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Sagittal trunk excursion and lumbar repositioning error between female and male patients with patellofemoral pain syndrome

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Background: Patellofemoral pain syndrome (PFPS) is a challenging clinical problem affecting adults, adolescents, and physically active populations. PFPS impacts the patient's trunk kinematics in the frontal plane. Previous studies have found gender-based biomechanical differences in patients with PFPS; however, sagittal trunk kinematics during mini-squats and lumbar proprioception in PFPS have not been studied previously.
Objectives: To investigate sagittal trunk excursion (It is defined as the sagittal trunk flexion angle from the start to the end of the mini squat) during mini-squats as well as lumbar repositioning error between individuals with and without PFPS, and determine gender differences in the outcome variables.
Methods: A sample of 56 participants aged 18–25 years was enrolled; 30 with PFPS (13 males, 17 females) and 26 asymptomatic controls (11 males, 15 females). The sagittal trunk excursion during mini-squats was examined by two-dimensional (2D) photographic analysis using Surgimap software. Active lumbar flexion repositioning error was assessed using an isokinetic dynamometer.
Results: For sagittal trunk excursion, no significant main effect of group was observed ($p = 0.136$). On the other hand, the main effect was significant for gender ($p = 0.005$), as was the interaction effect. Compared to the control group, the PFPS group showed significantly ($p = 0.01$) lower sagittal trunk excursion in females than in males during mini-squats. For active lumbar flexion repositioning error, no evidence was found for significant main or interaction effects ($p > 0.05$).

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Conclusion: Females with PFPS exhibit a more erect sagittal trunk posture than males during mini-squats. Trunk posture should be considered during weight-bearing activities in PFPS, and gender-specific assessment protocols should be developed.

Keywords: Lumbar proprioception; patellofemoral pain syndrome; trunk kinematics.

Introduction

Patellofemoral pain syndrome (PFPS) is a musculoskeletal disorder of the knee joint that is characterized by considerable pain and dysfunction, resulting in restrictions in physical activities.[1] It is considered to be one of the most common forms of knee pain, with an annual prevalence of 22.7% in the general population.[2]

There are several risk factors for the development of PFPS, including proximal, local and distal factors. Proximal factors related to weak hip musculature[3,4] and poor core endurance[5,6] have been found to contribute to PFPS. Quadriceps weakness has been consistently linked to the incidence of PFPS.[3,4] Further, distal factors such as calf muscle tightness has been reported.[3,4]

Aberrant movements of the pelvis and trunk can negatively affect the moments acting at the knee. During dynamic tasks, excessive trunk motions in the frontal and sagittal planes may reflect compensatory adjustments to accommodate hip muscle weakness and/or a lack of pelvic control.[7] Previous studies have demonstrated increased ipsilateral trunk lean during weight-bearing activities in patients with PFPS compared to asymptomatic controls.[8–10] So far, research on PFPS has focused on trunk kinematics in the frontal rather than sagittal plane.

Squatting is a common rehabilitation exercise used in PFPS treatment;[11,12] owing to its ability to activate multiple muscle groups in a single manoeuvre, including the quadriceps femoris, hip extensors, hip adductors, hip abductors, and triceps surae. Furthermore, substantial isometric activity is required by a wide range of supporting muscles (including the abdominals, erector spinae, and many others) to facilitate postural stabilization of the trunk.[13]

Squatting is a closed kinetic chain movement in which the distal segment is stationary. This means that motion at one joint is only possible with cooperative motion at other joints.[14] The ankle complex has a major contribution to the support and power generation during squatting.[15] It is thought that the medial head of the gastrocnemius provides dynamic knee stability, helping to counteract knee valgus moments together with controlling posterior tibial translation.[16] During squatting, the quadriceps femoris are the primary muscles acting about the knee, performing concentric knee extension during the ascent, in addition to eccentrically resisting knee flexion during the descent.[13] The hamstrings exert a counter-regulatory action to the quadriceps, helping to offset the anterior tibiofemoral shear, and thus relieving stress on the anterior cruciate ligament.[17] As knee flexion angle increases, both tibiofemoral and patellofemoral compression increases.[18] During squatting, the primary hip muscles involved are the gluteus maximus and the hamstrings.[19] Further, hip torques increase in combination with increase in hip flexion.[13]

