.

Clinical trials, systematic reviews and international guidelines recognize that being physically active implies changes in the musculoskeletal system, which increase general health outcomes (I. M. Lee et al., 2012). However, studies on the PA topic do not address the same aspects, making difficult to draw clinically useful conclusions regarding the PA effects on a specific anatomic structure as the PFM. Thus, to explore the connection between sports, the morphology and biomechanics of the PFM (Studies IV & V), the prevalence (Study II) and the risk factors to develop UI (Studies I & III), as well as to investigate the findings of the current scientific literature concerning women who practice sports and UI, we performed, firstly, a review of the literature (Chapter II) followed by five original studies (Chapter III). Our literature review evidenced the growing recognition among researchers that strenuous exercise, mainly high-impact sports (Eliasson et al., 2002), can induce adverse health effects on the PFM, and consequently incite the development of SUI. Importantly, this evidence is supported by the high prevalence rates of UI found in female athletes (Jacome, Oliveira, Marques, & Sa-Couto, 2011; Nygaard et al., 1994) and not on direct signs stating the true causes of UI or the level/amount of PA that could have negative effects on PFM in women engaged in exercise.

Two opposite's theories about the characteristics of PFM in athletes are widely recognized (Bø, 2004), one defending that athletes should have strong PFM while the other suggesting that the constant increase in IAP may overload

and stretch the PFM. Accordingly, assuming the hypothesis that high-impact sports might have a harmful effect on PFM, the objectives of Study I were to evaluate the frequency of UI among trampoline athletes and the relation between the training variables and the severity of SUI. Our results confirmed the high frequency of SUI in women performing high-impact sports (Eliasson et al., 2002; Nygaard et al., 1994), and evidenced a strong and positive correlation between both the accumulated training volume and the elite athletes' ranking in the championship with the ICIQ-SF score (Da Roza et al., 2014). This high frequency found is in line with the evidence from previous studies (Eliasson, Edner, & Mattsson, 2008; Nygaard et al., 1994; Thyssen, Clevin, Olesen, & Lose, 2002), which state that sports involving jumps are those more likely to induce urine leakage. In fact, with reference to a biomechanical perspective, during a jump the PFM suffer great pressures, mainly because they have to fight against the volume changes imposed by the jump-induced vertical accelerations (Hostettler, Nicolau, Remond, Marescaux, & Soler, 2010) and to limit the vertical viscera motion within the trunk; in response the PFM contract in each stimulus (Sapsford & Hodges, 2001), and consequently this exhaustive training can lead to adaptations in extrafusal and in intrafusal fibers (Dimitriou, 2014). In general, it might be expected that resistance exercise training leads on the trained muscles an increase in cross-sectional area, muscle mass and strength (Kirkendall & Garrett, 1998), but the continuous strenuous exercise can also induce damages in muscles spindles. Indeed, previous studies found that athletes presented increased cross-sectional area of PFM when compared with non-athletic women (Kruger et al., 2005) and strong PFM (Da Roza, Mascarenhas, Araujo, Trindade, & Jorge, 2013), which may corroborate with the positive effect in extrafusal fibers. Despite that, and controversially, our findings suggest that the athletes report frequently loss of urine (Study II), agreeing with previous study (Bø, 2004). In addition to this, our results show that the incontinent athletes had thicker PFM at level of midvagina than the continent ones (Study IV). If the maximum amount of force generated was directly dependent on cross-sectional area (Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997), it would be expected that incontinent athletes had

greater contraction force, and therefore should not present urine leakage. Curiously, no differences in strength were evidenced in the Oxford scale measurements, and during PFM contraction - evaluated by the dynamic MRI and by the 3D model simulations - the results presented similar displacement between the groups. Certainly, the capacity to generate force is one of many measures of the PFM function (Jones, Bishop, Woods, & Green, 2008). While pressure and thickness measurements are considered valid and reliable methods to assess the PFM for general female population (Morkved, Salvesen, Bo, & Eik-Nes, 2004), our study may indicate that thickness and MVC can be an insufficient methods to assess PFM function in female athletes. In this context, it seems apparent that force production to maintain the continence is a complex procedure that can not be explained just by muscle thickness alone, suggesting possible alterations in muscle response which we have designated as a delay in muscle contraction to the sudden increased IAP, as a probable consequence of negative effects in intrafusal fibers. Thereby, although both theories proposed are opposed (Bø, 2004) they could be explained by the exercise-induced alterations in extrafusal and intrafusal fibers.

