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Review

Novel Technologies Used in the Assessment of Patellofemoral Pain: A Scoping Review

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Abstract: This scoping review aims to present existing evidence on new technologies reported recently to assess patients with patellofemoral pain (PFP). The literature search was conducted in September 2023, and search engines were Medline (via Pubmed), Scopus, and Cochrane Central. The preferred search term was "patellofemoral pain", as the 2016 PFP consensus statement recommended, and several subgroups were arranged to find any possible technology-related assessment. The total number of articles found was 7927. After eliminating duplicates, 2058 articles remained for the title and abstract screening. Methods sections of the articles were investigated for data charting. Among the 652 full-text articles, 8 met our inclusion criteria on gait analysis, 34 on imaging, and 95 on EMG. However, only 5 included innovative technology, 2 used cone-beam CT, 1 used a device in medical imaging to apply stress to the patella in anatomical directions, and 2 used a novel EMG electrode system based on a high-density linear array. The results of this review demonstrate the large use of innovative technologies in PFP, particularly using medical imaging and state-of-the-art gait analysis, sometimes used together for thorough biomechanical studies. Because modern technology can provide precise and detailed information, exploiting these to design more effective prevention campaigns and patient-specific rehabilitation programs is fundamental. Investigations are becoming increasingly translational and multidisciplinary as a fusion of technological and clinical perspectives brings significant insights to PFP.

Keywords: patellofemoral pain; technology-based assessment; biomechanics; medical imaging; gait analysis; electromyography; clinical evaluation

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1. Introduction

Patellofemoral pain (PFP) is a common clinical condition especially in the young active population. It refers to pain during activities behind or around the patella and has a gradual onset with increased frequency or duration [1]. The literature for PFP reports concerns for the high incidence, prevalence numbers, disability levels, and poor prognosis [2,3]. Diagnosis of PFP relies mainly on clinical examination and imaging. Differential diagnosis is key to separate it from other possible causes of pain such as osteoarthritis and chondromalacia patellae. However, since it is a syndrome with unclear pathogenesis and still-debated biomechanics, understanding the causative reasons and clinical characteristics is a challenge for health professionals [4,5].

Associated with the large general developments of the technology, studies using state-of-the-art instruments and techniques, also during execution of daily living motor tasks,

are growing rapidly by examining PFP patients through kinematic and kinetic analyses, imaging technologies, electromyography (EMG), isokinetics, etc. Unfortunately, results gathered from imaging and assessment measures can hardly be merged or compared, because of different factors, such as the reliability of instruments, real-life adaptability of the measure (i.e., somehow predictability of real-life conditions), and the large spectrum of variables [6,7]. Due to these conflicts, manufacturers focused on developing new technologies to solve the inconsistency in the results and also tried to consider the issues such as cost-effectiveness, fewer side-effects, and practical use. Despite the heterogeneity of the technologies used, a number of studies have recently examined possible innovative technologies, also evaluating their cost-effectiveness, and pros and cons [8–10]. These studies have highlighted the relevance of technological innovations in musculoskeletal rehabilitation and their potential to improve the sustainability of healthcare systems for the assessment and management of general patients.

Although measures from medical imaging in static conditions definitely provide valuable information, functional assessments during motor tasks can also provide observations from daily living and in real-time, thus giving access to the dynamic interactions of hard and soft tissues [5,7]. This has been reported in a number of studies using gait analysis and biomechanical modeling [11,12]. Now, medical imaging in dynamic and weight-bearing conditions also in 3D are accessible [13–15] for these assessments. However, technical experience must become more mature, and costs, radiation, access to these instruments, data post-processing, etc., are known concerns that limit current relevant exploitations [7]. Bi-dimensional analyses are still frequently used, such as those for the frontal plane projection angle [16] and the Q-angle, but modern instrumented gait analysis provides thorough 3D dynamic measurements of joint kinematics and kinetics [17,18], in real-time and also synchronized with surface EMG.

The abovementioned technological innovations have led us to wonder whether they are used and whether any other technologies are currently used in people with PFP. Therefore, this review aims to present the existing evidence from the literature of novel technologies developed in the last decade to assess PFP, with a particular focus on the patellar area to avoid indirect assessments to the joint. As the intention was to provide existing evidence, the option was to conduct a scoping review to address what we already have in the heterogeneous literature as aimed in the scoping review methodologies. Also, the context of these novel assessments and the possible further directions are discussed.

2. Materials and Methods

This review was planned as a scoping review considering the breadth of the research topic and the expected large spectrum of technologies and articles. The present methods and the other sections are thus written according to the PRISMA-ScR guidelines for scoping review [19].

2.1. Literature Search

Since our aim was to investigate the novel technologies, we considered articles published in the last eleven years. The literature search was performed on 13 September 2023, and Medline (via Pubmed), Scopus, and Cochrane Central were used as search engines. We used the term 'patellofemoral pain' as stated as the preferred term in the Consensus Statement [20]. Then, we subgrouped all possible keywords in order to not miss any possible relevant article, and we combined these with the Boolean operators "AND" and "OR". The search strategy, actions, and results are shown in Figure 1. The exact search terms are shown in Table 1 and all search lines were used separately for each database. After initial data collection, EndNote and RAYYAN software tools were used to detect duplications, to order the articles, and to extract the results [21,22].

