# Effect of the position of feet on knee pressure distribution in a tall kneeling position

*Efecto de la posición de los pies sobre la distribución de la presión en la rodilla en posición de arrodillado erguido*

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## Abstract

Introduction: The kneeling position has frequently been associated with a higher prevalence of knee pathologies. People who adopt this position within their work and/or religious activities are more exposed to knee pathologies. In the tall keeling posture, the position of the feet can play an important role in the magnitude of the force and pressure supporting the knee.

Methods: The objective of this investigation was to compare the magnitude of the ground reaction force (GRF), the distribution of the support area, pressure and center of pressure (COP) associated with them, in the tall kneeling posture with two different positions of the feet, in order to identify the position in which less pain could be produced and to diminish the potential damage to this joint. Twenty volunteers (age=22.0±1.5 years; weight=70.3±13.5 kg) was assessed. Pressure, contact area, COP and GRF, all within the contact surface between the knees and the floor, as well as the pain described by the volunteers were measured in two different ankle positions: plantar flexion (PF) and dorsiflexion (DF). Post hoc statistical tests were applied with a significant level of 95%.

Results: In DF condition was observed: a higher frequency of a single pressure peak ($p < 0.0001$); a smaller contact area ($p = 0.005$); a predominantly anterior location of maximum pressures ($p = 0.002$) and a greater pain described by the volunteers ($p = 0.04$).

Conclusion: In the sample evaluated, it can be concluded that ankle position during the tall-kneeling posture altered the magnitude and distribution of forces, the contact area, and the location of the center of pressure across the support surfaces.

## Keywords

Kneeling; tall kneeling; contact area; center of pressure; knee stress; knee pain.

## Resumen

Introducción: La posición de arrodillado se ha asociado con frecuencia a una mayor prevalencia de patologías de rodilla. Las personas que adoptan esta postura en el contexto de su trabajo y/o de actividades religiosas están más expuestas a desarrollar patologías de rodilla. En la postura de arrodillado erguido, la posición de los pies puede desempeñar un papel importante en la magnitud de la fuerza y la presión que soporta la rodilla.

Métodos: El objetivo de esta investigación fue comparar la magnitud de la fuerza de reacción del suelo (GRF), la distribución del área de apoyo, la presión y el centro de presión (CDP) asociado a estas variables, en la postura de arrodillado erguido con dos posiciones diferentes de los pies, con el fin de identificar la posición que podría generar menos dolor y disminuir el potencial daño a esta articulación. Se evaluaron veinte voluntarios (edad = 22,0 ± 1,5 años; peso = 70,3 ± 13,5 kg). Se midieron la presión, el área de contacto, el CDP y la GRF en la superficie de contacto entre las rodillas y el suelo, así como el dolor referido por los voluntarios, en dos posiciones del tobillo: flexión plantar (FP) y dorsiflexión (DF). Se aplicaron pruebas estadísticas post hoc con un nivel de significancia del 95%.

Resultados: En la condición de DF se observó: una mayor frecuencia de un único pico de presión ($p < 0,0001$); un área de contacto menor ($p = 0,005$); una localización predominantemente anterior de las presiones máximas ($p = 0,002$) y un mayor dolor referido por los voluntarios ($p = 0,04$).

Conclusión: En la muestra evaluada, se puede concluir que la posición del tobillo durante la postura de arrodillado erguido modificó la magnitud y la distribución de las fuerzas, el área de contacto y la ubicación del centro de presión en las superficies de apoyo.

## Palabras clave

Arrodillado; área de contacto; centro de presión; estrés en la rodilla; dolor de rodilla.

