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Biomechanical analysis of the trunk and pelvis during pilates method exercises: systematic review

Análise biomecânica do tronco e pelve em exercícios do método pilates: revisão sistemática

Análisis biomecánico del tronco y de la pelvis en ejercicios del método pilates: revisión sistemática

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ABSTRACT | The pilates method is currently used in the rehabilitation and practice of physical activity. Some studies have investigated the effectiveness of the pilates method in the treatment of specific conditions, but information about the Biomechanical evaluation during the exercises are still scarce. Therefore, the purpose of this study was to conduct a systematic review of observational studies with biomechanical evaluation during the exercises based on the pilates method. The search was conducted based on data of the EMBASE, CINAHL, Web of Science, SPORTDiscus and PubMed databases. Some of the terms related to Biomechanics and pilates, as "cinematic" and "electromyography", were connected by or/and. The analysis of the methodological quality and electromyographic signal capture was based on the guidelines of STROBE (*Strengthening the Reporting of Observational Studies in Epidemiology*) and *Standards for Reporting EMG Data* of *ISEK*, respectively. Of the 14 studies included in a systematic review, only one cross-sectional study design was used of the case and control type. pilates exercises carried out in the soil and multifidus muscles were the most evaluated, using mainly the electromyographic evaluation. The results of the studies made it possible to observe that the multifidus muscles were the most used in some exercises of the pilates method and muscle activation is dependent upon the position of the practitioner and the position of the springs. The 14 studies published have a satisfactory methodological quality, but most of them have incomplete description of electromyography records. Thus, we can suggest that the change of positioningof the practitioner/springs and the choice of exercises interfere directly in the muscle activation during exercises of the pilates method.

Keywords | Motor Activity; Exercise Movement Techniques/rehabilitation; Exercise Therapy; Electromyography.

RESUMO | O método pilates é atualmente utilizado na reabilitação e na prática de atividade física. Alguns estudos investigaram sua eficácia no tratamento de condições específicas, mas informações sobre a avaliação biomecânica durante a realização dos exercícios ainda são escassas. Portanto, o objetivo deste estudo foi realizar uma revisão sistemática de estudos observacionais com avaliação biomecânica durante os exercícios baseados no método pilates. A busca foi realizada nas bases de dados Embase, CINAHL, Web of Science, SPORTDiscus e PubMed. Alguns dos termos relacionados à biomecânica e pilates, como "cinemática" e "eletromiografia", foram interligados por or/and. A análise da qualidade metodológica e da captação do sinal eletromiográfico foi baseada nas diretrizes do STROBE (*Strengthening the Reporting of Observational Studies in Epidemiology*) e dos *Standards for Reporting EMG Data* do *ISEK,* respectivamente. Dos 14 estudos incluídos na revisão sistemática, apenas um utilizou o desenho de estudo transversal do tipo caso e controle. Exercícios de pilates realizados no solo e os músculos multífidos foram os mais avaliados, utilizando principalmente a avaliação eletromiográfica. Os resultados dos estudos permitiram observar que os músculos multífidos foram

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os mais ativados em alguns exercícios do método pilates e que a ativação muscular é dependente da posição do praticante e da posição das molas. Os 14 estudos publicados possuem qualidade metodológica satisfatória, mas a maioria deles possui descrição incompleta dos registros eletromiográficos. Assim, podemos sugerir que a mudança de posicionamento do praticante/molas e a escolha dos exercícios interferem diretamente na ativação muscular durante a realização de exercícios.

Descritores | Atividade Motora; Técnicas de Exercício e de Movimento/reabilitação; Terapia por Exercício; Eletromiografia.

RESUMEN | La acumulación de la grasa torácica puede contribuir a la reducción de la movilidad torácica (MT) con disminución del volumen pulmonar. También las alteraciones de la MT pueden ocurrir en el envejecimiento, debido a la progresiva calcificación de las articulaciones implicadas en los movimientos respiratorios y a la reducción de los espacios intervertebrales. Este estudio tuvo el objetivo de verificar la influencia de la edad, de las características antropométricas y de la distribución de grasa corporal en conductas de la MT de mujeres, así como verificar cuál de las variables es la más relevante para la MT. Se trata de un estudio transversal, del cual participaron 100 mujeres con edades entre 25 y 75 años y con índice de masa corporal (IMC) entre 18,5 y 55kg/m^2. Se midieron las circunferencias del cuello (CC), de la cintura, de las caderas y la relación entre cintura/cadera. Se evaluó la MT a través de la cirtometría torácica en los niveles axilar y xifoides y, tras realizarse las tres mediciones, se determinó la MT por la diferencia entre el valor más grande obtenido en la inspiración y el menor valor en la espiración. Se emplearon los test de correlación y de regresión lineal múltiple. Mediante las correlaciones significativas, los resultados demostraron que la MT disminuye debido al aumento de edad y a la obesidad. La CC tuvo mayor influencia (16,60%) bajo la MT en el nivel axilar y el IMC en el nivel xifoides (18,16%). Se concluyó que la MT redujo con el envejecimiento y la obesidad, y que la acumulación de grasa en el cuello y el aumento del IMC son los factores que más influyen en el comprometimiento de la MT de mujeres.