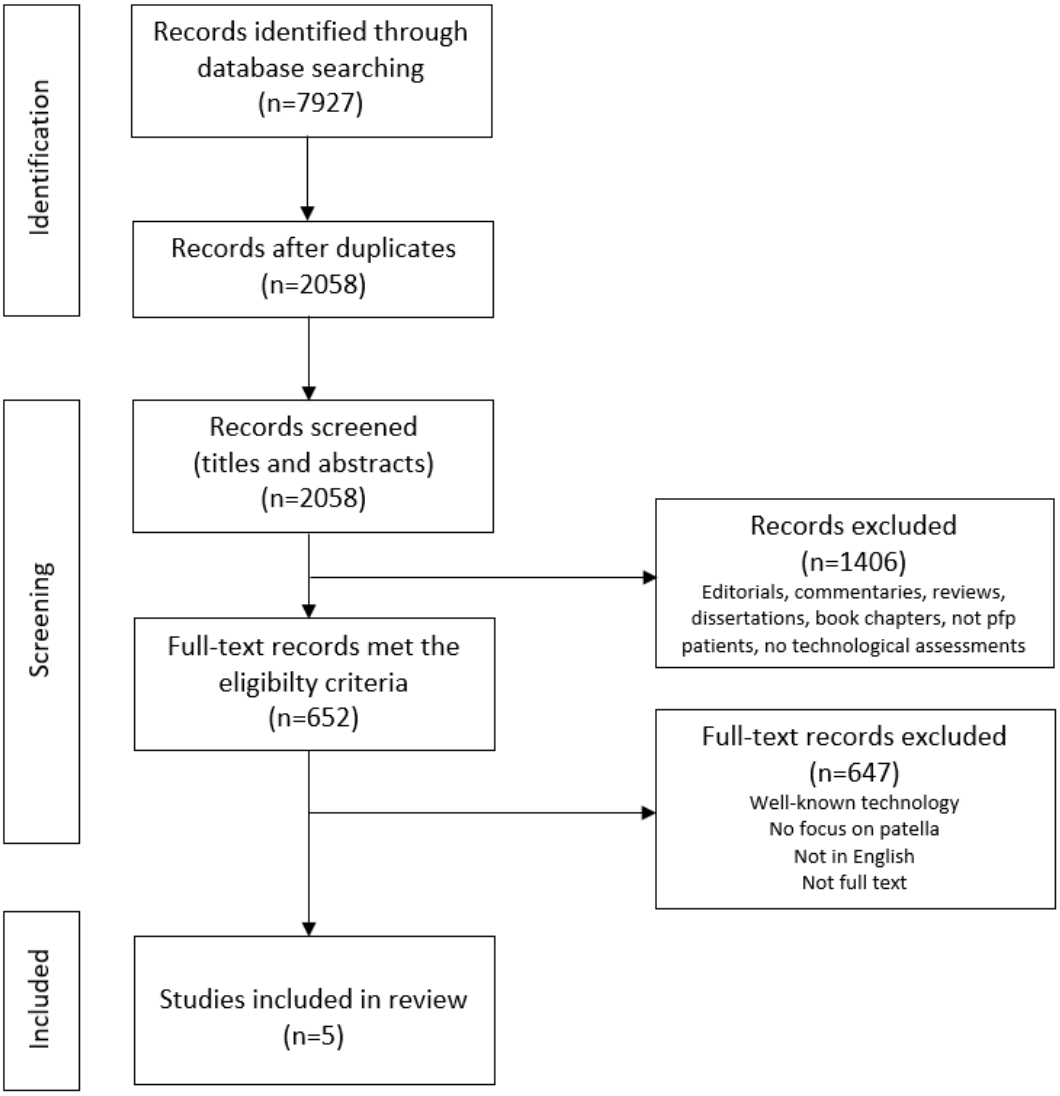


Figure 1. Diagrammatic representation of the flow-chart for the article search (according to terms in Table 1) and progressive selections, with corresponding results.

Table 1. Terms for the search strategy and relevant subgroups.

Gait analysis	"patellofemoral pain" AND ("3-D kinematics" OR "axial loading" OR biomechanics OR "contact pressure" OR gait OR "gait analysis" OR "human movement analysis" OR "joint load*" OR kinematics OR kinetics OR load-bearing OR loadbearing OR locomotion OR movement OR "plantar pressure" OR posturography OR pressure OR electro-goniometer OR electrogoniometer OR "walking speed" OR "weight bearing" OR weightbearing OR motion OR electromyography OR EMG OR in-vivo OR "in vivo")
Supporting devices	"patellofemoral pain" AND (treadmill OR orthosis OR brace OR shoes OR barefoot OR exoskeleton OR "supporting device" OR "supportive device")

Table 1. *Cont.*

Medical imaging	"patellofemoral pain" AND ("brain mapping" OR "computed tomography" OR CT OR "dynamic magnetic resonance" OR electroencephalography OR EEG OR fluoroscopy OR "functional magnetic resonance imaging" OR "functional MRI" OR FMRI OR "kinematic magnetic resonance" OR "kinematic MRI" OR "magnetic resonance spectroscopy" OR MRI OR sonography OR stereophotogrammetry OR tomography OR ultrasonography OR "weight-bearing CT" OR "weight-bearing magnetic resonance" OR X-ray OR in-vivo OR "in vivo" OR in-vitro OR "in vitro" OR "conebeam CT" OR CBCT OR "medical imaging")
Musculoskeletal computer modeling	"patellofemoral pain" AND (modelling OR modeling OR in-silico OR "in silico" OR simulation OR "musculoskeletal computer modelling" OR "musculoskeletal computer modeling")
Statistical analyses	"patellofemoral pain" AND ("artificial intelligence" OR "ayesian analysis" OR "ayesian model" OR ayesian OR "hierarchical cluster analysis" OR "hierarchical clustering")
Simple calculations	"patellofemoral pain" AND ("anatomical reference frame" OR "anatomical axis" OR position OR orientation OR "finite helical axis" OR "instantaneous helical axis" OR "mean helical axis" OR "principal component analysis" OR "joint angle" OR "euler angle" OR grood OR suntay)
Complex calculations	"patellofemoral pain" AND ("computational intelligence" OR "computer reasoning" OR "machine learning" OR "neural network" OR "finite element analysis" OR "artificial intelligence" OR "big data" OR "gait score" OR calculation)
Interventions	"patellofemoral pain" AND (surgery OR surgical OR operation OR rehabilitation OR physiotherapy OR experiment OR treatment OR "virtual reality" OR robotic OR "stroboscopic visual training")
Mobile devices	"patellofemoral pain" AND (application OR "mobile phone" OR "tablet" OR "mobile device")
Feedback use	"patellofemoral pain" AND (biofeedback OR feedback OR haptic*)
Wearable devices	"patellofemoral pain" AND (wearable OR "wearable technology" OR "activity tracker" OR accelerometer OR gyroscope OR magnetometer OR "inertial measurement unit" OR IMU OR "inertial motion unit" OR electrogoniometer)
Others	"patellofemoral pain" AND ("acoustical emission" OR acoustic OR acoustical OR bioengineering OR "video based assessment" OR weight-bearing OR weightbearing OR isokinetic)

Note: *: truncated keyword.

2.2. Eligibility Criteria

The two-step investigation was performed for eligibility of the articles. First, titles and abstracts were screened to detect the suitability of the article for the present scope. Articles using physical examination and non-technological assessments, study protocols, book chapters, congress proceedings, editorials, infographics, and reviews were excluded.

After this first step, the remaining articles were determined to be related to assessments with technology and to include PFP populations, and thus selected for the following full-text analysis. Only those articles whose full text could be accessed in English were examined. Among the suitable articles, studies using novel technology and focusing on patella-related features were retained and extracted.

