Is pregnancy related pelvic girdle pain associated with altered kinematic, kinetic and motor control of the pelvis? A systematic review

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Received: 11 February 2012 / Revised: 2 May 2012 / Accepted: 3 June 2012 / Published online: 21 June 2012
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Abstract

Purpose To determine the level of evidence for altered mechanical and motor control of the pelvis being associated with pregnancy-related pelvic girdle pain (PPGP).

Methods This systematic review was undertaken by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Six different databases were used for the electronic search. Observational cohorts, cross sectional or case–control studies focused on the association between altered kinematic/kinetic and motor control of the pelvis and PPGP during pregnancy were included. Study selection was conducted by two reviewers who firstly screened for titles, then for abstracts and finally for full articles. The Newcastle–Ottawa scale and the guidelines proposed by the Cochrane back review group were used to assess risk of bias and quality of evidence, respectively.

Results 354 references were identified, and after excluding unwanted articles, 10 studies met the final inclusion criteria. Studies not related to motor control or pelvic mobility were the main reason for exclusion. Seven studies were case–control and three were prospective cohort studies. Seven studies were ranked as high while three were ranked as low quality. Among the high quality studies, six found association between PPGP and altered motor control and mobility of the pelvis.

Conclusions The level of evidence for an association between PPGP and altered motor control and kinematic or kinetic parameters of the pelvis was found to be moderate.

Keywords Pregnancy related pelvic girdle pain · Pelvic motor control · Pelvic kinematic · Pelvic kinetics · Systematic review

Introduction

Epidemiological studies show that around twenty per cent of all pregnant women will develop pelvic girdle pain (PPGP) with continuing symptoms postpartum [1]. Consequently, this musculoskeletal disorder is responsible for high levels of sick leave and financial cost [2]. Studies report PPGP and low back pain account for one-third of sick leave in the Scandinavian countries [3–5]. Interestingly, PPGP is not influenced by economic or cultural differences when comparing different countries [6]. Several studies have tried to identify the etiology and pathogenesis of PPGP, but it still remains unknown. Although individual factors such as: mechanical, metabolic, traumatic, hormonal and degenerative are described as potential causes of PPGP [7] recent literature suggests a combination of factors might better explain its underlying mechanism [1].

A combination of mechanical and hormonal changes experienced during pregnancy is often cited as a possible cause for this disorder [8–10]. During pregnancy, the gravid uterus load acting on the spine and pelvis increases considerably. As pregnancy progresses the pubic symphysis softens, the pelvic ligaments become lax and the uterus tends to shift forward changing the line of gravity and orientation of the pelvis [11]. These mechanical and

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hormonal effects are thought to lead to constant overload of the pelvic ligaments and consequential instability. Palpation of the long dorsal sacroiliac ligament has been cited as highly specific in detecting PPGP [12] and its sensitivity, is also high when performed in patients with positive functional tests [13]. Although there is a logical rationale to support this theory, relaxin has not been shown to be an important factor in the development of PPGP [14–16]. Interestingly there is more evidence for relaxin not having a role in PPGP etiology than the contrary [17].

However, there is no doubt that the sacroiliac joint (SIJ) can be a source of low back or pelvic pain [18] and the theory that it can be caused by pelvic instability is supported by several studies [19, 20]. Pelvic instability, in this context, refers to a failure in the pelvic load transfer mechanism causing excessive pelvic joint movement, which has been verified by observing the displacement between the pubic bones on two-dimensional radiographs [21]. Ideally, the load transfer is supported by well coordinated neuromuscular and articular systems [22]. Due to articular anatomy, the relatively planar sacroiliac joint need extra support in order to achieve optimal equilibrium of the sacrum to the ilium. Muscles and fascia are key elements of support and achievement of equilibrium and any failure could result in an unstable SIJ. This is the underlying theory in the form and force closure model at this joint, which has been frequently cited and supported in the literature [23–25].