Palabras clave | Actividad Motora; Técnicas de Ejercicio con Movimientos/rehabilitación; Terapia por Ejercicio; Electromiografía.

INTRODUCTION

The pilates method is currently a widespread exercise mode[1-3], which has been used in rehabilitation and practice of physical activity. The main indications of the pilates method are control of symptoms of fibromyalgia[4], flexibility gain, improvement of postural changes[5], improvement of the muscle strength, improved coordination, improved balance, improvement of the muscle symmetry, improvement of the proprioception, increased movement amplitude, increased range of motion[6], treatment of low back pain[7-10] and pelvic and back stabilization[2,11]. The main focus of the pilates method is centralization, also known as power house, involving isometric and concentric muscular contractions of the abdominal muscles, hip flexors muscles, hip and pelvic floor flexors[12]. These strengthened muscles promote stability of lumbar spine and pelvis, helping on the dynamic stability of the body during the execution of the exercises[12].

Considering the spread of the use of pilates exercises, the criterion of choice of variables, for example, the position of the practitioner and the spring which modulates the overload of the exercises of the pilates method, still is being carried out through subjective evaluations[13]. Although some studies have investigated the effectiveness of pilates method in the treatment of musculoskeletal diseases[7,8,14-22], detailed information about the biomechanical evaluations of exercises performed on the pilates method are scarce. The knowledge of the biomechanical evaluations can be considered as a complementary tool in choosing the exercises of the pilates method during a rehabilitation program or physical fitness. With these data, the instructor can, for example, avoid inserting the springs and the positioning of the patient in inappropriately manner and that activates muscles in the recovery period of the injury, or choose exercise conditions that emphasize the activation of muscle groups responsible for the desired movement without compensation. Thus, the purposes of this study were to identify cross-sectional studies that used the biomechanical analysis of the muscles of the trunk and pelvis while conducting exercises of the pilates method, and to check the methodological quality of observational studies selected for this review.

METHODOLOGY

Inclusion Criteria

The criteria used for inclusion of studies were: observational studies, including cross-sectional study, cohort study, case-control and ecological studies, with biomechanical analysis of trunk and pelvis;

Biomechanical evaluation studies during the exercises of the pilates method; studies published in scientific journals; and in English or Portuguese.

Search Strategy

The search was conducted in the following databases: EMBASE, CINAHL, Web of Science, SPORTDiscus and Pubmed. Two block of terms were used, a related biomechanical analysis and another about pilates, interconnected by and/or. The search strategy is presented as supplementary material (Annex 1). Two independent reviewers performed a preliminary analysis of selected items based on title, abstract and key words, aiming at the same relationship with the purposes of the systematic review. After this analysis, selected papers were examined by full text. The last day of the survey was March, 20th 2014. The list of references of the studies selected was used to identify possible eligible studies.

Evaluation of Studies

Two reviewers performed the extraction of characteristics and results of eligible studies and rated the methodological quality, according to the guidelines of STROBE (*Strengthening the Reporting of Observational Studies in Epidemiology*)[23] and the use of *Standards for Reporting EMG Data* of ISEK[24] to describe the procedures of electromyographic data acquisition. When disagreements occur between reviewers, a third reviewer would make the consensus.

Annex 2 presents the methodological quality evaluation scale formulated from the guidelines of STROBE[23] and items included by the authors. Annex 3 presents the range formulated from the *Standards for Reporting EMG Data* of ISEK[24]. The last item in this scale, for the electromyographic signal processing for estimation of the muscle fiber conduction velocity, has not been evaluated because this analysis is specific to muscle fatigue evaluation and is not relevant to the selected studies in this systematic review.

RESULTS

Characteristics of Studies

Figure 1 presents a flow chart with each step of the study. 1725 papers were found, being 14 eligible papers. No papers have been found in the manual search for the list of references of eligible papers. Annex 4 shows the characteristics of the 14 studies in a descriptive form. It was observed that 14 papers come from three countries, more than 85% are from Brazil. An paper[25] included patients with low back pain. The others included ballet dancers[11], instructors of pilates method[11] and participants without any complaint or clinical condition.[13, 26-36]. The following were evaluated: ground exercises[26,27,30,31,33-36], exercises in apparatus *Reformer* and *Cadillac*[11,13,28,29,31,34]) and activation exercise of the power house[25,32]. Electromyography has been used for seven studies[25,26,30-32,35,36], two studies have associated electromyography with eletrogoniometry[11,13] and four with webcam[27,28,33,34] to identify the phases of exercises performed. A study used only the eletrogoniometry[29].