From the starting point, we needed this two-step investigation and changed our inclusion strategy since kinematic, kinetic, and EMG analyses are well-known methods for PFP. We excluded kinematic and kinetic analyses unless they were not specifically

related to the patella and included if they explicitly had an arranged marker set for patella tracking as well. Also, since EMG assessment is not novel and is very well known, EMG studies were excluded unless they reported any specific novel device or electrode targeting patello-femoral-based evaluations.

Inclusion and exclusion criteria were thus as follows:

Inclusion criteria:

- If novel technologies were used in the assessment;
- If the focus of the assessment and measurements was on patellar area.

Exclusion criteria:

- If assessments were not related to patellar area;
- Full text not available;
- Articles that are not in English;
- Well-known assessment methods and devices;
- Assessment made during surgery;
- Computer calculations, model simulations, and similar approaches where these analyses were performed after instrumental assessments;
- Simple range of motion analyses.

2.3. Article Selection

This literature search was performed by one investigator (GAB). Abstract screenings were performed independently by two investigators (GAB and FV) according to titles and abstracts, and any conflict was resolved by the other authors (CB, AL, MGB, and VBT). Also, full-text reviews were performed by GAB and FV, and conflicts were again resolved by CB, AL, MGB, and VBT.

2.4. Data Charting/Analysis

Data charting was arranged from the methods sections of the articles. Description of the methods was extracted according to the technology used in the study and analyzed qualitatively by grouping this extracted information. In particular, it was evaluated whether the method was a technology-based assessment method or a device using a novel technology, and also whether the technology was very novel and original, or the technology was developed and used recently (within the search period), i.e., 11 years. This information was charted according to the inclusion and exclusion criteria above. We also extracted from each article the study designs, the device info, the company names, the origin/country of the devices, and origin/country of the authors.

3. Results

3.1. Searches

According to this literature review, the total number of articles found was 7927. After removal of duplicates, 2058 articles remained after title and abstract screening. Of those, 652 met the eligibility criteria for full-text screening. Among these articles, 406 included biomechanical, 186 included imaging, and 150 included EMG assessments. Of the full-text read articles, only five articles included novel technology, and thus met all the inclusion criteria (Table 2).

3.1.1. General Study Details

Biomechanical analyses constituted the majority of the studies that were investigated for full-text analysis. Kinematics, kinetics, and projection angles were used in 406 studies; in particular, 95% of these included biomechanical and/or gait analysis, 14% addressed projection angles, and 43% performed kinetic analysis.

The second largest majority of articles was on medical imaging. There were 108 using magnetic resonance imaging (MRI) (6 functional MRI, 1 PET/MRI), 2 dynamic radiography, 3 fluoroscopy, 20 computed tomography (CT) (out of these, 2 were by cone-beam CT and

1 by PET/CT), 1 electroencephalography (EEG), and 27 X-ray studies. Also, there were 41 ultrasonography (USG) studies (of those, 2 were echo-intensity investigations, 1 used doppler ultrasound, 2 were about elastographic assessment).

A total of 48 studies used artificial intelligence, statistical, or computed calculations to interpret the functional parameters. Also, 79 studies used isokinetic assessments.

3.1.2. Biomechanical Analysis

In only 8 out of 406 biomechanical studies based on gait analysis, it was mentioned that an additional marker was placed on the patella, and full-text reading was performed to understand whether it was really a new technology or not. However, no new marker or system presence was found. Four of these included the Vicon Motion System and others included the SMART-BTS System for gait analysis.

3.1.3. Imaging Studies

In 34 out of 186 medical-imaging-based studies, we found the following: 9 used weight-bearing MRI, 1 used MRI in a number of different knee joint poses, 16 used dynamic MRI, 2 used dynamic radiography, 3 used fluoroscopy, 2 used cone-beam CT (CBCT), and 1 used a novel testing device. CBCT studies were eligible since this is a novel technology. Two studies used C-arm CT in weight-bearing [23,24]. One article was eligible with a patella stress testing instrument [25]. The Porto Patella Testing Device (Soplast-Moura, Moutinho & Morais, S.A., Porto, Portugal) is special device to be used in MRI or CT scans; this applies a force to the patella in different directions to create a stress on the medial facet during image data acquisition [26].

3.1.4. EMG Studies

Out of 150 EMG studies, only 95 investigated PFP with original techniques. It was identified that only two of them used a novel electrode that was a high-density linear electrode array [27,28].

Table 2. The final 5 selected papers, with brief description of the technology.

Reference	Study Design	Country/ Origin of Study	Country/ Origin of Device	Device	Info	Company
Yang, 2020 [23]	Cohort Cross-sectional	Stanford, CA, USA	Germany	CBCT	C-arm Computed Tomography	Artis Zeego, Siemens Healthineers, Forchheim, Germany
Pal, 2022 [24]	Intervention follow-up	Stanford, CA, USA	Germany	CBCT	C-arm Computed Tomography	Artis Zeego, Siemens Medical Solutions, Erlangen, Germany
Leal, 2020 [25]	Cross-sectional	Porto, Portugal	Portugal	Imaging instrument	Stress instrument testing	Soplast-Moura, Moutinho & Morais, S.A., Porto, Portugal
Gallina, 2018 [27]	Cross-sectional	Vancouver, BC, Canada	Italy	EMG electrode	High-density linear electrode array	OT Bioelettronica, Torino, Italy
Gallina, 2019 [28]	Cross-sectional	Vancouver, BC, Canada	Italy	EMG electrode	High-density linear electrode array	OT Bioelettronica, Torino, Italy

4. Discussion

The objective of this review was to present the existing available novel technologies used to assess PFP patients in the last decade. We presented an overview of these assessment

methods and original techniques, and also pointed out possible technological instruments that might be used in the assessment of PFP. Even though there are several uses of novel technologies in the PFP, there is still a greater need for the use of various novel technologies focusing on this joint in particular.

The results of this review reflect the growth in the collection and use of data from biomechanical, imaging, and EMG methods. The difficulty in the diagnosis, classification, and treatment of PFP syndromes prompted researchers to conduct more detailed studies and to improve the existing protocols by using these methods [5]. Currently, these investigations are becoming more and more translational and multidisciplinary, since blending technologic and clinical perspectives brings meaningful insights to the assessment of PFP. As an example, very technical investigations can take advantage of more precise clinical evidence, as in biomechanical modeling [29]. However, a number of articles were published in engineering journals, so we performed our searches in different databases to reach all possible articles and address the readers with clinical and engineering backgrounds at the same time.