Clearly, the etiology of UI symptoms in athletes cannot be determined on the basis of our results. However, these contradictory factors reinforce that this selected population can develop UI from different factors than those traditional risk factors commonly reported for elderly women (Bresee et al., 2014; Dolan et al., 2004; Gyhagen et al., 2013). Indeed, the aging process results in a gradual loss of muscle function, with typical muscle loss, and at the cellular level, muscles lose both cross-sectional area and fiber numbers, which can lead to weakness, fatigue, and slowing of movement (Kirkendall & Garrett, 1998). As PFM are made up of layers of skeletal muscles (DeLancey, 1994), these biologic effects also impact the PFM negatively (Marques, Stothers, & Macnab, 2010). Although the aging process is inevitable, these impairments can be potentially minimized with the regular PA (Kirkendall & Garrett, 1998). In this context, a cross-sectional study with 7.813 women found that moderate amounts of PA may be associated with longer telomeres, and in consequence, with a delay in the aging process (Du et al., 2012). Associated with this, it has

been suggested that decades of high-level exercise may delay functional decline in late aging (Mosole et al., 2014). However, the role of the contraction of the PFM against increased IAP during exercise remains enigmatic, especially regarding the synergic PFM activation with the abdominal muscles. This uncertainty leds to some controversy about the sports practice and its role on the development of UI (Danforth et al., 2007; Hannestad et al., 2000). It is assumed that regular, moderate to vigorous exercise is important to health (Medicine, 2009). However, the results of the literature linking PA recommendations with UI are variable, mainly due to the different methodologies applied to assess the frequency of urine leakage and the amount of PA performed each day, which makes difficult to compare results among the studies. Taking this into account and using the same methodology, we randomly selected an adequate sample size of young nulliparous women to verify if UI is associated with different levels of PA. After completing the inclusion criteria, women were separated by quartiles based on their amount of exercise practice per week, which ranges from inactive to athletic women. The results of Study II shows that the relative frequency of UI in the sample was 19.9%, but this rate was overestimated due to the presence of the athletes group (36.3% of UI). When divided by quartiles, the prevalence rates were 15.6% and 11.6% among physically active (3^{rd} and 2^{nd} quartiles, respectively) and 14.5% for inactive (1^{st} quartile) women. These rates are consistent with the prevalence presented by O'Halloran and colleagues (12.6%) in a non-athletes sample with very similar demographic characteristics (O'Halloran, Bell, Robinson, & Davis, 2012). Importantly, this study not only reinforces the high prevalence of UI among women training for competitive purposes, but also demonstrated their greater relative risk to develop UI when compared with the inactive women.

Apart from this, since women engaged in exercise (2^{nd} and 3^{rd} quartiles) did not present higher risk or increase in prevalence of UI when compared with the 1^{st} quartile, the results suggest that regular PA should be performed in order to gain the health benefits that come from the exercise. Besides that, new evidence suggests that a portion of the negative muscles changes during life

may be due to an increase in sedentary behavior (Trappe et al., 2013). Nowadays, the recommendations is to study the sedentary behavior in contradistinction to the effects of physical movement (Thyfault, Du, Kraus, Levine, & Booth, 2014). Since quantify the time spent in PA or in sedentary behavior is a challenge, Study III included the use of an accelerometer (allowing an objective assessment of PA) to evaluate the correlation between sedentary time, light, and moderate/vigorous PA with self-reported symptoms of UI. In fact, the international PA recommendations have long been based on research demonstrating objectively that at least 30 minutes of moderate-intensity daily exercise performed five days a week is necessary to achieve the benefits to general health (Nelson et al., 2007). In this context, this trial demonstrated that complying the 150 minutes of MVPA guidelines was not associated with UI symptoms, and opposite to that, we found a significant positive association between UI and the sedentary behavior.

Recent studies that objectively measured the daily sedentary time have shown that prolonged time in sedentary behaviors is a cardiometabolic risk factor regardless of MVPA (Bankoski et al., 2011; Owen, Sparling, Healy, Dunstan, & Matthews, 2010). Besides that, evidence from observational and intervention studies are beginning to show that disuse (sedentary behavior) may actually be the underlying reason for muscle atrophy and weakness (Peterson, Rhea, Sen, & Gordon, 2010). Thus and leading our findings account (Study III), perhaps the UI symptoms can also be linked to physical inactivity. On the other hand, our findings also showed that the time spent in light PA was negatively associated with UI. With the increasing interest in core training, cross-sectional and prospective studies have shown that light exercise may have a beneficial effect on the PFM (Danforth et al., 2007; Sapsford, 2004) e.g. walking was linked to a lower risk of developing UI (Danforth et al., 2007). These findings were supported by the fact that trunk exercises activate the PFM and, as the abdominal muscles are accompanied by a PFM's contraction, they should not be discouraged during PFM treatment (Sapsford et al., 2001). Concerning core muscles, a recent study demonstrated that if a subject stiffens the trunk segment during a jump, it can reduce the viscera vertical displacement into 30%

(Cazzola, Alberti, Ongaro, & Minetti, 2014), which can suggest that, if general PA strengthen the core muscles, this stability will lead to a decrease in forces upon the PFM during daily exercises. So, regular exercise can be beneficial to the PFM not only due to the training by co-contraction, but also because it can strength the core muscles and decrease the forces that the PFM need to counteract. Therefore, since PA is strongly recommended to reduce the risk of several health problems (Haskell et al., 2007; Pedersen & Saltin, 2006) and, considering that active women did not present higher risk or increase in prevalence of UI (Study II) and that sedentary time was associated with UI (Study III), we assume that a lack of PA can lead to muscle weakness and for this reason sedentary women should be encouraged to become physically and/or to engage in physical exercise programs as a protective behavior against UI. Nevertheless, more research is necessary to understand the mechanisms underlying the adverse UI effects of sedentariness.