## Introduction

Knee pain has a substantial impact on lower-limb function, thereby affecting both daily activities and work performance (Ogunbode et al., 2014). Its prevalence has been reported to range between 10% and 60% (Miranda et al., 2002), depending on individual, occupational, and sociocultural risk factors (Bhattacharya et al., 1985; Seidler et al., 2008; Virayavanich et al., 2013; Xiao et al., 2013). In this context, a higher prevalence of knee disorders has been observed among individuals who practice religions that involve frequent kneeling (Chokkhanchitchai et al., 2009). Similarly, occupational kneeling is associated with an increased risk of knee pain, with workers in such roles exhibiting a significantly higher prevalence of knee complaints than those in less physically demanding jobs (Jensen et al., 2000). Biomechanical studies have demonstrated an increase in mechanical stress on the knee during the kneeling position(Jensen et al., 2000; Pollard et al., 2011; Porter et al., 2010; Xu et al., 2017). These studies describe several variations of the kneeling posture, the most frequent being Near Full (both knees on the ground with maximal knee flexion), One Knee Kneeling (only one knee on the ground), Near 90° (both knees on the ground with approximately 90° of knee flexion), and Squat (Hirokawa & Fukunaga, 2013; Pollard et al., 2011). The Near 90° posture, also called tall-kneeling, has been shown to produce the highest levels of mechanical stress on the knee (Jensen et al., 2010; Pollard et al., 2011; Porter et al., 2010; Xu et al., 2017). In occupational and workplace settings, the search for strategies to prevent injuries and protect workers' knees has driven the development of devices such as kneepads, which have proven effective in reducing mechanical stress on the knee joint during kneeling (Jensen et al., 2010; Pollard et al., 2011; Xu et al., 2017). However, in non-occupational settings, where the use of these devices is uncommon due to cultural or religious factors, there is a need to seek posture-based alternatives to reduce mechanical stress on the knee. The position of the lower-limb segments is one of the possible associated factors that could modify the magnitude or distribution of these contact forces and, therefore, alter the mechanical stress borne by the knee support surface in the kneeling posture(Chokkhanchitchai et al., 2009). In the tall-kneeling posture, the foot segment is also responsible for supporting part of the body weight (Xu et al., 2017). Therefore, ankle position could be a determining factor in the loads that the knee must bear in this posture. In the literature, the effect of ankle position on the forces and pressures exerted on the knee support surface in the tall-kneeling position has been scarcely addressed. Our hypothesis is that ankle position has an effect on the mechanical stress borne by the knee during tall-kneeling position. Thus, the aim of this study was to compare the magnitude of the ground reaction force, the distribution of the support area, pressures, center of pressure (COP) and pain, all as indicators of mechanical stress, in the tall-kneeling posture with two different ankle positions. It is expected that an ankle plantarflexion posture will reduce the mechanical stress borne by the knee in the tall-kneeling position.

## Method

### *Design*

The present investigation consisted of a cross-sectional study and was conducted in the Laboratorio Integrativo de Biomecánica y Fisiología del Esfuerzo (LIBFE). All participants gave their consent by signing a written informed consent document. The protocol of this study was approved by the Scientific Ethics Committee of Universidad de los Andes (Folio: SCEC201610, 01/24/2017). All procedures performed in this study were in accordance with the Helsinki declaration (Carlson et al., 2004).

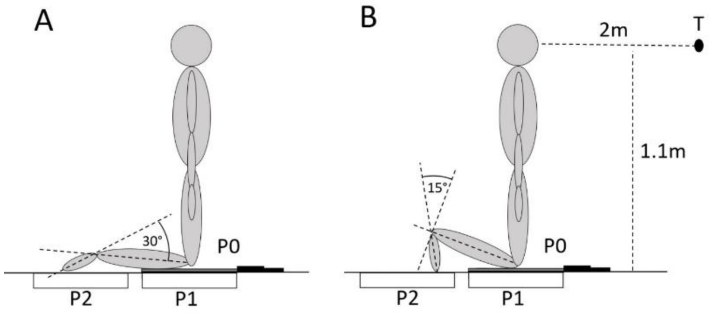
### *Participants*

Twenty healthy young university students (10 women, 10 men; age 22.0 ± 1.5 years; height 169.2 ± 9.2 cm; body mass 70.3 ± 13.5 kg; BMI 24.4 ± 3.4 kg/m$^2$) participated in this study. Volunteers were excluded if they met any of the following criteria: (1) history of injury or surgery involving the spine and/or lower extremities within the previous year; (2) presence of spine and/or lower extremity pain persisting for more than 3 days at the time of evaluation; or (3) current use of neuroleptic or psychotropic medication