4.1. Biomechanical Analyses

There has been an increasing number of biomechanical studies in recent decades. This may be accounted for by the development of kinematic and kinetic analyses, the first game-changing technologies that later became the gold standard.

Biomechanical studies based on state-of-the-art gait analysis are substantial to interpret motion patterns at the knee joints. A number of studies show that excessive load at the patellofemoral joint leads to increased patellofemoral contact force, which can result in altered tibial and femoral kinematics, both in the frontal and transverse planes [30,31]. Indeed, there is still a debate on these mechanisms, for which biomechanics can provide relevant evidence. To set standardized approaches to the kinematics and kinetics of the major joints of the lower limbs, a number of protocols have been developed and compared [17,18]. Known limitations include adequate data collection, skin motion artifacts, anatomical landmark identification, and tracking [17]. Appropriate marker positioning is essential to determine the joint kinematics and kinetics, and thus to work out relevant patterns within the gait cycle. The large majority of gait analysis protocols calculate motion of the tibiofemoral joint in the frontal and sagittal planes, and only a few on the transverse plane. Since skin markers should track motion of the underlying bones [5], this assumption is particularly critical for the patella, because of its small motion, small dimension, and the large gliding of the skin. Metal probes have been implanted into the patella to obtain a rigid connection with the markers and thus a reliable joint motion, but this was possible only in in vitro studies [5,32–37]. Thus, adapting the results of these studies to real patellofemoral joint function and PFP is difficult. Nevertheless, there are studies reporting the placement of skin markers on the patella [38–45]; careful full-text readings, however, revealed that patella movements apparently were not tracked in these articles. The present observation also points out the importance of consistent reports in the literature.

4.2. Imaging Studies

Radiographic, CT, and MRI evaluations are commonly preferred for differential diagnosis of PFP [46]. Initially, anteroposterior and lateral radiographic imaging is involved for the evaluation since it is a simple and quick option to see the patellar position (patella alta, patella baja, lateromedial subluxation) for the first clinical diagnosis [7]. However, CT and MRI imaging have advantages over radiographic assessments since they provide static and dynamic cross-sectional scanning including soft tissues and information about other possible abnormalities [6,7]. However, all of the imaging techniques offer dynamic evaluations, and all of them have advantages and disadvantages in terms of radiation exposure, acquisition quality, and time limitations [5,47–49]. Imaging is often performed in the supine position in which the patella is simply not exposed to any muscle forces. However,

PFP patients experience symptoms while the patella is exposed to muscle forces such as running and stair ascent and descent. Especially with the advancement in biomechanical analysis and improved understanding of patellar kinematics [30], acquisition techniques have become more specific and tailored by applying devices to create weight-bearing conditions. Thus, dynamic assessments have gained importance to provide a real-time interplay of soft tissue and bone structures.

In the current review, there were 34 articles using imaging evaluations in weight-bearing and dynamic conditions. Thirty of these used standard MRI, CT, and other radiographic devices with custom-built loading platforms to apply forces at the patello-femoral joint. These platforms were mainly fixed under the feet and allowed the subject to push and release force in their muscles. So far, the technology was well known but the technique was different from static acquisition. However, two studies used CBCT, which is quite a breakthrough version of CT [23,24]. CBCT is an emerging medical imaging technique forming a cone shape as opposed to the spiral slicing of conventional CT [13]. CBCT uses a rotating platform with a radiation emitter and flat panel detector to gather multiple quick exposures and produce a 3D volumetric image. By projecting a collimated beam with a large rotation around the stationary patient, a complete volumetric three-dimensional data-set is collected. This differs from traditional CT scans, which use a helical 2D fan shape, resulting in slower scanning times and higher radiation dosages. Exposure to less than half the radiation dosage compared to traditional CT has been noted for these foot and ankle scans [50]. CBCT also has less image distortion and fewer artifacts associated with patient movement [51]. This technique provides convenience by collecting the data very quickly, enables data collection in an up-right posture, and implies less radiation exposure. While up-right evaluation is particularly important for foot and ankle studies, these devices enable visualization and measures of the position of bones and muscles under physiological load, which is much better when compared to CT scans under simulated loading conditions. However, the cone-shaped beam causes scatter interference when radio-opaque materials, like metal, are in the anatomical area of interest. This interference significantly reduces the image quality [51]. Regarding the cost-effectiveness, it has been reported that the yearly mean profit can even be over EUR 53,000 in a typical hospital [52]. Also, it has been shown that using CBCT shortens the scanning time 77% per patient in the same study.

One original article from this review used a novel instrument to test stress on the patella [25]. This instrument, known as the Porto Patellar testing device (PPTD), is safe and compatible for use within MRI/CT and is claimed to be reliable [26]. This polyurethane modular device provides stress on the medial facet of the patella by applying a lateral force vector, in case at different knee flexion angles. Authors reported that the device has a reproductible stress force application and results in better lateral patellar translation than manual translation with more accurate measurements [26,53]. The device uses an air pump system with compressed air cylinders to apply force to the patella through its lateral and medial edge, patella's basis, apex, and anterior face, which can reach a maximum of 0.5 Bar or approximately 52.5 N load. This force is incrementally increased to a quarter of the published MPFL tensile strength (208 N) [54] and is controlled by the patient's feedback to ensure their safety and comfort to comply with the viscoelastic mechanical characteristic of human tissue safety. Authors found that knees with anterior pain show a significantly higher patellar lateral position after lateral stress through PPTD testing compared to non-painful knees [55]. Since it is a newly developed device, there are not many studies to support these results in other populations, which points out the need for further relevant studies.

4.3. EMG Studies

The number of EMG studies demonstrates the importance of assessing muscle forces in PFP. These studies reported on a wide range of motor tasks and of muscle groups, also including those around the hip and the ankle joints, and both flexors and extensors. However,

standard data collection methods and systems were used. Only two studies [27,28], though the same research team reported the utilization of original high-density surface EMG (HDsEMG) electrodes; this technology enables the placement of several tens of electrodes for each single muscle. HDsEMG is a linear electrode grid array with 16 silver bar electrodes, with a 10 mm interelectrode distance (OT Bioelettronica, Torino, Italy). Each grid comprised 64 electrodes arranged in 5 columns and 13 rows with a single electrode missing in one of the corners. This electrode is claimed to provide information about innervation zones and anatomical factors for the best estimation of neuromuscular activation and regions. Using these electrodes, data from the vastus medialis and vastus lateralis were collected, since these can be placed between the edges of each muscle [27,28]. Acknowledged advantages of HDsEMGs with respect to traditional bipolar electrodes are a topographical representation of the EMG amplitude, more selective recordings, and reliable motor unit behavior [56,57]. Another study from the same team aimed to investigate whether Principal Component Analysis (PCA) and non-Negative Matrix Factorization (NMF) can provide similar results when used to identify regional muscle activation from HDsEMG signals and showed that a single factor from either the NMF or PCA explained on average 70% of the variance across channels [58]. They found that up to 30% of the variance was explained by regional variations in muscle activity rather than common fluctuations across the muscle, suggesting that a single bipolar electrode would not fully capture the EMG across the whole muscle.