Therefore, the present investigation focuses on sagittal trunk excursion during squats, as understanding the differences in sagittal trunk excursion can assist physiotherapists modify squat exercises to help PFPS patients. Only one study examined patellofemoral joint kinematics during squatting between patients with PFP compared with healthy controls. They found significant differences in patellar kinematics during squatting at 30° knee flexion between both groups.[20]

In addition to affecting trunk kinematics, PFPS affects the dynamic knee stability produced by the immediate surrounding muscles and more proximal muscles (hip and trunk).[21–23] Therefore, researchers are increasingly investigating the role of lumbo-pelvic-hip musculature in lower extremity function and injury, particularly in the past decade.[24–26] A recent systematic review revealed that lumbar proprioception impairment is a risk factor for the development of lower extremity injuries.[27] It has also been shown that decreased active lumbar proprioception during a repositioning task increases knee injury risk in female athletes by 2.9-fold.[28] To our knowledge, no previous study has investigated lumbar proprioception between PFPS patients and asymptomatic controls.

Interestingly, despite being common in males, PFPS incidence is two times higher in females.[29] Gender-specific differences in kinematics and muscle recruitment of trunk and lower limbs were previously examined in PFPS. Altered frontal and transverse plane lower limb kinematics during landing task increased the risk for the development of PFP in military female cadets.[30] Further, females with and without PFPS exhibited significantly larger ipsilateral trunk lean than males during single leg squat.[10] In addition, females with PFPS and their counterpart controls showed delayed activation of the *vastus medialis* complex compared to males.[31]

Given that females and males exhibit differences in kinematics, strength, and neuromuscular activation during functional and sports activities,[32–34] understanding the gender differences in patients with PFPS during functional activities may enable clinical physiotherapists to design gender-specific interventions.

This study was designed to investigate sagittal trunk excursion during mini-squats as well as active lumbar repositioning error between individuals with and without PFPS. We also examined gender differences in the outcome variables.

Methods

Design of the study: Cross-sectional study

Participants

A convenience sample of 58 students (aged 18–25 years) at the Faculty of Physical Therapy, Cairo University, was recruited for the study. The sample comprised of 26 asymptomatic participants (11 males and 15 females) as controls and 30 patients (13 men and 17 women) with clinically diagnosed PFPS. This age group was selected as knee problems were common in college students who are physically active.[35,36] The procedures of this study were explained to the participants and all of them signed a consent form prior to their participation in the study. Approval for this work was obtained from the Ethical Committee of Faculty of Physical Therapy, Cairo University. The participants were screened using the following inclusion criteria (two students did not meet these criteria): Anterior or retropatellar knee pain from at least two of the following activities: Prolonged sitting, stair climbing, squatting, running, kneeling, hopping/jumping, isometric quadriceps contraction, and palpation of the medial and/or lateral facet of the patella; experienced pain for > 3 months; body mass index within the normal range (18–25 kg/m^2). Additionally, participants with pain intensity of > 3 on a numeric rating scale (NRS) were included. Prospective participants were excluded if they had a history of any of the following conditions: Meniscal or other intra-articular pathologic conditions, cruciate or collateral ligament involvement, traumatic patellar subluxation or dislocation, previous surgery of the knee or hip joints, knee or hip joint osteoarthritis, metabolic diseases such as diabetes, foot deformities (flat foot or high-arched foot), history of lower back, hip or ankle injury or pain within six months prior to participation, leg length discrepancy > 1.5 cm (abnormal leg length measurement were excluded as it distort PF mechanics and may be related to aggravating the symptoms of PFPS),[37,38] head trauma with residual neurological deficits, and inner ear infection or vestibular disorder with unresolved balance disturbance.