## *Procedure*

All assessments were conducted in a controlled laboratory environment. The experimental setup consisted of two force plates (FP4060, Bertec Corporation, USA) and a rigid pressure plate (P0; Footwork, IST Informatique, France), which was positioned on top of one of the force plates (P1), as shown in Figure 1. Participants, who were barefoot and wore sports shorts ending above the knees, were instructed to adopt a tall-kneeling posture with both knees placed on the pressure plate. They were asked to distribute their body weight evenly between knees while maintaining 90° of knee flexion. The knees were positioned at hip-width, with the feet resting on the posterior force plate (P2, Figure 1). Participants were instructed to maintain the posture with their arms relaxed at their sides, the trunk upright, the hip joint in a neutral position, and their gaze fixed on a target marked on a wall 2.0 m away at a height of 1.10 m. For the plantar flexion (PF) condition, participants were instructed to “place the instep of the feet on the ground,” achieving approximately 25–30° of plantar flexion. For the dorsiflexion (DF) condition, they were instructed to “support only the toes,” maintaining approximately 10–15° of dorsiflexion. Ankle position was verified at the beginning of each trial using a goniometer. Loss of the initial ankle position was considered a criterion for trial invalidation. The order of execution of the PF and DF conditions was randomly assigned for all participants. Each volunteer was asked to maintain the tall-kneeling position combined with either PF or DF for 60 seconds. Previous studies have reported recording times between 10-20 seconds (Jensen et al., 2010; Pollard et al., 2011; Xu et al., 2017). In our study, this duration was extended to approximate a more realistic condition; however, we chose not to prolong it excessively to avoid subjecting volunteers to undue pain and to safeguard their well-being. At the end of each record, volunteers were asked about the level of knee pain perceived during the test, for which the visual analogue scale (VAS) was used. During each trial, the vertical ground reaction force (GRF), pressure, and contact area between the support surfaces and the knees were recorded synchronously. The records were made using two data capture software (Bertec Digital Acquire 4.0.11.404, Bertec Corporation, USA and Footwork 3.7.8.0, IST Informatique, France). Data was recorded at a sampling frequency of 100Hz.

Figure 1. An illustration of the set-up is shown. The volunteer was placed on his/her knees on two force plates; the anterior plate (P1) that supported the knees, and the posterior plate (P2) that supported the feet. A pressure plate (P0) was installed between the plate P1 and the knees. One target (T) was used, located at a height of 1.1m and at a distance of 2 meters from the volunteer, on which volunteers were asked to fix their sight. A: tall kneeling position with plantar flexion (PF). B: tall kneeling position with dorsiflexion (DF).



## *Data analysis*

Records in relation to force and pressure were analyzed in a data processing software (IgorPro 6.22, WaveMetrics, USA), from which the following analysis variables were calculated for each knee: i) Average of the vertical GRF recorded in the anterior plate (P1) and posterior plate (P2), both expressed in an absolute way (Newton) and adjusted to body weight (BW%); ii) contact area between the knee and the support surface, expressed in cm2; iii) Peak pressure recorded within the contact area, expressed in kPa; iv) Average pressure recorded in the contact area, expressed in kPa. In order to represent the pressures and contact areas of both knees, the average between the right and left knee was taken into consideration; v) Position of the center of pressure (COP) on each knee expressed as the difference between the position of the center and the most anterior edge of the contact area; vi) Number of peaks recorded in the contact area; vii) The degree of pain perceived in the knees using the visual analogue scale.

### *Statistical analysis*

The sample size was calculated using a paired mean-difference model (two-tailed), with 80% statistical power and an assumed effect size of 1.5. For this calculation, we used the ground reaction force data reported by Pollard et al. (2011), obtained in two variants of the tall-kneeling position (28 ± 13 %BW vs 11 ± 6 %BW). The minimum required sample size was 6 participants; however, the sample was increased to 20 volunteers given the feasibility of recruiting this number. The sample size was calculated using G*Power software (Version 3.1.9.6 Franz Faul, Universität Kinel, Germany).

Using the Shapiro-Wilk test, it was evaluated whether the analysis variables fulfilled the assumptions of normality or not. In the first instance, the variables of area and average pressure, peak pressure and COP were compared between the right and left knees under each condition by using the t-student test for independent data or the Mann-Whitney test, according to the fulfilment of the assumption of normality. This was conducted with the purpose of determining whether there was any difference between both knees within the PF and DF conditions. Since there was no difference between them (Table 1), the variables of both knees were grouped by their average.