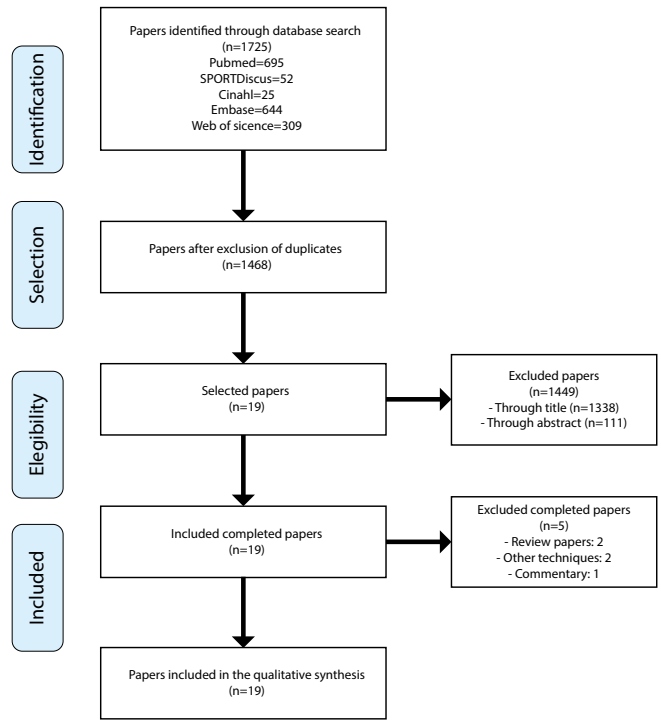

Figure 1. Selection process for papers included in the analysis

Results of Methodological Quality

In the evaluation of the methodological quality (Table 1), the items relating to the description of the objectives, outcomes, method of evaluation, statistical methods and descriptive data were clearly presented for all studies[11,13,25-36]. Only one study[28] described the reliability and reproducibility of the instrument used for evaluation and another study[29] described the potential

sources of bias. The item referring to the participants was described by a study[25].

Table 1. The result of the evaluation of the methodological quality of observational studies

Author	Items														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Petrofsky et al., 2005[26]	+	0	+	0	n.a.	+	+	0	0	+	-	+	+	+	0
Silva et al., 2009[13]	+	0	-	0	n.a.	+	+	0	0	+	-	+	+	+	0
Menacho et al., 2010[27]	+	0	+	0	n.a.	+	+	0	0	+	-	+	+	+	+
Queiroz et al., 2010[11]	+	0	+	0	n.a.	+	+	0	0	+	-	+	+	+	0
Loss et al., 2010[28]	+	0	-	+	n.a.	+	+	+	0	+	-	+	+	+	+
Melo et al., 2011[29]	+	0	-	0	n.a.	+	+	0	+	+	-	+	?	+	?
Souza et al., 2012[31]	+	0	-	0	n.a.	+	+	0	0	+	-	+	+	?	0
Silva et al., 2013[30]	+	0	+	0	n.a.	+	+	0	0	+	-	+	+	+	0
Barbosa et al., 2013[32]	+	0	-	?	n.a.	+	+	0	0	+	-	+	+	0	?
Silva et al., 2013[33]	+	0	+	0	n.a.	+	+	0	0	+	-	+	+	+	0
Marques et al., 2013[25]	+	0	+	0	+	+	+	0	0	+	+	+	+	+	+
Menacho et al., 2013[34]	+	0	+	0	n.a.	+	+	0	0	+	-	+	+	+	+
Kim et al., 2014[36]	+	-	+	0	n.a.	+	+	0	0	+	-	+	+	0	+
Rossi et al., 2014[35]	+	-	+	+	n.a.	+	+	0	0	+	-	+	+	+	+

Captions: + = positive rating; ? = dubious delimitation or method; - = negative rating; 0 = no information available; n.a. = not applicable.

In assessing the use of *Standards for Reporting EMG Data*(Table 2), 13 studies were analyzed, because a study only used the eletrogoniometry[29]. Three [11,34,35] studies described all items. Only one study[26] did not describe the type of surface electrode used in the collection and the filtering description of the raw EMG signal. The EMG signal sampling and data normalization were the only items described by all studies[11,13,25-36].