PPGP during pregnancy may have different mechanisms that disturb pelvic equilibrium, leading to pelvic instability and pain. Although the literature presents different theories to explain this disorder its cause remains unknown. The aim of this systematic review (SR) is to present the level of evidence for altered mechanic and motor control of the pelvis being associated with PPGP during pregnancy.

Methodology

This SR was carried out following the guidelines described by the PRISMA statement [26].

Eligibility criteria

Inclusion criteria

Cohort, cross sectional, or case control observational studies, as well as, studies focusing on the association between PPGP and mechanical factors and motor control of the pelvis during pregnancy were included in this SR. Pregnant women in any stage of pregnancy with no age limits also were included. Studies written in English, Spanish, French or Portuguese as these are the languages we have translate capacity were accepted.

Exclusion criteria

Studies were excluded if they were related to literature or systematic reviews, theses or dissertation and they did not consider PPGP as a musculoskeletal disorder.

Information sources

The electronic search was conducted using the following databases: Medline (1966 to December 2011), Amed (1985 to December 2011), EMBASE (1988 to December 2011), Proquest (December 2011), Web of Science (December 2011) and Scopus (December 2011).

Search

A literature search was performed to identify all available published articles focusing on the relation and/or association between PPGP and mechanical factors and motor control of the pelvis during pregnancy. An experienced health science librarian at the University of Otago helped with the identification of terms used in the search and the search strategy. The search terms were based on key words from previous publications as well as database specific search terms [subject terms, subject headings (SH) and MeSh]. A string search was created adding 'OR' and 'AND' to combine the key words and the subjects areas. The keywords relating to mechanical factors and motor control of the pelvis and PPGP included: 'kinematic' or 'kinetic' or 'mechanics' or 'biomechanics' or 'muscle activity' or 'EMG' or 'electromyography' or 'joint mobility' or 'joint stiffness' or 'laxity' and 'pelvic girdle pain' or 'low back pain' or 'pelvic pain' or 'peripartum pelvic pain' or 'posterior pelvic pain' or 'pelvic insufficiency'. Additionally, one author (DA) scanned the reference lists of retrieved articles.

Study selection

After electronic search, all studies were stored in Endnote® software (v.14 Thomson Reuters). Following removal of duplicate manuscripts all titles retrieved from the electronic search and other sources were screened by DA. Thesis dissertations, review articles and unrelated titles were rejected and removed from the database. At the second stage of selection of studies, abstracts and full-text articles were screened, by two assessors (DA and MB), against the predetermined inclusion and exclusion criteria. Titles, abstracts and manuscript were not blinded for journal titles, authors and institutions, since blinding was shown not to affect study selection and data extraction [27]. Disagreement between the reviewers during the screening process was determined by consensus. If consensus could not be

reached a third reviewer (SM) provided the majority opinion.

Data collection process

Data extraction from selected studies followed guidelines proposed by the Cochrane Back Review Group [28]. This was firstly performed by the principal investigator (DA) and subsequently confirmed by MB. The following data were extracted: study design, year of the study, aim of the study, sample size population, gestational period of the population, dependent and independent variables analysed, dependent and independent variables assessment and outcome, statistical analysis and main findings and conclusion.

Risk of bias in individual studies

Newcastle–Ottawa scale (NOS) for observational studies was used independently by two authors (DA and MB) for the assessment of risk of bias in individual studies [29]. Developed for the assessment of case–control and cohort observational studies this instrument has three main categories: selection of the participants, comparability of the groups and ascertainment of either the exposure (for case–control) or outcome of interest (for cohort studies). A maximum score of nine points was given for the study that fulfilled all quality criteria. In this SR, studies with five or more points were considered as high quality. This categorization was previously used in others systematic reviews [30, 31].

The following criteria were used when assessing for risk of bias in individual studies (Tables 3, 4): for both item 1 (selection for case–control studies) and item 6 (outcome for cohort studies), studies were awarded a point when at least one specific test for PPGP and pelvic pain location were described. The PPGP specific tests considered as suitable were: posterior pelvic pain provocation (P4 test), active straight leg raise, modified Trendelenburg, Patrick's Faber and Menell's tests. These tests were established as having either high sensitivity or specificity for sacroiliac or symphysis joint pain [32].