Comparisons between both conditions (PF vs. DF) were carried out using the t-student test for paired data when the variables fulfilled the assumption of normality and using a Wilcoxon test when this assumption was not fulfilled. The number of pressure peaks recorded in the contact areas in each condition was compared with a Fisher's exact test. All the analyses were carried out using statistical analysis software (GraphPad Prism 10.6.1, GraphPad Software, USA), using a statistical confidence level of 95% and a one-tailed test. Statistically significant differences associated with a p-value < 0.05 were considered as significant. For each significant difference the power associated with it (1-β) was calculated, using the G-Power software (Version 3.1.9.6 Franz Faul, Universität Kinel, Germany). Additionally, effect sizes for significant differences were calculated using Cohen's d. Cohen's d was interpreted as follows: 0–0.19, small; 0.20–0.49, medium; 0.80–1.29, large; and ≥1.30, very large. (Selya et al., 2012; Sullivan & Feinn, 2012)

Table 1. Values of median and confidence interval (95%, lower[CI l] / upper[CI u] in brackets) of peak pressure (PP), mean pressure (MP), contact area (CA) and center of pressure (COP) in healthy volunteers (n=20) as recorded in both knees in two tall kneeling position variants, with plantar flexion (PF) and dorsiflexion (DF).

| | PP (Kpa) | | | MP (Kpa) | | | CA (cm$^2$) | | | CoP (mm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R | L | *p* | R | L | *p* | R | L | *p* | R | L | *p* |
| PF | 374 | 405 | 0.62* | 115 | 128 | 0.20* | 26 | 30 | 0.30# | 22 | 22 | 0.95# |
| CI l | 343 | 365 | | 111 | 119 | | 24 | 26 | | 26 | 24 | |
| CI u | 417 | 432 | | 136 | 139 | | 29 | 31 | | 54 | 49 | |
| DF | 373 | 370 | 0.27* | 123 | 123 | 0.83* | 24 | 23 | 0.41# | 19 | 16 | 0.50# |
| CI l | 329 | 350 | | 110 | 116 | | 21 | 22 | | 15 | 17 | |
| CI u | 393 | 428 | | 136 | 133 | | 28 | 28 | | 26 | 28 | |

*Mann-Whitney test; #Unpaired t-student test. p= p-value.

## Results

No significant differences were observed in the variables of peak pressure and mean pressure between the evaluated positions (p > 0.05). The contact area was significantly higher in the position associated with PF (p = 0.005; 1-β=0.72 and effect size= 0.64).

The magnitude of the vertical GRF recorded in the anterior plate (P1), turned out to be significantly greater in the condition of PF (p < 0.0001; 1-β=0.99 and effect size= 2.7), while this same variable was significantly higher (p < 0.0001; 1-β=0.99 and effect size= 2.7) in the posture with DF for the posterior plate (P2). The CoP above the knee had a significantly more posterior position in PF, if compared to DF (p = 0.002;1-β=0.98 and effect size= 0.92). The ratio of two pressure peaks was higher in tall kneeling position with PF in relation to DF (p < 0.0001), as shown in Table 2. Furthermore, the VAS score was greater in the condition of DF (p = 0.047; 1-β=0.61 and effect size= 0.40). In Table 3, median values and confidence intervals of the assessed variables are shown. Figure 2 shows a pressure distribution graph on the contact surfaces in different conditions.

Table 2. Presence of one or two peak(s) recorded within the support area of the knee in healthy volunteers (n=20), in two tall kneeling position variants, with plantar flexion (PF) and dorsiflexion (DF).

| | One Peak | Two Peaks | Total |
|---|---|---|---|
| PF* | 8 | 32 | 40 |
| DF* | 34 | 6 | 40 |
| Total | 42 | 38 | 80 |

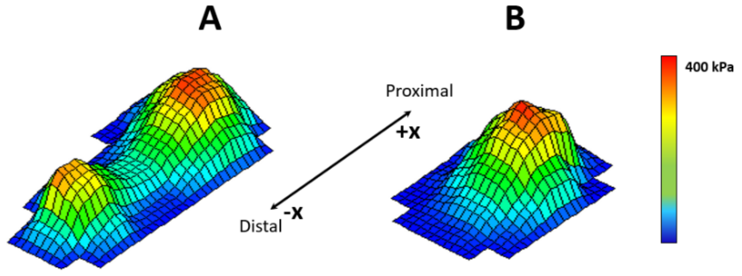
*p-value <0.0001, Fisher's exact test

Table 3. Values of median and confidence interval (95%, lower / upper in brackets) of peak pressure (PP), mean pressure (MP), contact area (CA), visual analogue scale (VAS) in healthy volunteers, vertical ground reaction forces (Fz, P1:Anterior force plate, P2: Posterior force plate) in healthy volunteers (n=20), in two tall kneeling position variants, with plantar flexion (PF) and dorsiflexion (DF).