Instrumentation and measurements

Two-dimensional (2D) photogrammetric analysis was carried out using a digital camera (iPhone 6 camera, 8 megapixel sensor, f/2.2 aperture, 29 mm, 1/3", 1.5 μm) to record the participants' movement during their performance of a mini-squat (up to 60° knee flexion). The recorded data were analysed by Surgimap software to measure the sagittal trunk angle. Surgimap is a reliable and valid instrument for measuring sagittal plane spinopelvic parameters.[39,40] The Biodex System 3 Pro Isokinetic Dynamometer (Biodex Medical Systems, Shirley, NY, USA) was used for positional accuracy measurements during lumbar repositioning. The Biodex dynamometer is a reliable and valid instrument for measuring positional accuracy,[41] with a measurement resolution from less than $\pm 0.1^\circ$ to $\pm 1^\circ$.[42]

Procedures

Prior to data collection, participants who met the inclusion criteria underwent a standardized history and physical examination, which included examination of hamstring flexibility which was tested by performing an active straight leg raise. Also, foot posture was assessed while standing; as excessive pronation can usually be seen in relaxed standing. The *Q*-angle was assessed in the supine position. Possible leg length discrepancy was also evaluated. All potential participants were examined by two licensed physical therapists (with > 10 years of experience) to confirm a clinical diagnosis of PFPS. PFPS diagnosis was confirmed by tenderness of the medial and lateral patellar facets and a positive patellar compression test. The patellar compression test has acceptable sensitivity (68%–82%) and specificity (54%) +LR (1.5–1.8) and –LR (0.3–0.6).[43] The study was conducted at the Isokinetic Lab, Faculty of Physical Therapy, Cairo University, from January 2017 to April 2017.

Sagittal trunk excursion

For 2D photogrammetric analysis (lateral view analysis), four reflective spherical adhesive markers were placed on the pelvis and trunk of each participant. To allow adequate skin exposure for placing the reflective markers, male participants wore well-fitted shorts, while female participants wore compression shorts and a support top. A single examiner placed two markers on the pelvis: One at the anterior superior iliac spine (ASIS) and another at the posterior superior iliac spine (PSIS), and one on the mid-iliac crest and another on the lateral surface of the acromion process of the scapula. A trunk angle of 0° was defined as the point at which the straight line joining the markers on the acromion and mid-iliac crest intersected with the straight line joining the ASIS and PSIS while standing (Fig. 1). The angle of sagittal trunk excursion was defined as the angle between these

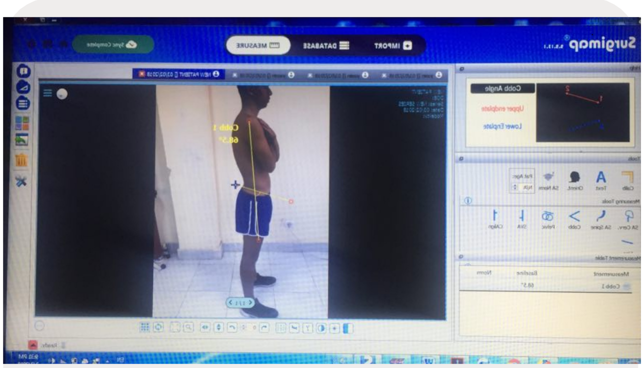

Fig. 1. Measurement of Sagittal trunk angle during standing using Surgimap software.

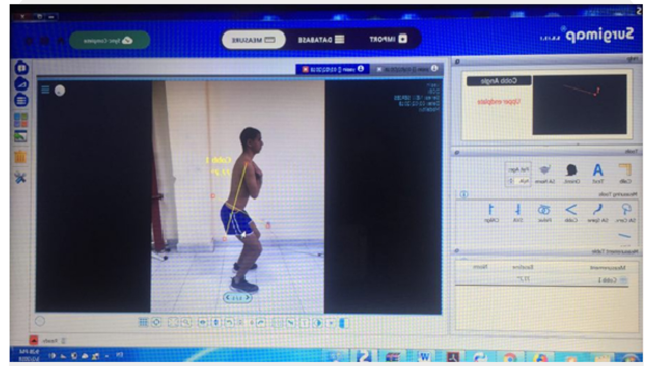

Fig. 2. Measurement of Sagittal trunk angle during mini-squatting using Surgimap software.

two lines during a mini-squat to 60° knee flexion (Fig. 2) to avoid the higher joint forces associated with increased ranges of motion.[44] Mini-squat at 60° knee flexion was found to be a desirable and safe task for evaluation in patients with PFPS.[45] As closed kinetic chain exercises are safer because of a lower amount of shear force between the tibiofemoral joint surfaces in the functional range of motion,[46] it simulates many functional movements in daily activities.[45]