Table 2: Result of the evaluation of the use of standards for the presentation of EMG data

Author	Items							
	1	2	3	4	5	6	7	Total
	-	-	-	-	+	+	+	3
Silva et al., 2009[13]	+	-	+	-	+	+	+	5
Menacho et al., 2010[27]	+	+	+	-	+	+	+	6
Queiroz et al., 2010[11]	+	+	+	+	+	+	+	7
Loss et al., 2010[28]	+	+	+	-	+	-	+	5
Melo et al., 2011[29]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Souza et al., 2012[31]	+	+	+	-	+	-	+	5
Silva et al., 2013[30]	+	+	+	-	+	-	+	5
Barbosa et al., 2013[32]	+	+	+	-	+	+	+	6
Silva et al., 2013[33]	+	+	+	-	+	-	+	5
Marques et al., 2013[25]	+	+	+	-	+	+	+	6
Menacho et al., 2013[34]	+	+	+	+	+	+	+	7
Kim et al., 2014[36]	+	-	+	-	+	-	+	4
Rossi et al., 2014[35]	+	+	+	+	+	+	+	7

Captions: + = positive rating; - = no information available; n.a. = not applicable

DISCUSSION

This is the first and only systematic review of observational studies on the Biomechanical evaluation during exercises of the pilates method. The use of this method has been growing in rehabilitation clinics and gyms, even with little evidence on the subject. This review found 14 papers[11,13,25-36], being only one[25] with the description of the case and control.

Based on the results of papers evaluated, we can notice that many papers have evaluated[11,27,28,33,34,36] the multifidus muscle activation, and found that this muscle is more activated in the following exercises *hundred, leg pull front support*[33], *swimming*[27,36], *leg beat*[36], *swan drive and breast stroke* performed on the *Reformer*[34]. In addition, during hip extension performed in Cadillac, multifidus muscles are more activated when using the

spring in high position with the patient far from the end of the apparatus,[28] and in the exercise of the knee stretch, when it is performed with the anteversion of the pelvis and trunk extension[11]. The rectus femoris muscle is more activated in the hundred exercise, carried out both in the ground and in the Reformer[31], while hip extension exercise is performed in the Cadillac, this muscle is activated eccentrically when spring is in low position. With the spring in high position, the most activated muscles are biceps femoris and semitendinosus[13].

The abdominal rectus muscle had greater activation during teaser exercise on Cadillac[31] and *cure-up*[30], and was boosted by the activation of the *power house*[32]. On the other hand, the change of position of the pelvis and trunk does not change its activation on the *knee stretch*[11] exercise. With respect to the *hundred*[35] exercise, a greater coactivation of global muscles (rectus abdominis and iliocostalis) and local muscles (multifidos and internal oblique) was observed. The external oblique muscle obtained greater activation in the roll-up exercise[30] and when the spring was used in low position and with the patient around the end of the Cadillac in the hip extension exercise[28]. In addition, this muscle was more activated when the knee stretch exercise is performed with tilted pelvis and trunk flexion, as well as the gluteus maximus[11]. The only study[25] that evaluated patients with low back pain showed that they have a lower activation and co-contraction of antagonistic of trunk stabilizers (internal oblique and multifidus muscles) during the activation of the power house. Finally, it was observed that the addition of a resistance apparatus to the pilates exercises is equal to the performance of exercises with equipment with medium weight[26].

The results of the methodological quality evaluation were satisfactory. However, some items were neglected, for example, the sample calculation. According to the STROBE[37], the researchers must report the calculation of sample size in a formal form, since the appropriate sampling calculus increases the external validity of the study and improves its methodological quality. In the evaluation on the use of *Standards for Reporting EMG Data* of ISEK[24], only two studies[26, 36] scored below 5 items. The absence of appropriate descriptions may compromise the methodological quality of a study, since the inferences about the results and comparisons with similar studies are not possible. Moreover, it disregards one of the main recommendations of the Surface ElectroMyoGraphy for the Non-Invasive evaluation of Muscles[38], to standardize the procedures of electromyographic data acquisition. Thus, despite the guidelines used in this study did not have a graduation in their scores, we believe that when more methodological criteria are met, there is an increased chance that the results of the studies are considered reliable and applicable to the target population.

Thus, the results of the eligible studies can help in the construction of a rehabilitation program, with the recommendation of the prescription of exercises evaluated in some musculoskeletal disorders, such as in chronic low back pain. However, we believe that more biomechanical studies that analyze the exercises of the pilates method should be performed by comparing the exercises performed on the ground and/or apparatus, the best articular positions, types of springs and healthy practitioners with patients with musculoskeletal disorders, taking into account that most of the studies did not evaluate the patients with any complaint or clinical condition. Thus, these results may assist in the clinical practice of physical therapists regarding the best selection of exercises for the treatment of major musculoskeletal dysfunctions.

In this review, more than 90% of the studies found were cross-sectional, and only one[25] case and control study. Although the pilates method is practiced by healthy individuals, it would be important to carry out further studies on practitioners with some kind of illness or musculoskeletal symptom, since these exercises have been increasingly prescribed in the clinical environment. In addition, we suggest that future studies drawn up according to the recommendations of STROBE, including samples more representative of the target population, and directing the choice of exercises and muscles evaluated for an injury or specific purpose.