| | PP (Kpa) | MP (Kpa) | CA (cm$^2$) | VAS | Fz (%BW) | | Fz (N) | CoP (mm) |
|---|---|---|---|---|---|---|---|---|
| | | | | | Anterior(P1) | Posterior(P2) | P1 + P2 | |
| PF | 392 | 121 | 28 | 3 | 95 | 5 | 693 | -40 |
| CI | (360 / 420) | (116 / 136) | (25 / 30) | (2 /4) | (94 / 96) | (4 / 6) | (627 / 749) | (-48 / -28) |
| DF | 383 | 121 | 25 | 4 | 89 | 11 | 693 | -19 |
| CI | (347 / 402) | (115 / 133) | (22 / 28) | (3 / 5) | (86 / 89) | (10 / 14) | (625 / 748) | (-25 / -17) |
| *p-value* | 0.173$^{\#}$ | 0.147* | 0.005$^{\#}$ | 0.047* | < 0.0001* | <0.0001* | 0.215$^{\#}$ | 0.002* |
| 1-β | -- | -- | 0.72 | 0.61 | 0.99 | 0.99 | -- | 0.98 |
| ES | -- | -- | 0.64 | 0.40 | 2.7 | 2.7 | -- | 0.92 |

*Wilcoxon test; $^{\#}$Paired t-student test; p: p-value; 1-β: Power. ES: Effect Size (d Cohen´s)

Figure 2. Example of the distribution of pressures recorded in the contact surfaces of the knees for the tall kneeling condition with ankle plantar flexion (A), and with dorsiflexion (B). It should be noted that in combination with plantar flexion, two contact peaks are observed, while, with dorsal flexion, only one is observed



## Discussion

The results of the present study indicate that ankle position modulates the force applied to the knee support surface during the tall-kneeling posture. The force magnitudes recorded here were comparable to those previously reported in both cadaveric models (Abo-Alhol et al., 2014) and in situ investigations (Xu et al., 2017). However, those studies did not consider ankle position as a potentially influential factor on these forces.

In our study, tall-kneeling performed with plantarflexion (PF) was associated with a greater load borne by the knees (anterior platform), accounting for approximately 95% of body weight (BW), whereas in dorsiflexion (DF) the knees supported 89% of BW. This difference is explained by a greater redistribution of load toward the feet (posterior platform) in DF, where the feet supported 11% of BW, compared with 5% in PF (Table 3). In addition, PF was associated with a significant increase in the knee–ground contact area (Table 3). Collectively, these findings might suggest higher mechanical stress over the knee support surface in PF than in DF due to the greater force borne by the knees. Nevertheless, this was not observed in our data, as the PF-related increase in force coincided with a significant expansion of the anterior contact area (Table 3), which likely offset the greater load and resulted in relatively stable pressure values. Likewise, the maximum and average values of the pressures recorded in relation to the support surfaces of the knees turned out to be similar to those previously reported (Jensen et al., 2010; Porter et al., 2010).

From a neuromechanical perspective, the tall-kneeling posture combined with PF was associated with lower scores on the visual analogue scale (VAS) compared with the DF condition (p = 0.047). This finding may be partly explained by differences in the contact area between the knee support surfaces and the ground. Specifically, the contact area in PF increased significantly ($p = 0.005$), which is consistent with the change in the angle between the leg segment and the support surface. In PF, this angle decreases, so the leg adopts a more parallel orientation relative to the ground (Figure 1), promoting contact of more proximal regions of the segment with the surface and, consequently, increasing the support area (Figure 2). In addition, a higher frequency of double pressure peaks was observed during PF compared with DF (Table 2, $p < 0.0001$). Taken together, a larger contact area and a load distribution across multiple peaks may be associated with recruitment of a greater number of mechanoreceptors and free nerve endings within the contact region. This would imply that the mechanical stimulus is distributed across more receptors, reducing the load per receptor and potentially keeping it below activation thresholds. In contrast, in DF, the smaller contact area may concentrate the mechanical stimulus, bringing it closer to activation thresholds and thereby contributing to greater pain perception.