In the group comparability section (both case control and cohort studies; Tables 3, 4) history of low back pain (LBP), history of PPGP during or after pregnancy, body mass index (BMI), parity, smoking and stress levels were considered for personal factors and psychosocial factors. These factors have been presented as strong risk factors for developing PPGP [2, 33–36]. Studies controlling for one or more than one of the above listed factors were awarded with one or two points, respectively.

Ascertainment of exposure, item 6 (exposure for case control studies) and item 3 (selection for cohort studies), were considered according to the variable on which the selected studies focussed. After study selection five main

categories were identified relative to exposure. They were categorized as: pelvic mobility (symphyseal width and shift), sacroiliac joint (SIJ) stiffness, muscle activity, muscle fatigue and pelvic kinematics. Therefore, items 6 and 3 were specifically assessed against these biomechanical and motor control factors. For studies that assessed pelvic mobility, recognition was given when the assessment was made by means of X-ray or ultrasonography. These methods have been previously used and are recognised as reliable [37, 38]. Studies which have used Doppler imaging of vibration (DIV) for assessing SIJ Stiffness were also recognised. DIV were found to be a reliable and valid method for measuring SIJ stiffness [39–41]. Evidence for quantification of muscle activity and muscle fatigue by means of intramuscular or superficial EMG were awarded a point. Superficial and intramuscular EMG have been frequently used and described as a reliable and valid method for assessing muscle activity when electrodes are placed correctly [42]. Studies using optical motion analysis systems for pelvic kinematic monitoring were also awarded with one point. Optical motion analysis systems are considered the non-invasive 'gold standard' for measuring human movement presenting a tri-dimensional coordinate system error within 1.5 mm [43, 44].

The level of agreement between reviewers (inter-tester reliability) was conducted by means of Kappa analyses. The Statistical Package for the Social Science (Version 16 SPSS Inc., Illinois, USA) was utilized for all analyses.

Quality of evidence assessment

The quality of evidence that PPGP is related to altered mechanics and motor control of the pelvis was graded according to the 2009 guidelines for systematic reviews proposed by the Cochrane Back Review Group [28]. This grading system is based on four elements: inconsistency, indirectness, imprecision and publication bias. Five levels of evidence can be considered: high, moderate, weak and very weak. A high quality of evidence was given if 75 % of all the studies presented same findings with no limitations in the study design, presenting direct and precise data without bias. A moderate quality of evidence was given if one of the above domains did not match. A weak and very weak quality of evidence was given if two or three of the above domains did not match, respectively.

Results

Study selection

A diagram showing the study selection can be seen in Fig. 1. Our search identified 354 studies in total. One

Fig. 1 Study selection

hundred and seventeen were from Ovid, 20 from CINAHL, 66 from Embase, 80 from Scopus and 71 from Science Direct. After screening all titles and abstracts eight studies were found which addressed the inclusion and exclusion criteria [15, 45–51]. In addition to these, two more articles were found after hand searching [52, 53].

Study characteristics

Overall characteristics of the studies related to pelvic mobility and motor control, respectively are presented in Tables 1 and 2, respectively. In total, six studies reported the relationship between PPGP and pelvic mobility [15, 45, 51–54] and four studies reported the relationship between motor control and PPGP [47–50]. Among them, seven were considered as case control [15, 45, 46, 49, 50, 52, 53] and three as cohort studies [47, 48, 51]. The pregnancy period covered by the studies varied widely: from 12th until 36th weeks. Results related to the postpartum period were not considered as the purpose of this SR was to focus on findings related to pregnancy period only [51, 52, 54]. Consequently, one study which assessed women in two periods, 36th week and postpartum, and was categorised as a cohort was considered in this SR as a case control [54].