The camera was placed at a standard height (floor to camera) of 43 cm and distance of 280 cm in the sagittal plane (from the camera to the centre of the participant's stance) to the right of the participant.[47] Each participant stood with their arms crossed over their chest, and a static image was recorded using the camera. Then, the participants were instructed to start the mini-squat with their feet shoulder-width apart and pointing forwards (in line with the sagittal plane), and then to keep their feet flat on the floor and the chest facing forwards while slowly squatting to 60° knee flexion; this angle was defined by a video that was recorded during squatting. The knee flexion angle was captured using the Surgimap software. The image was captured when the knee reached 60° flexion. All participants verbally confirmed that they understood the instructions, and then they performed three practice mini-squats. After that, they were allowed a rest period of 1 min.

The examiner then instructed the participants to perform three squats. Each participant was given approximately 10 s between the trials. A metronome set at 60 beats per minute was used to provide regular beats, and the participants were instructed to move 'down on a beat and up on a beat'. They were given feedback to help them to maintain a consistent movement speed for each trial.[48]

2D photogrammetry techniques are inexpensive and user-friendly for measurement of joint angles during dynamic movement.[49] Compared to 3D systems, 2D techniques have good to excellent validity[50,51] although it restricts angular measurements to single planes.[52]

Active lumbar repositioning error

The Biodex dynamometer underwent system calibration prior to each session. With each participant in the sitting position on a chair, knee block positions were adjusted using two curved anterior leg pads. The participant's feet were not in contact with the ground and two straps were used to stabilize the thighs. The superior aspect of the proximal thighs was then stabilized with a pelvic brace secured tightly but comfortably, and the lower lumbar spine was rested on a lumbar pad. The seat was adjusted so that the axis of the actuator arm of the dynamometer was aligned with the L5/S1 disc space, which was achieved by palpating the PSIS and then moving 1 inch superiorly. The dynamometer has a forward-tilted back attachment to which the patient's upper trunk segment is fastened with a belt. Sitting upright, the force application straps were adjusted vertically with the second intercostal cartilage on the anterior chest wall. The head was maintained neutrally on an adjustable head rest.

The erect neutral starting position of each participant was adjusted by confirming the proper ASIS and PSIS.[53] The pre-set lumbar range of motion was from the neutral spinal posture to 30° lumbar flexion.[54] This target angle was selected so that it could be accomplished by all participants.[55] Before the experimental task, each participant was asked to bend their trunk as much as they could to determine the participants' maximum available lumbar range of movement (ROM) and their ability to perform the experimental task. After that, the dynamometer was locked in the 0° position to guarantee uniformity of the starting position in the three testing trials for each participant.

A practice trial was performed before the testing procedure, in which each participant performed the test three times. Then, the standard test session began. The dynamometer moved each participant passively to a position of 30° of lumbar flexion for 10 s. The participants were instructed to remember this position as they would be required to repeat it with closed eyes (Fig. 1). Subsequently, they returned to the neutral position and were asked to repeat the target position as precisely as possible. Each participant informed the examiner when they felt that they had attained the target position, and they were required to maintain that position for 3 s. A 'hold' button was pressed so that the repeated position was recorded. The test was run three times with a pre-set rest period of 10 s between the trials. The participants did not receive verbal or visual feedback on performance.[53,56,57]

Data collection and analysis

Sagittal trunk excursion (Fig. 3) was determined as the difference in the sagittal trunk flexion angle from the start to the end of the mini-squat (end angle minus start angle).[58] A single examiner performed the 2D analysis after data collection using Surgimap software. The built-in angle tool was used to determine joint angle values for each participant. The angle tool permits the measurement of a generic angle between the two segments. The angle (in degrees) created between the set of two lines is displayed on the image. On the selected image, the examiner drew lines from which he could measure the trunk angles. The measured angle is graphically represented on the image by an arc. Good intra-rater reliability for measuring the sagittal trunk angle was established in the standing and mini-squat positions (ICC = 0.89 and 0.86, respectively).