None of the 14 papers selected[11,13,25-36] reviewed the exercises and/or muscles in equal conditions, which made it impossible to carry out a meta-analysis. Finally, one can observe a tendency towards a regionalization of the pilates method, because 12 papers[11,13,25,27-34] were led by Brazilian researchers, and of these, six[13,28-31,33] were published in a national journal and eight[11,25-27,32,34-36] in international journals.

CONCLUSION

Based on the results of the eligible studies on Biomechanical evaluation during exercises of the pilates method, it is possible to suggest that the positioning

change of the practitioner and the choice of exercises interfere directly in muscle activation. The studies have satisfactory methodological quality, but have an incomplete description of electromyography records, and for the most part, healthy subjects and different exercises/muscles were evaluated. Through these differences, it is difficult to establish conclusions about this type of evaluation, in particular, about muscle activation. More studies are required, featuring rigid methodological quality including significant samples and participants with musculoskeletal diseases, to assist in prescribing exercises for rehabilitation or fitness programs.

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Annex 1. Search Strategy

Search strategy for the PubMed database (1800-2013)	
Mesh terms	**Number of papers found**
#1-electromyogr*	76,889
#2- torque	15,094
#3-biomechanic*	100,371
#4-kinematic*	19,636
#5-kinetic*	595,801
#6-muscle strength	38,836
#7- #1 OR #2 OR #3 OR #4 OR #5 OR #6	807,523
#8-exercise movement techniques	5,360
#9-exercise movement technics	5,362
#10-pilates training	5,390
#11-pilates-based exercises	5,370
#12-#8 OR #9 OR #10 OR #11	5,396
#13-#7 AND #12	687

Search strategy for the SportDiscus database (1985-2013)	
Mesh terms	**Number of papers found**
#1-electromyogr*	10,161
#2- torque	6,039
#3-biomechanic*	44,528
#4-kinematic*	10,573
#5-kinetic*	20,273
#6-muscle strength	14,083
#7- #1 OR #2 OR #3 OR #4 OR #5 OR #6	85,028
#8-exercise movement techniques	41
#9-exercise movement technics	0
#10-pilates training	147
#11-pilates-based exercises	24
#12-#8 OR #9 OR #10 OR #11	209
#13-#7 AND #12	29

Search strategy for the CINAHL database (1937-2013)	
Mesh terms	**Number of papers found**
S1-electromyogr*	8,845
S2- torque	4,070
S3-biomechanic*	13,368
S4-kinematic*	5,831
S5-kinetic*	5,137
S6-muscle strength	10,480
S7- S1 OR S2 OR S3 OR S4 OR S5 OR S6	37,949
S8-exercise movement techniques	2
S9-exercise movement technics	0
S10-pilates training	31
S11-pilates-based exercises	7
S12-S8 OR S9 OR S10 OR S11	38
S13-S7 AND S12	12

Search strategy for the Web of Science database (1900-2013)	
Mesh terms	**Number of papers found**
#1-electromyogr*	33,658
#2- torque	60,375
#3-biomechanic*	51,444
#4-kinematic*	107,789
#5-kinetic*	759,165
#6-muscle strength	32,191
#7- #1 OR #2 OR #3 OR #4 OR #5 OR #6	1,014,809
#8-exercise movement techniques	715
#9-exercise movement technics	1
#10-pilates training	61
#11-pilates-based exercises	12
#12-#8 OR #9 OR #10 OR #11	785
#13-#7 AND #12	273

Search strategy for the Embase database (1966-2013)	
Mesh terms	**Number of papers found**
#1-electromyogr*	90,326
#2- torque	16,149
#3-biomechanic*	109,222
#4-kinematic*	23,787
#5-kinetic*	1,087,181
#6-muscle strength	67,387
#7- #1 OR #2 OR #3 OR #4 OR #5 OR #6	1,394,052
#8-exercise movement techniques	1,372
#9-exercise movement technics	2
#10-pilates training	95
#11-pilates-based exercises	10
#12-#8 OR #9 OR #10 OR #11	1,470
#13-#7 AND #12	622

Annex 2. Scale of the evaluation of the methodological quality of observational studies