Pelvic mobility was assessed by means of X-ray in two studies [52, 53], ultrasonography in two studies [15, 51] and DIV in two [45, 46]. Motor control of the pelvis was assessed by using surface EMG in three studies [47–49] and one study used kinematic assessment [50]. The majority of the studies adopted ASLR test and the P4 test for assessing PPGP [15, 45, 50, 51, 54]. The most recent study was carried out by Dumas et al. [48] and the earliest one written by Abramson et al. [52].

Risk of bias within studies

Inter-rater reliability between reviewers was considered moderate ($K = 0.584$). The quality scores results related to case control and cohort studies are presented in Tables 3 and 4, respectively. Seven out of nine studies were considered as high quality studies since they presented five or more points [45, 48–51, 54].

Results of individual studies

Results of individual studies can be seen in Table 5, related to pelvic mobility, and Table 6, related to motor control of the pelvis.

Table 1 Study characteristics related to pelvic mobility

Author	Design	Years	PPGP assessment	Pelvic mobility assessed	Pelvic mechanic measurement	Gestational period Control/case (if applicable)
Abramson et al.	Case–control	1934	Self report and clinical findings (not reported)	Symphyseal width	X-ray	Last 2 months/4th–9th months
Gwozdz and Oko	Case–control	1968	Pubic symphysis pain when walking which disappeared in lying position	Symphyseal width	X-ray	Last month/last third trimester
Bjorklund et al.	Cohort	1999	ASLR test P4 Symphysis and SIJ palpation	Symphyseal width and shift	Ultrasonography	12 and 35th weeks
Bjorklund et al.	Case–control	2000	ASLR test P4 Symphysis and SIJ palpation	Symphyseal width	Ultrasonography	35th weeks
Damen et al.	Case–control	2001	ASLR test P4 QBPDS Pain intensity	SIJ laxity	DIV	36.2th weeks
Damen et al.	Case–control	2002	ASLR test P4 QBPDS Pain intensity	SIJ laxity	DIV	36.3th weeks

DIV Doppler imaging of vibrations, *LBP* low back pain, *EMG* electromyography, *QBPDS* Quebec back pain disability scale, *ASLR* active straight leg raise test, *P4* posterior provocation test

Table 2 Study characteristics related to motor control of the pelvis

Author	Design	Years	PPGP assessment	Motor control assessed	Motor control measurement	Gestational period Control/case (if applicable)
Sihvonen et al.	Cohort	1998	LBP presence or not Oswestry questionnaire Pain intensity	Degree of flexion relaxation phenomena in the paraspinal muscles	Surface EMG	20 and 36th months
de Groot et al.	Case–control	2008	QBPDS ASLR test	Muscle activity During ASLR	Surface EMG	26.8/26.6th weeks
Wu et al.	Case–control	2008	ASLR test P4 test SIJ palpation Iliac compression	Pelvis, lumbar and thorax rotational amplitudes during gait	Kinematics assessment	27/28.9th weeks
Dumas et al.	Cohort	2010	LBP presence or not Oswestry questionnaire	Back muscles fatigability (longuissimos dorsalis and multifidus)	Surface EMG	20 and 36th weeks

LBP low back pain, *EMG* electromyography, *QBPDS* Quebec back pain disability scale, *ASLR* active straight leg raise test, *P4* posterior provocation test

Mechanics of the pelvis

The first study which looked at pelvic mobility and its relation with PPGP was undertaken by Abramson et al.