HDsEMGs differ from conventional sEMGs in terms of their scopes. Conventional sEMGs are mainly used in movement studies by yielding concurrent information on activity in different muscles. With HDsEMGs, it is possible to subtract information at a single motor unit, and also muscle-fiber conduction velocity can be gathered as in the needle EMG [59]. Surface electromyographic amplitude is influenced by factors such as adipose tissue thickness, normalization, cross-talk, and motor unit action potential cancellations [27]. As signals are collected from different locations of the muscles, HDsEMG helps to overcome the limitations such as describing activation of the regions within a muscle and taking into account the effect of location of the innervation zone [28]. For example, in the selected study, Gallina et al. showed that females with PFP have simpler VM and VL activation strategies, observed as a lower co-activation of regions between VM and VL and a lower redistribution of activation from VL to VM when the concentric and eccentric phases of the knee extension are compared by using this novel electrode [28]. HDsEMG is an electrode that needs uniformity from different perspectives since it is still in a very early stage in terms of clinical applications and the existence of different names for HDsEMGs (high-resolution EMG, multi-array EGM, matrix electrodes).

Despite the obvious experimental issues, these novel electrodes may provide relevant information regarding femur muscle characteristics in different motor tasks.

4.4. Recommendations for Future Studies

Among all well-known technological assessments, there are a few promising methods and approaches that are already used or might be used more in PFP patients.

4.4.1. Finite Element Analysis/Calculations/Networks/Artificial Intelligence

Since our aim was finding novel technologies, studies using calculations, networks, data processing, finite element analysis, machine learning, and artificial intelligence are not included in this review. However, these assessment approaches seem to be receiving a lot of attention in the literature and there has been a rise in their number [60–62]. These methods either enable large amounts of data to be processed efficiently and yield results [63,64] or provide very detailed results from a very small number of subjects with detailed assessments [11,61,65–72]. They seem to have important potential for future studies, as they are approaches for processing data independent of the technology used. However, the obtained information should be manageable and convertible into useful information at the clinical level. It seems that the development of common approaches to understand the PFP characteristic may be useful for further studies.

4.4.2. Combined fMRI-, TMS-, and EEG-Based Analysis

By understanding the importance of central nervous system processes that modulate the interaction between pain and sensorimotor control for the people with movement dysfunctions, investigating brain activity has gained popularity in chronic pain patients [73,74]. This has led researchers toward technological evaluation methods that can be used to investigate the relationship between brain-activity-related signals and PFP. In the current review, there were studies using functional MRI (fMRI), electroencephalography (EEG), and transcranial magnetic resonance (TMS) imaging techniques to evaluate patient differences or the effectiveness of taping or exercise [73–80]. Although these methods were used in PFP patients and PFP-focused groups, they were not included in this review, since they did not directly evaluate the knee and patella. However, they can be taken into consideration in further studies in order to present objective results in terms of the importance of psychosocial aspects in PFP patients [81].

4.4.3. Ultrasonographic Imaging

Ultrasonographic evaluations are frequently used in the clinic because of their easy access and use. Although this is not in itself a novel technology, some its novel features can be taken into consideration in the future to understand the soft tissue properties in PFP through elastographic, architectural, and echo-intensity feature assessments of muscles [82–84]. In addition, with the introduction of portable systems and transducer fixation devices, dynamic skeletal muscle evaluation has become possible during different motor tasks [85].

4.4.4. Acoustic Emission

Acoustic emission is a technique used to detect the waveform features, which has been shown to provide potential biomarkers collected from the knee joint. Shark et al. conducted a study on osteoarthritis patients to demonstrate the differences in the knee from degeneration and age in the flexion–extension-related tasks [86]. The results showed that there was higher movement variation and increased asymmetry in the patient group compared to healthy individuals. Acoustic emission is shown as a measurement reflecting a composite of structural changes and joint loading factors and is highlighted as a potential candidate for relevant future studies [87]. However, even collecting data has some challenges such as application difficulties, optimal placement, accessibility, and being a novel method that still needs improvement. It can also be considered as a promising technology with the advantages of being non-invasive and non-radioactive and providing information about internal joint contact forces [88,89].

4.4.5. Myotonometry/Reaction Time

In the present search, three new technologies for PFP assessments were found. However, these were not exactly related to the patellofemoral joint but somehow to relevant muscular conditions. One is tensiomyography, which evaluates the muscular mechanical and contractile properties by means of an external electrical stimulus of controlled intensity. It provides information on fatigue, muscle activation, and tone [90]. Another one, used in the same study, is a myotonometry device that measures the stiffness of the muscle at rest [90]. Both of these assess biomechanical muscular properties in an objective way and have been shown to be of value. Muscle stiffness and fatigue are mentioned in fact to be among possible risk factors for knee-joint-related injuries [91]; thus, these new methods may provide original information in addition to EMG.

The third method can evaluate the muscle reaction time, i.e., the time from the appearance of unpredictable stimuli to the start of the selected motor response. It includes central processing and motor time that is necessary for motor response. The reaction time was found higher in PFP patients compared to healthy populations, with this being a valuable representation of the central process and motor reaction delay [92,93]. This assessment can be used as a non-invasive and easy alternative for central deficit assessments.

4.4.6. Accelerometers

With the increased use of microsensor technology, relevant devices have become available to quantify kinetic and kinematic outcomes. Tibial accelerometers have been used in the past also in vivo, being mounted directly on the bone using transcortical pins to infer tibial axial acceleration from ground reaction forces [94]. More recently, skin-mounted accelerometers have been utilized to determine physical activity loading, running kinematics, and even ground reaction forces [95]. Being less expensive, user-friendly, and accessible than force plates, skin-mounted tibial accelerometers could be another novel option in research or clinical settings in PFP patients. However, it should be kept in mind that they do not measure vertical ground reaction forces as standard force plates; they are considered accurate and reliable tools to measure lower extremity load in constant-velocity running [95].