ITEM	EVALUATION
	Introduction and Methods
1. Purpose of the study	+ The purpose of the study was described clearly; ? Questionable description; 0 There is no information about the purpose
2. Context/Location	+ The collection locations and relevant dates were described (for example, dates from the period of recruitment and evaluations, including segments); ? Questionable description; + Only the locations or dates were described (for example, dates from the period of recruitment and evaluations, including segments); 0 No information about locations and relevant dates, periods of recruitment and exposure, monitoring and data collection.
3. Sample	+ The eligibility, origin of participants and methods of the participants selection were described; ? Questionable description of the eligibility criteria, origin of participants and methods of the participants selection; - Only the eligibility criteria or the origin of participants and methods of the participants selection was described; 0 There are no information on the eligibility criteria, origin of participants and methods of the participants selection.
4. Sample size	+ The sample calculation was described; ? Description of the calculation of the questionable sample; 0 There is no information about the sample calculation.
5. Control group (if applicable)	+ The pairing between the participants was described in a proper manner; ? Questionable pairing description; 0 No information about pairing of the participants control.
6. Outcomes	+ All the outcomes of the study were described clearly; ? Questionable description; 0 There is no information about the outcomes evaluated.
7. Evaluation	+ The methods used in the evaluation were described; ? Questionable description; 0 There is no information on the methods used in the evaluation.
8. Reliability and reproducibility of the instrument used to evaluate	+ The instrument used to evaluate has intra or inter-rater reliability and reproducibility or intraclass correlation coefficient was made to the outcome; ? Questionable description; 0 There is no information about the intra or inter-rater reliability and reproducibility.
9. Bias	+ All the measures adopted to avoid potential sources of bias were described; ? There is no description of any measures adopted to avoid potential sources of bias; 0 There is no information of any measures adopted to avoid potential sources of bias;
10. Statistical methods	+ All statistical methods were described; ? Description of the questionable statistical methods; 0 There is no information about the statistical methods.
	Results and Discussion/Conclusion
11. Participants	+ The number of participants at each stage of the study was described (e.g., number of potentially eligible participants, examined according to eligibility criteria, eligible in fact, included in the study, which ended the monitoring and were effectively analyzed); ? Questionable description; The number of participant in each step was not described; 0 There is no information on the number of participants.
12. Descriptive data	+ The characteristics of participants were described (e.g. demographic, clinical and social); - All the characteristics of participants were not described; 0 There is no information about the characteristics of participants.
13. Results	+ The results were described clearly; ? Questionable description.
14. Clinical implications	+ Clinical implications have been described according to the result of the study; ? Description of the questionable clinical implications; 0 There is no information about the clinical implications of the results of the study.
15. Limitations	+ The limitations of the study were described; ? Description of the questionable limitations; 0 there is no information about the limitations of the study.

Legend: + = positive rating; ? = dubious delimitation or method; - = negative rating; 0 = no information available

Annex 3. Scale based on the *Standards for Reporting EMG Data*

ITEM	RECOMMENDATION
1. Description of the type of surface electrode used	+ Describe the placement of the electrode material (for example, Al/AgCl etc.), form (for example, discs, rectangular bars, etc.), size (for example, diameter, radius, length, width), use of gel or paste, abrasion and cleaning of the skin with alcohol, trichotomy, inter-electrodes distance, electrode location and its guidance on the muscle in relation to tendons, motor point and the direction of the fibers. 0 No information.
2. Detection mode and EMG signal amplification	+ Describe if the detection was monopolar, differential, dual differential etc., the input impedance, common mode rejection ratio, signal-to-noise ratio and gain used. 0 No information.
3. Description of the filtering of the raw EMG signal	+ Describe the type of the filter used (or example, Butterworth, Chebyshev, etc.), high pass and low pass filter and the filter order (if the first order, second order, etc.). 0 No information.
4. Description of the rectification of the EMG data	+ Describe if the EMG signal was rectified by complete or partial wave. 0 No information.
5. Sampling of the EMG signal	+ Describe if a frequency of 1000 Hz was used, at a minimum, and the number of bits, model and manufacturer of analog digital converter. 0 No information.
6. Processing of the EMG signal	+ Describe the signal processing (for example, linear envelope, rectified average value, square root of the average and integrated electromyography) and, where appropriate, processing in the frequency domain (for example, window type used before Fourier transform, the algorithm used, the equation used to calculate median frequency, medium frequency, times, etc.). 0 No information.
7. Standardization of data	+ Describe the standardization of data: If was at maximum peak, medium peak or fixed electromyographic signal, maximum voluntary isometric contraction of each muscle, including how participants were trained to perform the maximum voluntary isometric contraction, rate of strength increase, speed of shortening or lengthening, amplitude of the articular angle or muscle length in non-isometric contraction, load applied in non-isometric contractions, when applicable. 0 No information.