[52]. In this study, a control group of 136 non-PPGP primipara and multipara women were compared to 25 PPGP patients radiologically measured symphyseal width. Although no statistics analyses were performed, the results

Table 3 Risk of bias for case–control studies based on Newcastle–Ottawa Quality assessment scale

References	Selection				Comparability	Exposure			Total
	1	2	3	4		6	7	8	
Abramson et al. [52]	B	B	C	B	C	A*	A*	B	2
Gwozdz and Oko [53]	B	B	C	B	C	A*	A*	A*	3
Bjorklund et al. (1999)	A*	A*	A*	B	C	B*	A*	A*	6
Damen et al. [45]	A*	A*	A*	A*	C	A*	A*	A*	7
Damen et al. [45]	A*	A*	A*	A*	C	A*	A*	A*	7
de Groot et al. [49]	B	B	C	A*	A*B*	B*	A*	A*	6
Wu et al. [50]	A*	A*	A*	B	B*	C	A*	A*	6

Selection

1. Is the case definition adequate?

- (a) yes, with independent validation*
- (b) yes, e.g. record linkage or based on self-reports
- (c) no description

2. Representativeness of the cases

- (a) consecutive or obviously representative series of cases
- (b) potential for selection biases or not stated

3. Selection of controls

- (a) community controls*
- (b) hospital controls
- (c) no description

4. Definition of controls

- (a) no history of disease (endpoint)*
- (b) no description of source

Comparability

5. Comparability of cases and controls on the basis of the design or analysis

- (a) study controls for *personal factors**
- (b) study controls for any additional factor *psychosocial factors**

Exposure

6. Ascertainment of exposure

- (a) secure record (e.g. surgical records)*
- (b) structured interview where blind to case/control status*
- (c) interview not blinded to case/control status
- (d) written self-report or medical record only
- (e) no description

7. Same method of ascertainment for cases and controls

- (a) yes*
- (b) no

8. Non-response rate

- (a) same rate for both groups*
- (b) non respondents described
- (c) rate different and no designation

Total score calculated by the sum of the stars (*)

showed that the PPGP group demonstrated 15 % greater symphyseal width (9.3 mm) than the control group (7.7 and 7.9 mm). Gwozdz and Oko [53] also carried out a study using X-ray in pregnant women who presented with PPGP and compared results to matched controls. Although no

statistical analyses were provided, both the control and PPGP groups demonstrated similar symphysis pubis width (4–13 mm). As a conclusion, the authors suggested that a 9–13 mm symphysis can be considered as a physiological pregnancy response if not accompanied by pain. They also

Table 4 Risk of bias for cohort studies based on Newcastle–Ottawa Quality assessment scale

References	Selection				Comparability	Outcome			Total
	1	2	3	4		6	7	8	
Sihvonen et al. [48]	C	C	B*	B	C	B*	A*	A*	4
Bjorklund et al. (1999)	D	A*	B*	B	B*	B*	A*	B*	6
Dumas et al. [48]	C	A*	A*	A*	A*	B*	A*	C	6

Selection

1. Representativeness of the exposed cohort
 - (a) truly representative of the average in the community ($\geq 75\%$)*
 - (b) somewhat representative of the average in the community (>50 or $<75\%$)*
 - (c) selected group of users e.g. nurses, volunteers
 - (d) no description of the derivation of the cohort
2. Selection of the non-exposed cohort
 - (a) drawn from the same community as the exposed cohort*
 - (b) drawn from a different source
 - (c) no description of the derivation of the non-exposed cohort
3. Ascertainment of exposure
 - (a) secure record (e.g. surgical records)*
 - (b) structured interview*
 - (c) written self-report
 - (d) no description
4. Demonstration that outcome of interest was not present at start of study
 - (a) yes*
 - (b) no

Comparability

5. Comparability of cohorts on the basis of the design or analysis
 - (a) study controls for personal factors*
 - (b) study controls for any additional factor (psychosocial factors)*

Outcome

6. Assessment of outcome
 - (a) independent blind assessment*
 - (b) record linkage*
 - (c) self-report
 - (d) no description
7. Was follow-up long enough for outcomes to occur
 - (a) yes (at least 1 year)*
 - (b) no
8. Adequacy of follow up of cohorts
 - (a) complete follow up—all subjects accounted for *
 - (b) subjects lost to follow up unlikely to introduce bias—small number lost— $>80\%$ *
 - (c) follow up rate $<75\%$ (select an adequate %) and no description of those lost
 - (d) no statement

Total score calculated by the sum of the stars (*)

concluded that the symphysis shape might play a role in PPGP symptoms as they found the majority of the severe cases associated to symphysis type 4 and 5 where these classifications are described as having edges or pubic bones diverging downwards or upwards.