4.5. Limitations

To restrict the present search in such a broad area of clinical interest, we looked only for articles that reported evaluations of the patellofemoral joint in patients with PFP and not in other clinical populations. Our search strategy could have included other populations with pathological conditions such as patellar instability, arthritis of the patellofemoral joint, and chondromalacia of the patella, but they all fall into the main category of patients with PFP. However, the inclusion of other populations, and thus other studies, could likely lead to identifying other novel methodologies not reported here.

5. Conclusions

The results of this review demonstrate the use of innovative technologies in PFP patients, either in isolation or in combination. Interestingly, medical imaging and state-of-the-art gait analysis, sometimes used together for thorough biomechanical studies, have many applications for these patients. The results from this review showed that novel technologies help to gather information from PFP patients, providing more realistic environments by allowing data collection within an up-right position or during the imaging process with imaging technologies and throughout the muscles using novel electrodes with more details about motor unit activations. Since modern technology can provide precise and detailed information, exploiting these to design more effective prevention campaigns and patient-specific rehabilitation programs is now possible and thus recommended. Investigations are becoming increasingly translational and multidisciplinary, assuming that the fusion of technological and clinical perspectives can bring significant insights to PFP. This study highlights the benefits that these devices offer for clinical and research-based assessments, making it a useful reference for future research endeavors.

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References

1. Crossley, K.M.; Callaghan, M.J.; van Linschoten, R. Patellofemoral pain. *BMJ* **2015**, *351*, h3939. [CrossRef] [PubMed]
2. Smith, B.E.; Selfe, J.; Thacker, D.; Hendrick, P.; Bateman, M.; Moffatt, F.; Rathleff, M.S.; Smith, T.O.; Logan, P. Incidence and prevalence of patellofemoral pain: A systematic review and meta-analysis. *PLoS ONE* **2018**, *13*, e0190892. [CrossRef] [PubMed]
3. Barton, C.J.; Silva, D.D.O.; Morton, S.; Collins, N.J.; Rathleff, M.S.; Vicenzino, B.; Van Middelkoop, M.; Crossley, K.M.; Callaghan, M.J.; Selfe, J. REPORT-PFP: A consensus from the International Patellofemoral Research Network to improve REPORTing of quantitative PatelloFemoral Pain studies. *Br. J. Sports Med.* **2021**, *55*, 1135–1143. [CrossRef]
4. Hong, E.; Kraft, M.C. Evaluating anterior knee pain. *Med. Clin.* **2014**, *98*, 697–717. [CrossRef] [PubMed]
5. Yu, Z.; Yao, J.; Wang, X.; Xin, X.; Zhang, K.; Cai, H.; Fan, Y.; Yang, B. Research methods and progress of patellofemoral joint kinematics: A review. *J. Healthc. Eng.* **2019**, *2019*, 9159267. [CrossRef] [PubMed]
6. Drew, B.T.; Redmond, A.; Smith, T.; Penny, F.; Conaghan, P. Which patellofemoral joint imaging features are associated with patellofemoral pain? Systematic review and meta-analysis. *Osteoarthr. Cartil.* **2016**, *24*, 224–236. [CrossRef]
7. Gulati, A.; McElrath, C.; Wadhwa, V.; Shah, J.P.; Chhabra, A. Current clinical, radiological and treatment perspectives of patellofemoral pain syndrome. *Br. J. Radiol.* **2018**, *91*, 20170456. [CrossRef]
8. Lippi, L.; Turco, A.; Folli, A.; D'Abrosca, F.; Curci, C.; Mezian, K.; de Sire, A.; Invernizzi, M. Technological advances and digital solutions to improve quality of life in older adults with chronic obstructive pulmonary disease: A systematic review. *Aging Clin. Exp. Res.* **2023**, *35*, 953–968. [CrossRef]
9. Rojo, A.; Santos-Paz, J.Á.; Sánchez-Picot, Á.; Raya, R.; García-Carmona, R. FarmDay: A Gamified Virtual Reality Neurorehabilitation Application for Upper Limb Based on Activities of Daily Living. *Appl. Sci.* **2022**, *12*, 7068. [CrossRef]
10. Lippi, L.; Turco, A.; Moalli, S.; Nascimben, M.; Curci, C.; de Sire, A.; Rimondini, L.; Invernizzi, M. Quantitative Assessment of Upper-Limb Volume: Implications for Lymphedema Rehabilitation? *Appl. Sci.* **2023**, *13*, 9810. [CrossRef]
11. Besier, T.F.; Pal, S.; Draper, C.E.; Fredericson, M.; Gold, G.E.; Delp, S.L.; Beaupré, G.S. The role of cartilage stress in patellofemoral pain. *Med. Sci. Sports Exerc.* **2015**, *47*, 2416. [CrossRef] [PubMed]
12. Chen, Y.-J.; Powers, C.M. Comparison of three-dimensional patellofemoral joint reaction forces in persons with and without patellofemoral pain. *J. Appl. Biomech.* **2014**, *30*, 493–500. [CrossRef] [PubMed]
13. Leardini, A.; Durante, S.; Belvedere, C.; Caravaggi, P.; Carrara, C.; Berti, L.; Lullini, G.; Giacomozzi, C.; Durastanti, G.; Ortolani, M. Weight-bearing CT Technology in Musculoskeletal Pathologies of the lower limbs: Techniques, initial applications, and preliminary combinations with gait-analysis measurements at the Istituto Ortopedico Rizzoli. In *Seminars in Musculoskeletal Radiology*; Thieme Medical Publishers: New York, NY, USA, 2019; pp. 643–656.
14. Lullini, G.; Belvedere, C.; Busacca, M.; Moio, A.; Leardini, A.; Caravelli, S.; Maccaferri, B.; Durante, S.; Zaffagnini, S.; Marcheggiani Muccioli, G.M. Weight bearing versus conventional CT for the measurement of patellar alignment and stability in patients after surgical treatment for patellar recurrent dislocation. *La Radiol. Medica* **2021**, *126*, 869–877. [CrossRef] [PubMed]
15. Ruggeri, M.; Gill, H.S.; Leardini, A.; Zaffagnini, S.; MacLeod, A.; Ortolani, M.; Faccia, F.; Grassi, A.; Dal Fabbro, G.; Durante, S. Superimposition of ground reaction force on tibial-plateau supporting diagnostics and post-operative evaluations in high-tibial osteotomy. A novel methodology. *Gait Posture* **2022**, *94*, 144–152. [CrossRef]
16. Mansfield, C.; Rethman, K.; Stephens, J.; Di Stasi, S.; Vanetten, L.; Briggs, M. The association and reliability of the frontal plane projection angle during the lateral step down test on knee function in patients with patellofemoral pain. *Knee* **2022**, *36*, 87–96. [CrossRef]
17. Leardini, A.; Sawacha, Z.; Paolini, G.; Ingrosso, S.; Nativo, R.; Benedetti, M.G. A new anatomically based protocol for gait analysis in children. *Gait Posture* **2007**, *26*, 560–571. [CrossRef]
18. Ferrari, A.; Benedetti, M.G.; Pavan, E.; Frigo, C.; Bettinelli, D.; Rabuffetti, M.; Crenna, P.; Leardini, A. Quantitative comparison of five current protocols in gait analysis. *Gait Posture* **2008**, *28*, 207–216. [CrossRef]
19. Tricco, A.C.; Lillie, E.; Zarin, W.; O'Brien, K.K.; Colquhoun, H.; Levac, D.; Moher, D.; Peters, M.D.J.; Horsley, T.; Weeks, L.; et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Ann. Intern. Med.* **2018**, *169*, 467–473. [CrossRef]
20. Crossley, K.M.; van Middelkoop, M.; Callaghan, M.J.; Collins, N.J.; Rathleff, M.S.; Barton, C.J. 2016 Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 2: Recommended physical interventions (exercise, taping, bracing, foot orthoses and combined interventions). *Br. J. Sports Med.* **2016**, *50*, 844–852. [CrossRef]
21. Bramer, W.M.; Giustini, D.; de Jonge, G.B.; Holland, L.; Bekhuis, T. De-duplication of database search results for systematic reviews in EndNote. *J. Med. Libr. Assoc. JMLA* **2016**, *104*, 240. [CrossRef]
22. Ouzzani, M.; Hammady, H.; Fedorowicz, Z.; Elmagarmid, A. Rayyan—A web and mobile app for systematic reviews. *Syst. Rev.* **2016**, *5*, 210. [CrossRef] [PubMed]
23. Yang, J.-S.; Fredericson, M.; Choi, J.-H. The effect of patellofemoral pain syndrome on patellofemoral joint kinematics under upright weight-bearing conditions. *PLoS ONE* **2020**, *15*, e0239907. [CrossRef] [PubMed]
24. Pal, S.; Choi, J.H.; Delp, S.L.; Fredericson, M. Botulinum neurotoxin type A improves vasti muscle balance, patellar tracking, and pain in patients with chronic patellofemoral pain. *J. Orthop. Res.* **2023**, *41*, 962–972. [CrossRef] [PubMed]
25. Leal, A.; Andrade, R.; Hinckel, B.; Tompkins, M.; Bastos, R.; Flores, P.; Samuel, F.; Espregueira-Mendes, J.; Arendt, E. Patients with different patellofemoral disorders display a distinct ligament stiffness pattern under instrumented stress testing. *J. ISAKOS* **2020**, *5*, 74–79. [CrossRef]