From a biomechanical point of view, this study shows that the CoP, recorded in the contact area of the knees with the ground in the condition of DF, was found in a more anterior position if compared to the condition of PF (Table 3, $p = 0.002$; $1\text{-}\beta=0.98$ and effect size= 0.92). This finding could mean that in the combination of kneeling with DF, the contact forces of greater magnitude are predominantly concentrated in the anterior region of the support surface, when compared to the position with PF (Figure 2), which could produce greater mechanical stress in the anterior region of the support during the position with DF, if compared to the position with PF. In this same context, in the position with DF, a greater proportion of a single peak of pressure was recorded inside the contact area, while in the position with PF, a greater proportion of two peaks was observed (Table 2 and Figure 2). Both findings indicate that the mechanical stress of the anterior region of the knee support area is increased in the condition of DF. This concentration of mechanical stress in the anterior region can be explained by the increase in the angle between the leg segment and the ground surface, which is observed when the tall kneeling position is combined with DF. The increased mechanical stress over the anterior region of the knee support surface may, in turn, exacerbate irritation of anterior knee structures, thereby increasing the risk of overload and injury to tissues such as the superficial and deep infrapatellar bursae, the patellar tendon, and the patellar apex (Steinbach & Stevens, 2013). In contrast, the position combined with PF, showed a lower comparative mechanical stress on the anterior region of the support surface, given the more posterior location of the CoP, added to the higher frequency in the presence of two pressure peaks within of the contact area (Figure 2), which shows a distribution of load towards the posterior regions of the support. The concentration of forces in the anterior region of the support surface, the existence of a single peak of pressure and the smaller contact area could be the causes of the greater pain described by the volunteers in the tall kneeling position combined with DF, when compared to the position with PF. Another biomechanical factor that may contribute to the lower VAS values observed in the plantarflexion (PF) condition is reduced tension in the gastrocnemius muscles. These are biarticular muscles, as they span both the knee and the ankle (Moya Jofré et al.). Under dorsiflexion (DF), the gastrocnemius remains under tension. This tension may generate a posterior shear component at the knee, potentially increasing patellofemoral compression against the femoral trochlea and increasing tensile loading on the patellar tendon. Both mechanisms may be associated with greater perceived discomfort in this posture. In contrast, during tall-kneeling combined with PF, lower gastrocnemius tension may reduce the shear component and, consequently, decrease perceived discomfort. Future studies should incorporate electromyographic measures to elucidate the role of muscle activation across different variants of the tall-kneeling position.

Within the limitations identified in this study we can find, firstly, the low specificity of the visual analogue scale (VAS) in order to assess the pain in relation to other instruments (Das & Gangopadhyay, 2015). Although tools that may be more sensitive for assessing discomfort during motor tasks are available—for example, the Body Part Discomfort Diagram by Corlett and Bishop (Corlett & Bishop, 1976)—this scale has not been culturally or linguistically validated for the population included in the present study. Therefore, a visual analogue scale (VAS) was chosen because of its simplicity of administration. Another limitation was associated with the way of assessing the pressures applied to the contact surface of the knee. In the present study, the pressures applied directly to the knee were not evaluated, but recorded using a rigid pressure plate, unlike that described by Xu et al. (Xu et al., 2017), who placed pressure sensors directly on the skin. Notwithstanding, when using a rigid plate, the recording of the areas that are producing direct contact with the support surface is ensured. Another limitation of this study is the recording duration (60 s), which may not fully reflect the time for which the tall-kneeling position is typically maintained in some occupational and/or sociocultural activities. However, our recording time was longer than that used in previous studies on similar topics, which reported registration periods of 10–20 s (Pollard et al., 2011; Xu et al., 2017) and 20 s (Jensen et al., 2010). This duration was chosen to minimize the adoption of compensatory postures that might arise during longer trials—thereby reducing the introduction of additional confounding variables—and to avoid exposing volunteers to unnecessary pain, thus safeguarding their well-being. Another limitation of our study relates to the external validity of the results. This is constrained by the nature of the sample, which is not population-based, thereby reducing the possibility of extrapolating the findings to a broader population. Nonetheless, we consider that our study presents high internal validity, supported by the methodological design employed and the appropriate control of the variables considered.

From a clinical perspective, and considering the limitations noted, the findings of this study suggest that maintaining the tall-kneeling posture with plantarflexion (PF) may be a more favorable alternative than dorsiflexion (DF) to protect the knee and/or reduce discomfort associated with this posture. This recommendation may be particularly relevant for individuals with pathology or sensitivity involving anterior knee structures, as well as in contexts where cost, availability, or cultural factors limit the use of kneepads.

## Conclusions

In the sample evaluated, it can be concluded that ankle position during the tall-kneeling posture altered the magnitude and distribution of forces, the contact area, and the location of the center of pressure across the support surfaces. These results suggest that tall-kneeling combined with PF may be a more favorable alternative than DF to protect the knee and/or reduce pain associated with this posture

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