Bjorklund et al. (1999, 2000) also conducted two studies assessing symphyseal width by means of ultrasonography.

In the earliest study four groups were assessed in two pregnancy periods: 12th and 35th weeks. According to their findings, pregnant women who suffer from pronounced to severe pain during pregnancy with no postpartum symptoms, present a greater symphyseal width than pregnant women who have none or mild pain during pregnancy with no postpartum pain ($p < 0.01$) or who

Table 5 Main results of individual studies: PPGP and pelvic mechanics

Author	Pelvic mobility variable	Control group/ baseline outcome (<i>n</i>)	PPGP group/follow- up outcome (<i>n</i>)	Main findings	<i>p</i> value
Abramson et al.	Symphyseal width	7.7–7.9 mm (136)	9.3 mm (25)	Pain group has 15 % greater pelvic width	Not stated
Gwozdz and Oko	Symphyseal width	4–13 mm (30)	7–13 mm (13)	Symphysis shape might play a role in PPGP symptoms	Not stated
Bjorklund et al.	Symphyseal width/shift	Group A 3.5/ 0.0 mm (33)	Group A 4.5/ 0.5 mm (33)	Group C > A (width and shift)	$p < 0.01$
		Group B 3.3/0.0 mm (4)	Group B 4.7/ 1.5 mm (4)	Group C > B (width)	$p < 0.01$
		Group C 3.5/0.4 mm (6)	Group C 6.3/ 1.8 mm (6)		
		Group D 3.6/ 0.0 mm (5)	Group D 5.1/ 1.3 mm (5)		
Bjorklund et al.	Symphyseal width	Group A 4.5 mm (38)	Group B 5.7 mm (11)	Group B > A	$p = 0.044$
			Group C 7.4 mm (18)	Group C > A	$p < 0.0001$
Damen et al.	Number of subjects who presented asymmetric SIJ laxity	4 (90)	27 (73)	4.4 % control 37 % pain group	37 % sensitivity 95.6 % specificity
Damen et al.	Percentage of subjects who presented asymmetric SIJ laxity	Group A 4.7 (64)	Group C 17 % (29)	Group D > A	$p < 0.001$
		Group B 0 % (4)	Group D 65 % (26)	Group D > B	$p = 0.001$
				Group D > C	$p < 0.001$

Group A none or mild pain during pregnancy with no postpartum pain, *group B* pronounced to severe pain during pregnancy with postpartum pain, *group C* pronounced to severe pain during pregnancy with no postpartum pain and *group D* mild pain during pregnancy with postpartum pain (Bjorklund et al. 1999). *Group A* none or mild pain during pregnancy, *group B* disabling pain during pregnancy, *group C* referral patients due to pelvic pain (Bjorklund et al. 2000). *Group A* none or mild pain during pregnancy with none or mild postpartum pain, *group B* none or mild pain during pregnancy with moderate to severe postpartum pain, *group C* moderate to severe pain during pregnancy with none or mild postpartum pain, *group D* moderate to severe pain during pregnancy with moderate to severe postpartum pain (Damen et al. 2002)

present with pronounced to severe pain during pregnancy with postpartum pain ($p < 0.01$) [51]. In their second study, a cohort of pregnant women with PPGP were compared at 35 weeks to a cohort of pregnant women free of pain. The authors found women with PPGP had the greater symphyses width (non pain = 4.5 mm and pain group = 5.7 and 7.4 mm) comparing with the pain free group ($p = 0.044$ and $p < 0.0001$) [15].