Legend:+ = positive rating; 0 = no information available

Annex 4. Characteristics of Studies

Author	Country	Purposes	Sample Characteristics	Exercises evaluated	Main results obtained
Petrofsky et al. (2005)[26]	United States	Evaluate the EMG activity of rectus abdominis, paraspinal, femoral quadriceps, hip adductor and abductor, gluteus maximus and gastrocnemius in pilates exercises with and without resistance apparatus and with elastic band and exercises with equipment with weights	6 healthy subjects Gender: both Age: 25,3±1,5 years old Height: 169.9±6.7 cm Body Mass: 69.8±9.6 Kg	Squat until 45° of knee flexion, squat until 90° of knee flexion, adduction of the right and left hip and right and left hip extension	Exercises of the pilates method showed good result for resistance training. The addition of a resistance apparatus in pilates exercises has led to an increase in the workload, equivalent to an exercise of equipment with weight of medium intensity, and activation of multiple muscle groups at the same time, which is more efficient than the equipment with weight
Silva et al. (2009)[13]	Brazil	Compare EMG activity of rectus femoris, long head of the biceps femoris muscle and semitendinosus and the resistance torque of hip extension movement performed with the spring in two positions	12 healthy practitioners experienced in pilates Gender: both Age: 34,3±11,5 years old Height: 163.8±11.5 cm Body Mass: 62.1±14.0 Kg	Hip extension in the Cadillac: supine, five repetitions of 90° of flexion to the full extension, in two spring positions (high and low)	With the spring in high position, the resistance torque was classified as declining occurring in the flexion "direction"; in the low position, was classified as declining to approximately 60 degrees of hip flexion in the flexion "direction", and then, was classified as declining occurring in the extension "direction". The EMG activity of the rectus femoris was greater than the extensor
Menacho et al. (2010)[27]	Brazil	Check the EMG activity bilaterally of the multifidus during three exercises of the pilates Mat	11 healthy subjects Gender: female Age: 22±5 years old Height: 165±6 cm Body Mass: 57.7±8 Kg	Traditional Mat pilates exercises: swimming, single leg kick with static prone back extension and double leg kick	The EMG activation level of the multifidus ranged between 15% and 61% of maximum voluntary contraction in three years. The swimming exercise significantly increased the EMG activation of multifidus, compared with other exercises. In addition, the double leg kick significantly resulted in more activity in the multifidus than the single leg kick
Queiroz et al. (2010)[11]	Brazil	Compare EMG activity in four variations of trunk stabilization exercises of the pilates method in quadrupedal position	19 healthy pilates instructors and dancers experienced in pilates Gender: both Age: 31±5 years old Height:166±9 cm Body Mass: 60±11 kg	Exercises on the Reformer in four-position support associated with translation of the pelvis with trunk flexion, anteversion of the pelvis with trunk extension, neutral pelvis with trunk inclination in relation to the apparatus or neutral pelvis with trunk parallel to the apparatus	There was a statistically significant difference between the variations of exercises for the abdominal rectus, gluteus maximus, multifidus and external and internal oblique. However, for the iliocostalis, there was no significant effect
Loss et al. (2010)[28]	Brazil	Verify the influence of different spring heights and participant's positions on the EMG activation of multifidus and external obliques during exercises of hip flexion-extension on the Cadillac	8 healthy practitioners experienced in pilates Gender: female Age: 27,7±1,8 years old Height: 160±6 cm Body Mass: 55.6±5.7 Kg	Hip extension on the Cadillac with the participant positioned near and far from the end of the apparatus and the spring adjusted at high and low position in relation to the participant	The multifidus showed activation values of 10 to 20% of maximum voluntary contraction, the largest activation was with the spring in the lowest position and the participant closest to the edge of the apparatus. The external oblique muscles showed activation values of 20 to 45% of maximum voluntary contraction and activation was greater with the spring in the highest position and the participant farther from the edge of the apparatus
Loss et al. (2010)[28]	Brazil	Evaluate the behavior of the resistance torque of hip extension exercise performed on the Cadillac in four situations, using springs fixed at two positions	14 healthy practitioners experienced in pilates Gender: female Age: 30,9±8,6 years old Height: 160±0.4 cm Body Mass: 55.5±4.3 Kg	Hip extension in the Cadillac: supine, five repetitions of 90° of flexion to the full extension, in two spring positions (high and low)	The resistance torque and the resulting muscle strength showed similar behavior in all situations. However, the maximum resistance torque values did not occur in the same articular position that the resulting maximum muscle strength
Souza et al. (2012)[31]	Brazil	Compare EMG activity of the abdominal rectus and rectus femoris in two exercises performed on the ground and on the apparatus	11 healthy practitioners experienced in pilates Gender: female Age: 29,6±8 years old Height: 158.1±4.7 cm Body Mass: 62.3±4.1 kg	Hundred (performed on the ground and on the Reformer) and teaser (performed on the ground and on the Cadillac)	No difference was observed between exercises, considering the muscles evaluated. When the muscle groups were compared, the rectus femoris showed higher levels of activation in the exercise performed on the ground and on the reformer, while the rectus abdominis presented greater activation during teaser exercise performed on the Cadillac