26. Leal, A.; Andrade, R.; Hinckel, B.B.; Tompkins, M.; Flores, P.; Silva, F.; Espregueira-Mendes, J.; Arendt, E. A new device for patellofemoral instrumented stress-testing provides good reliability and validity. *Knee Surg. Sports Traumatol. Arthrosc.* **2020**, *28*, 389–397. [CrossRef]
27. Gallina, A.; Hunt, M.A.; Hodges, P.W.; Garland, S.J. Vastus lateralis motor unit firing rate is higher in women with patellofemoral pain. *Arch. Phys. Med. Rehabil.* **2018**, *99*, 907–913. [CrossRef]
28. Gallina, A.; Wakeling, J.M.; Hodges, P.W.; Hunt, M.A.; Jayne Garland, S. Regional vastus medialis and vastus lateralis activation in females with patellofemoral pain. *Med. Sci. Sports Exerc.* **2019**, *51*, 411–420. [CrossRef]
29. Federer, S.J.; Jones, G.G. Artificial intelligence in orthopaedics: A scoping review. *PLoS ONE* **2021**, *16*, e0260471. [CrossRef]
30. Bazett-Jones, D.M.; Neal, B.S.; Legg, C.; Hart, H.F.; Collins, N.J.; Barton, C.J. Kinematic and kinetic gait characteristics in people with Patellofemoral Pain: A systematic review and Meta-analysis. *Sports Med.* **2023**, *53*, 519–547. [CrossRef]
31. Powers, C.M.; Witvrouw, E.; Davis, I.S.; Crossley, K.M. Evidence-based framework for a pathomechanical model of patellofemoral pain: 2017 patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester, UK: Part 3. *Br. J. Sports Med.* **2017**, *51*, 1713–1723. [CrossRef]
32. Merican, A.M.; Amis, A.A. Iliotibial band tension affects patellofemoral and tibiofemoral kinematics. *J. Biomech.* **2009**, *42*, 1539–1546. [CrossRef] [PubMed]
33. Lorenz, A.; Müller, O.; Kohler, P.; Wünschel, M.; Wülker, N.; Leichtle, U.G. The influence of asymmetric quadriceps loading on patellar tracking—An in vitro study. *Knee* **2012**, *19*, 818–822. [CrossRef] [PubMed]
34. Belvedere, C.; Leardini, A.; Ensini, A.; Bianchi, L.; Catani, F.; Giannini, S. Three-dimensional patellar motion at the natural knee during passive flexion/extension. An in vitro study. *J. Orthop. Res.* **2009**, *27*, 1426–1431. [CrossRef] [PubMed]
35. Belvedere, C.; Ensini, A.; Leardini, A.; Dedda, V.; Feliciangeli, A.; Cenni, F.; Timoncini, A.; Barbadoro, P.; Giannini, S. Tibio-femoral and patello-femoral joint kinematics during navigated total knee arthroplasty with patellar resurfacing. *Knee Surg. Sports Traumatol. Arthrosc.* **2014**, *22*, 1719–1727. [CrossRef] [PubMed]
36. Belvedere, C.; Ensini, A.; Tamarri, S.; d'Amato, M.; Barbadoro, P.; Feliciangeli, A.; Rao, A.; Leardini, A. Does navigated patellar resurfacing in total knee arthroplasty result in proper bone cut, motion and clinical outcomes? *Clin. Biomech.* **2019**, *69*, 168–177. [CrossRef] [PubMed]
37. Belvedere, C.; Tamarri, S.; Ensini, A.; Durante, S.; Ortolani, M.; Leardini, A. Can Computer-Assisted Total Knee Arthroplasty Support the Prediction of Postoperative Three-Dimensional Kinematics of the Tibiofemoral and Patellofemoral Joints at the Replaced Knee? *J. Knee Surg.* **2021**, *34*, 1014–1025. [CrossRef] [PubMed]
38. Bley, A.S.; Correa, J.C.F.; Reis, A.C.D.; Rabelo, N.D.D.A.; Marchetti, P.H.; Lucareli, P.R.G. Propulsion phase of the single leg triple hop test in women with patellofemoral pain syndrome: A biomechanical study. *PLoS ONE* **2014**, *9*, e97606. [CrossRef]
39. Dos Reis, A.C.; Correa, J.C.F.; Bley, A.S.; Rabelo, N.D.d.A.; Fukuda, T.Y.; Lucareli, P.R.G. Kinematic and kinetic analysis of the single-leg triple hop test in women with and without patellofemoral pain. *J. Orthop. Sports Phys. Ther.* **2015**, *45*, 799–807. [CrossRef]
40. Ferreira, A.S.; de Oliveira Silva, D.; Briani, R.V.; Ferrari, D.; Aragão, F.A.; Pazzinatto, M.F.; de Azevedo, F.M. Which is the best predictor of excessive hip internal rotation in women with patellofemoral pain: Rearfoot eversion or hip muscle strength? Exploring subgroups. *Gait Posture* **2018**, *62*, 366–371. [CrossRef]
41. Kalytczak, M.M.; Lucareli, P.R.G.; Dos Reis, A.C.; Bley, A.S.; Biasotto-Gonzalez, D.A.; Correa, J.C.F.; Politti, F. Kinematic and electromyographic analysis in patients with patellofemoral pain syndrome during single leg triple hop test. *Gait Posture* **2016**, *49*, 246–251. [CrossRef]
42. Kalytczak, M.M.; Lucareli, P.R.G.; Dos Reis, A.C.; Bley, A.S.; Biasotto-Gonzalez, D.A.; Correa, J.C.F.; Politti, F. Female PFP patients present alterations in eccentric muscle activity but not the temporal order of activation of the vastus lateralis muscle during the single leg triple hop test. *Gait Posture* **2018**, *62*, 445–450. [CrossRef] [PubMed]
43. de Almeida Novello, A.; Garbelotti, S., Jr.; dos Anjos Rabelo, N.D.; Ferraz, A.N.; Bley, A.S.; Correa, J.C.F.; Politti, F.; Lucareli, P.R.G. Descending stairs: Good or bad task to discriminate women with patellofemoral pain? *Gait Posture* **2018**, *65*, 26–32. [CrossRef] [PubMed]
44. Sayer, T.; Hinman, R.; Paterson, K.; Bennell, K.; Fortin, K.; Timmi, A.; Pivonka, P.; Bryant, A. Differences in hip and knee landing moments across female pubertal development. *Med. Sci. Sports Exerc.* **2019**, *51*, 123–131. [CrossRef] [PubMed]
45. Sayer, T.A.; Hinman, R.S.; Paterson, K.L.; Bennell, K.L.; Fortin, K.; Kasza, J.; Bryant, A.L. Differences and mechanisms underpinning a change in the knee flexion moment while running in stability and neutral footwear among young females. *J. Foot Ankle Res.* **2019**, *12*, 1. [CrossRef] [PubMed]
46. Thomas, S.; Rupiper, D.; Stacy, G.S. Imaging of the patellofemoral joint. *Clin. Sports Med.* **2014**, *33*, 413–436. [CrossRef]
47. Demehri, S.; Thawait, G.K.; Williams, A.A.; Kompel, A.; Elias, J.J.; Carrino, J.A.; Cosgarea, A.J. Imaging characteristics of contralateral asymptomatic patellofemoral joints in patients with unilateral instability. *Radiology* **2014**, *273*, 821–830. [CrossRef]
48. Mariani, S.; La Marra, A.; Arrigoni, F.; Necozione, S.; Splendiani, A.; Di Cesare, E.; Barile, A.; Masciocchi, C. Dynamic measurement of patello-femoral joint alignment using weight-bearing magnetic resonance imaging (WB-MRI). *Eur. J. Radiol.* **2015**, *84*, 2571–2578. [CrossRef]
49. Tanaka, M.J.; Elias, J.J.; Williams, A.A.; Demehri, S.; Cosgarea, A.J. Characterization of patellar maltracking using dynamic kinematic CT imaging in patients with patellar instability. *Knee Surg. Sports Traumatol. Arthrosc.* **2016**, *24*, 3634–3641. [CrossRef]