For active lumbar repositioning, the absolute error values for the 30° target position were recorded for the three trials performed by each participant. The mean deviation for each participant was calculated.[59]

Statistical analysis

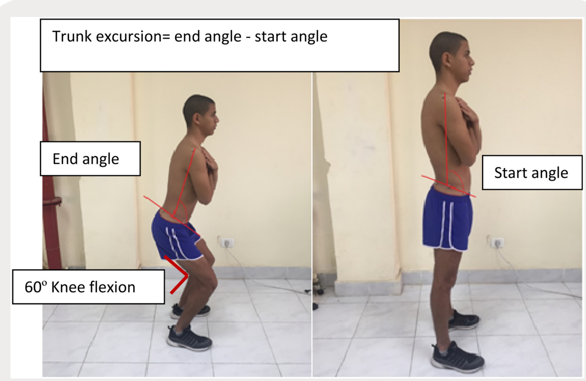

Fig. 3. Measurement of trunk excursion.

Data analysis was performed using SPSS 20.0 statistical software for Windows. All data were treated as normally distributed based on the outcomes of the Shapiro–Wilk test. Descriptive data for the participants' characteristics and dependent variables were calculated as the mean ± SD. The outcome variables were the sagittal trunk excursion and active lumbar repositioning error. The differences in dependent variables (outcome measures) between the two independent variables (between-subject effects; control group versus PFPS group, and male versus female) were compared using 2 × 2 two-way multivariate analysis of variance (MANOVA). Furthermore, testing for interaction effects between the two independent variables was conducted. An alpha level of < 0.05 was used to indicate statistical significance.

Results

The participants' general characteristics are shown in Table 1. Independent sample t-tests revealed no significant differences in the mean age ($p = 0.17$), height ($p = 0.22$), weight ($p = 0.4$) or body mass index ($p = 0.88$) between the PFPS and control groups ($p > 0.05$). The pain intensity level of the PFPS individual was 3–7 on the NRS, and their pain history ranged from > 3 months to 2 years.

Sagittal trunk excursion

Initially, there was no significant difference ($p = 0.52$) between the PFPS and control groups for the sagittal trunk angle during standing. The main effect of gender revealed significantly greater trunk excursion in males compared to females (mean difference = 6.9°, $p = 0.005$). On the other hand, there was no significant main effect of group (mean difference = 4.4°, $p = 0.136$) on sagittal trunk excursion during mini-squats. For the interaction effect, the two-way MANOVA revealed a significant interaction between gender and group during squatting. Interestingly, females with PFPS exhibited significantly less sagittal trunk excursion than males with PFPS during the mini-squats (mean difference = 6.8°, $p = 0.01$, Table 3). Although the females in the control group exhibited less sagittal trunk excursion than males during mini-squats (mean difference = 5.2°), this difference was not statistically significant ($p = 0.09$, Table 3). On the other hand, there were no significant differences ($p > 0.05$; Table 3) for sagittal trunk excursion between the PFPS and control groups for each gender (Table 2).

Table 1. Mean (SD) of age, weight, height, and BMI of patients with PFPS and Controls.

Variable	PFPS ($N = 30$) Mean ± SD	Controls ($N = 26$) Mean ± SD
Age (years)	20.9 ± 1.4	20.5 ± 1.2
Weight (Kg)	69.1 ± 11.2	71.7 ± 11.3
Height (cm)	169 ± 8.6	171.7 ± 7.7
BMI (Kg/m^2)	24.2 ± 3.6	24.3 ± 4

Note: SD: Standard Deviation; BMI: Body Mass Index; and PFPS: Patellofemoral Pain Syndrome.

Lumbar active repositioning error

MANOVA showed no significant ($p > 0.05$) main or interaction effects of gender and group on active lumbar repositioning error (Tables 2 and 3, respectively).

Discussion

The most important finding of our study is that females display more erect posture than males during mini-squats. This was the case for both the control and PFPS groups, although the difference was not statistically significant ($p = 0.09$) for the control group. This result is consistent with the idea that females, who represent a population at heightened risk for knee injury,[60,61] display a more erect posture than males during gait and landing tasks,[62–64] as evidenced by simultaneous more extended knee,[63–65] hip[63–65] and trunk[65] positions, suggesting sagittal plane joint coupling.