Author	Country	Purposes	Sample Characteristics	Exercises evaluated	Main results obtained
Silva et al. (2013)[30]	Brazil	Analyze and compare the EMG activity of the rectus abdominis and external oblique during a traditional abdominal exercise program and a program of exercises based on the pilates method using a ball and an elastic band	10 healthy subjects Gender: female Age: 21,5±0.6 years old Body Mass Index: 19.6±0.4 Kg/m2	Traditional curl-up and roll-up based on the pilates method with a ball and an elastic band	On comparison between exercises, the external oblique muscle in the concentric phase obtained a greater roll-up recruitment with the ball. On the comparison between the muscles in each exercise, the rectus abdominis showed greater activation in concentric and eccentric phases of the exercise
Barbosa et al. (2013)[32]	Brazil	Evaluate the EMG behavior of the biceps brachii and superior abdominal rectus during a flexion of the forearm with and without activation of the power house	10 healthy practitioners experienced in pilates Gender: female Age: 21,9±3.3 years old Body Mass Index: 21.6±2.7 Kg/m2	Elbow flexion (standing position) with the knee flexed at 20º and forearms flexed at a 90° angle with total lateral rotation	Muscle activation was greater with the activation of the power house in both muscles, with greater activity in the concentric phase in relation to the eccentric phase
Silva et al. (2013)(30)	Brazil	Compare and analyze the multifidus during exercises of the pilates method, Spine stabilization and series of Williams	10 healthy subjects Gender: female Age: 21,5±0.6 years old Body Mass Index: 19.6±0.4 Kg/m2	Leg pull front support modified pilates method, the fourth exercise of additional series of Williams and the quadruped exercise of Spine Stabilization	Upon the comparison between exercises, significant differences were observed for the multifidus, with greater activation during the exercise of the pilates method both in the concentric and eccentric phases, which proves to be the exercise with EMG largest activation for the analyzed muscle
Marques et al. (2013)(25)	Brazil	Analyze the EMG activity of the iliocostalis lumborum, internal oblique and multifidus and antagonist co-contraction during the realization of the power house	18 healthy practitioners experienced in pilates Gender: female Group: low back pain Age: 19,5±1.1 years old Height: 160±0.1 cm Body Mass: 59.6±7.1 kg Control group: Age: 20,8±2.4 years old Height: 160±0.1 cm Body Mass: 61.2±8.4 kg	Two isometric contractions of the internal oblique muscle during the power house in a sitting position	Co-contraction of the muscles evaluated was higher in the control group, indicating that this group presented a greater stabilizing muscles recruitment than the low back pain group during the activation of the power house
Menacho et al. (2013)(34)	Brazil	Compare EMG activity of multifidus during the execution of the same pilates exercise under two conditions	16 healthy practitioners experienced in pilates Gender: female Age: 24,3±3.1 years old Height: 160±0.1 cm Body Mass: 20.7±1.3 kg	Swam Dive (Reformer and ground) and Breast Stroke (Reformer and solo)	Comparing the phases of the two exercises in different conditions, muscle activity was the greatest during the concentric phase. There was a difference between the conditions of dive and Swam Breast Stroke a favor of Reformer compared to the soil.
Kim et al (2014)(36)	South Korea	Analyze the EMG activity of muscles of the back muscles, multifidus, gluteus maximus and semitendinosus during three modified pilates Mat exercises in prone position	14 healthy practitioners experienced in pilates Gender: Female Age: 29,2±4.7 years old Height: 162.4±5.6 cm Weight: 52.2±3.8 kg Body Mass Index: 19.8±1.2 kg/m2	Modified Mat pilates exercises: Swimming, Double Leg Kick and Leg Beat	EMG activation levels ranged from 20.5% to 52.3% during the three years. The EMG activity of the dorsal was higher during the Swimming, the multifidus during Swimming and Leg Beat, the gluteus maximus was greater during the Swimming Leg and Beat compared to the Double Leg Kick exercise and the semitendinosus was the highest in the Leg Beat followed by Swimming
Rossi et al (2014)(35)	Brazil	Compare the antagonist coativation of local and global muscles during exercises based on Mat Skilled Modern pilates to investigate which exercises stimulate greater local muscular coativation	12 practitioners physically active without prior experience with pilates Gender: Female Age: 20,0±2.5 years old Height: 162±0.1 cm Weight: 56.7±7.7 kg Body Mass Index: 21.6±2.3 kg/m2 Physical activity level: 5.5±1.9 hours/week	Exercises based on Mat Skilled Modern pilates: Hundreds level I, Hundreds level II, One Leg Stretch level I, One Leg Stretch level II and Scissors level I	On the right side, there was a significant difference in the coactivation between exercises and between local and global antagonist coactivation. On the left side, there was a difference of percentage of agonist coactivation/antagonist between local and global muscles. The percentage of agonist coactivation/antagonist (RA/IL) was 52% (to the right) and 45.5% (to the left) higher than the percentage of agonist coactivation/antagonist (OI/MU). In relation to the exercises, Hundreds level I and level II had a coactivation higher than the One Leg Stretch level I, One Leg Stretch level II and the Scissors level I.

* EMG: electromyographic