Damen et al. (2001, 2002) conducted two studies observing the number of pregnant women who presented with asymmetric SIJ laxity and how it was related to PPGP. In the first study, only 4.4 % of pregnant women free from pain presented with asymmetric SIJ laxity against 37.0 % on the pain group. Moreover, it was shown that the asymmetric SIJ laxity sensitivity was 37.0 % and its specificity was 95.6 % [55]. In the second study, a group consisting of pregnant women who presented with moderate to severe pain during pregnancy and moderate to severe pain postpartum had more asymmetric SIJ laxity cases than any other group [54].

Motor control

Results related to studies on the relationship between PPGP and motor control about the pelvis are presented in Table 6. In a cohort study, Sihvonen et al. [47] evaluated the flexion relaxation phenomena in the paraspinal muscles (FLR) in the 20th week of pregnancy and correlated it with the PPGP presence or not in the 30th week. FLR were assessed while participants performed back flexion and extension. According to this study, activation of the paraspinal muscles during back flexion in the second trimester of pregnancy correlates with pain intensity at last trimester in subjects who presented with a history of PPGP ($p < 0.00$ and $r = 0.7$) [47].

Muscle activity was also evaluated by de Groot et al. [49] who found that muscle activity of four muscles (Rectus Femoris, External Oblique, Psoas Major and Adductor Longus) bilaterally and their consequential force production during the active straight leg raise test (ASLR) showed significantly increased scores in the PPGP group

Table 6 Main results of individual studies: PPGP and motor control of the pelvis

Author	Motor control variable	Control group/ baseline outcome (<i>n</i>)	PPGP group/ follow-up outcome (<i>n</i>)	Main findings	<i>p</i> value
Sihvonen et al.	FLR baseline	Group A 13.375 (32)	Group A 5.8/9.21	FLR in the second trimester correlates with pain intensity at last trimester in group A	$p < 0.00$
	VAS1/2 follow up	Group B 8.17 (21)	Group B 0/14.67		$r = 0.703$
de Groot et al.	Muscle activity	RF homo $\approx 28\%$ (13)	RF homo $\approx 40\%$ (11)	PPGP group showed increased muscle activity and less force produced	$p = 0.001$
	During ASLR test and force produced	PM homo $\approx 32\%$	PM homo $\approx 51\%$		$p < 0.001$
		EO homo $\approx 26\%$	EO homo $\approx 52\%$		$p = 0.023$
		EO hetero $\approx 28\%$	EO hetero $\approx 38\%$		$p = 0.005$
		Hip force at 0 cm 129	Hip force at 0 cm 83		$p = 0.000$
		Hip force at 20 cm 84.7	Hip force at 20 cm 42.4		$p = 0.000$
Wu et al.	Pelvis, lumbar and thorax	Pelvis rotation (12)	Pelvis rotation (12)	PPGP group presented increased rotational	$p < 0.0001$
	Rotational amplitudes	Lumbar rotation	Lumbar rotation		$p < 0.0001$
	during gait	Thorax rotation	Thorax rotation		$p = 0.01$
Dumas et al.	Slopes of median	14th week -0.27 (10/8)	34th week -0.21 (18/14)	Fatigability cannot predict LBP during pregnancy	$p = 0.14$
	frequency of EMG power spectrum of low back muscles/ Back pain occurrence (YES/NO)	24th week -0.19 (21/11)			$p = 0.13$

Group A pregnant women with history of low back pain, *group B* pregnant women with no history of low back pain, *FLR* back muscle activity in body flexion at the beginning of pregnancy, *EXF* back muscle activity during back motion at first trimester [48], *ASLR* active straight leg raise test, *RF* rectus femoris, *PM* psoas major, *EO* external oblique, *Homo* homolateral to the leg raised, *hetero* heterolateral to the leg raised

compared with the matched controls. The most recent study was carried out by Dumas et al. [48]. In this work, back muscle fatigability was assessed and used for predicting LBP during pregnancy. Median frequency of the power spectrum were measured in 14th, 24th and 34th weeks and occurrence and severity of back pain in these same periods and also at 19th and 29th weeks. Although the authors argue that their small sample size means that their results need to be interpreted with caution increased fatigability seems not to predict LBP during pregnancy [48]. Finally, Wu et al. [50] used a 3D kinematic analysis to compare pelvic, lumbar and thorax rotation during gait in two groups: pregnant women free from pain compared to pregnant women presenting with PPGP. The results showed that the PPGP group presented with increased pelvic, lumbar and thorax mobility ($p < 0.0001$, $p < 0.0001$ and $p = 0.01$).