Identify the risk factors for UI is a major goal to prevent this common and distressing condition (Stothers & Friedman, 2011). In attempt to understand the long-term effect of high and low-impact exercise on the PFM, results of Study V demonstrated that both women had morphological changes in the PFM. Evidently, we cannot affirm that the observed alterations were only due to exercise, since some of the variables were not sufficiently controlled and the women had influence of individual anthropometric and genetic characteristics. Accordingly with a recent systematic review (Bø & Herbert, 2013) only two studies assessed Pilates exercise as intervention for PFM dysfunctions (Culligan et al., 2010; Savage, 2005). One of them had insufficient data (Savage, 2005) and could not have a definitive conclusion about the effect of the Pilates program, and the other one demonstrated improved PFM strength at the end of the Pilates protocol (Culligan et al., 2010), similarly as in our work. We found an increase of PFM strength and thickness after 4 years in women who performed Pilates, while woman practicing gym did not demonstrate differences. In our study, the Pilates classes incorporate contraction of PFM, and possibly, these muscles were in fact trained. Notably, this study does not suggest Pilates as a treatment for PFM dysfunction. It has been claimed that

high-impact exercise is a risk factor to develop UI (Nygaard et al., 1994), but it is important to note that this condition only applies to athletes who perform large volume training (Da Roza et al., 2014). Our findings demonstrated that both women remained continent after 4 years of PA, and it is quite possible that performing high-impact exercise in long-term without hard training programs does not interfere with urinary continence.

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Chapter V

Conclusions

Conclusions

The connection between sports, known risk factors to develop UI and the methods to treat it among young fit women were analyzed. Although no single factor completely explains SUI etiology, it is generally assumed that the integrity and function of the PFM are the main contributing factors to maintain the continence in women. Among sports practitioners, the literature shows that the highest prevalence of UI is found in those women who perform sports for competitive purposes, particularly athletes of the high-impact sports. Given that the existing of several risk factors contributing to SUI, the recognition of weakness, fatigue and/or delay of the PFM contraction were the most mentioned alterations in sport women who do not present the traditional risk factors. Importantly, changes in PFM morphology, damage to the connective tissue and hormonal factors also were cited as factors to increase the risk to develop SUI in this specific population.

The main conclusions of this thesis are summarized below:

In **Study I**, as expected, the results show a high frequency of SUI in young trampolinists. Moreover, the athletes' ranking and the training volume were also identified as important risk factors to the emergence and severity of SUI, supporting the theory of the harmful chronic effects of high demand physical training in the PFM function.

Data from **Study II** shows that, comparatively to a sedentary behavior, female athletes with a high exigency training level have a 2.53 times greater risk to develop UI, while women performing exercise for recreational purposes did not evidence any increase in that relative risk.

In **Study III**, the results showed that the time spend in sedentary behavior is associated with the frequency, amount and severity of UI as well as the incontinent women demonstrated higher time spend in sedentary behavior than the continent ones. Furthermore, the results also evidence that the accomplishment of PA guidelines recommendations is not associated with UI symptoms.

Finally, **Study IV** showed that incontinent athletes have thicker PFM at level of midvagina when compared to continent ones. Moreover, during PFM voluntary contraction, there were no significant differences in strength neither in the displacement measured by dynamic MRI and computational simulation. This suggests that thicker muscles of the incontinent athletes do not always reflect better function, which can points to a decreased response or delayed reaction. The morphological differences that result from low *versus* high-impact exercises for recreational purposes - **Study V** - apparently also do not affect either the displacement of the PFM during contraction or the self-reported symptoms of UI. In summary, the effect of high-impact sports in the PFM relies more on the impact over an altered function than on their morphological characteristics.

Chapter VI

Future perspectives

Future perspectives

The results of this dissertation emphasize that future research needs to be directed to a clinical identification of the pathophysiology of urinary incontinence in young female athletes. Efforts to measure intra-abdominal pressure during activities such as exercise are also essential. Accordingly, strategies to real-time assessment of this increase in intra-abdominal pressure and pelvic floor muscles response should be development soon. Moreover, this issue should receive high research priority, with the completion of randomized control trials to evaluate moderate physical activity and its effect on urinary incontinence when compared with inactive women.

Regarding computational simulation, the use of biomechanical models that include as much as possible the structures that induce intra-abdominal pressure, such as the abdominal muscles, the diaphragm and the lumbar spine, as well as the pelvic organs, would allow a more realistic view of the female pelvic cavity in order to verify the effect of exercise on the pelvic floor muscles.