A number of previous findings may help explain this difference in posture and how it affects the demands on the knee joint. Compared to males, it has been reported that females activate their quadriceps muscles earlier relative to the hamstring muscles[66,67] and are often quadriceps dominant, indicating that they preferentially activate their quadriceps over their hamstrings during functional movements.[68] This preference leads to a more upright posture during these activities compared to males.[63,69,70]

Consistent with our finding that there is no difference in sagittal trunk excursion during mini-

Table 2. Comparison of Mean ± SD of sagittal trunk excursion and lumbar active repositioning error between sexes within each group and between groups within each gender.

Outcomes	Group × Gender	Male (mean ± SD)	Female (mean ± SD)	*P* value	95% CI
Sagittal trunk excursion°	PFPS	15.3 ± 5.6	8.5 ± 3.1	0.01*	1.49–12.1
	Controls	17.5 ± 8	12.3 ± 4.5	0.09	−0.93–11.36
	P value	0.39	0.21		
	95% CI	−7.56–3	−9.9–2.3		
Lumbar repositioning error°	PFPS	2.7 ± 8	3.7 ± 1.1	0.13	−2.25–0.31
	Controls	3.4 ± 1.1	3.6 ± 1.2	0.75	−1.73–1.25
	P value	0.24	0.96		
	95% CI	−2–0.52	−1.52–1.46		

Note:*P <0.05; CI: Confidence Interval; PFPS: Patellofrmoral Pain Syndrome; and SD: Standard Deviation.

squats in people with and without PFPS for each gender, Schwane *et al.*[71] observed no difference in trunk kinematics, specifically trunk flexion and ipsilateral trunk lean, between females with and without patellofemoral pain during stair descent.

Regarding active lumbar repositioning error, we show that there are neither differences between people with and without PFPS or between genders, nor interaction effects. This may be attributable to the short duration of symptoms experienced by patients with PFPS (two years). The literature suggests 1–3 years as a time frame for altered proprioception of the injured knee.[72] As our sample experienced pain for ≤2 years, this duration was insufficient to induce proprioceptive deficits in more proximal parts (trunk) of the kinetic chain. This explanation is supported by the finding demonstrated by Schwane *et al.*,[71] where the relatively low level of pain experienced by patients with PFPS may be a result of mild dysfunction (i.e., that proprioception is not sufficiently severely altered in patients with PFPS to elicit pain).

To our knowledge, only one previous study has examined the lumbar proprioception in knee injury. In this study, the mean difference in active lumbar repositioning between males and females with PFPS was 1°, but this difference was not significant. This finding is in agreement with the previous study of lumbar proprioception in knee injury,[28] which reported no statistically significant difference between genders in the knee-injured group. However, the same study found that the average active lumbar repositioning error in uninjured females was significantly lower than that in uninjured males, which differs from our finding.

The higher (but not statistically significant) active lumbar repositioning error in females may be explained by the significantly worse body sway in females with injured knees than in males with injured knees.[73] In addition, the decreased active lumbar proprioception predicts knee injury risk in female athletes but not in male athletes.[28]

These findings may be limited by the lack of kinetic data, especially ground reaction force (GRF), and trunk muscle strength. Furthermore, we evaluated only one plane of trunk kinematics, and did not include the hip or ankle kinematics. These findings cannot be extrapolated to adolescents aged < 18 years, adults aged > 25 years, athletes and patients with chronic severe symptoms. With a small sample size and inadequately blinded examiner, these results therefore need to be interpreted with caution. However, it is postulated that objective outcomes may be less prone to assessment bias than subjective outcomes.[74] A larger sample should be examined in the future.

Conclusion

Compared with males, females with PFPS show decreased forward trunk excursion during mini-squats. The evidence from this study suggests that sagittal trunk posture should be considered during mini-squats when examining individuals with PFPS. Further, gender-based assessment methods should be utilized.

Conflict of Interest

The authors declare no conflict of interest.

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Author Contributions

I. Hassan participated in developing the idea, patients', recruitment, data collection and writing this paper. M. Elkeblawy oversaw the research work, shared in framing the hypothesis and drafting this paper. M. Abdelsalam shared in patients', recruitment, drafting this paper. E. Embaby shared in conception and work design, contributed to the supervision of data collection, performed statistical analysis, drafted and revised this paper. All authors approved the final version of this paper.

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