Discussion

The aim of this SR was to establish the level of evidence for altered mechanical and/or motor control of the pelvis being related to PPGP. Eight out of 10 studies (80 %) were found to confirm at least one of these associations. Among these studies, five focused on mechanics of the pelvis and three focused on altered motor control of the pelvis. Risk of

bias scores for these studies ranged from 2 to 7 out of a possible 9. Consequently, the level of evidence for PPGP being related to altered pelvic mechanics and/or motor control was only considered to be moderate. According to the 2009 updated guidelines for systematic reviews high quality of evidence is given for an outcome if 75 % of all the studies presented same findings with no limitations in the study design, presented direct and precise data without bias. A moderate quality of evidence is given for a outcome which has more than 75 % of agreement between studies but one of the above domains does not match, in the case of the present analysis not all of the quality studies presented no risk of bias [28].

From all studies that found an association between PPGP and altered mechanics and motor control of the pelvis just two presented high risk of bias [47, 52]. The main problem of bias in these studies was related to the selection of participants. Neither study indicated a clear definition of PPGP assessment or appropriately controlled the non pain group. Moreover, neither study controlled for any of the risk factors considered for this SR, such as history of LBP or PPGP, BMI, parity, smoking or stress levels.

The majority of the studies associating PPGP with altered mechanics and motor control of the pelvis were scored as low risk of bias [15, 45, 49–51, 54] as PPGP assessment was clearly demonstrated with use of either the

P4 or the ASLR test. The latter is a functional pelvic assessment, which has been recognised as a reliable tool for assessing the quality of load transfer from trunk to leg [56]. The P4 test is a passive test which is highly specific and sensitive for detecting PPGP [57]. The use of adequate tests in diagnosing PPGP must be done since it is important to exclude low back pain and gynaecological symptoms [32].

It is interesting to note that even though these tests are theoretically performed in order to verify different elements of the pelvis (active or passive structures, ASLR and P4 test, respectively) they are both associated with altered motor control and mechanics of the pelvis. Positive ASLR tests were found in patients with PPGP who presented with asymmetric laxity of the pelvis [45, 46], and also, positive P4 tests were found in PPGP patients with altered gait patterns [58]. It is well known that a proper muscle activation integrated with an intact articular system is required in order to have an appropriate load transfer pelvis mechanism [13, 59, 60]. However, it is still not clear how the musculoskeletal passive and active structures can interact and cooperate to achieve pelvic joint stability. The association between passive elements and altered motor control and active elements and impaired sacroiliac joint found in this review draw attention to this potential interaction. Further, these observations highlight the possible association between pelvic mobility and motor control as a cause or consequence of PPGP. Although more research is required in order to confirm such associations, the evidence seems plausible for PPGP etiology to be linked to these phenomena.

Conclusion

Eight out of ten studies found a positive association between PPGP and altered pelvic joint mechanics and/or altered motor control of muscles relative to pelvic movement. Among these, six were considered as a high quality studies. Consequently, the quality of evidence of such association was considered moderate. This evidence identifies two strong and inter-related directions for our research programme that is currently exploring the relationships between: PPGP and altered kinematic/kinetic loading about the pelvic joints and PPGP and altered motor control of the contractile elements about the pelvis relative to disturbed joint proprioception.

Acknowledgments Support was provided by the University of Otago (PhD Scholarship). The authors would like to thank Judy Fischer (Faculty Librarian) in assisting with the electronic search strategy for this study.

Conflict of interest None.

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