50. Barg, A.; Bailey, T.; Richter, M.; de Cesar Netto, C.; Lintz, F.; Burssens, A.; Phisitkul, P.; Hanrahan, C.J.; Saltzman, C.L. Weightbearing computed tomography of the foot and ankle: Emerging technology topical review. *Foot Ankle Int.* **2018**, *39*, 376–386. [CrossRef]
51. Bailey, J.; Solan, M.; Moore, E. Cone-beam computed tomography in orthopaedics. *Orthop. Trauma* **2022**, *36*, 194–201. [CrossRef]
52. Richter, M.; Lintz, F.; de Cesar Netto, C.; Barg, A.; Burssens, A. Results of more than 11,000 scans with weightbearing CT—Impact on costs, radiation exposure, and procedure time. *Foot Ankle Surg.* **2020**, *26*, 518–522. [CrossRef] [PubMed]
53. Leal, A.; Pereira, R.; Pereira, H.; Flores, P.; Silva, F.S.; Espregueira-Mendes, J. Design of a new medical device for aiding clinical diagnosis of patellofemoral disorders. In *New Trends in Mechanism and Machine Science: From Fundamentals to Industrial Applications*; Springer International Publishing: Cham, Switzerland, 2015; pp. 633–641.
54. Mountney, J.; Senavongse, W.; Amis, A.; Thomas, N. Tensile strength of the medial patellofemoral ligament before and after repair or reconstruction. *J. Bone Jt. Surg. Br. Vol.* **2005**, *87*, 36–40. [CrossRef]
55. Leal, A.; Andrade, R.; Flores, P.; Silva, F.S.; Fulkerson, J.; Neyret, P.; Arendt, E.; Espregueira-Mendes, J. Unilateral anterior knee pain is associated with increased patellar lateral position after stressed lateral translation. *Knee Surg. Sports Traumatol. Arthrosc.* **2020**, *28*, 454–462. [CrossRef]
56. Martinez-Valdes, E.; Laine, C.; Falla, D.; Mayer, F.; Farina, D. High-density surface electromyography provides reliable estimates of motor unit behavior. *Clin. Neurophysiol.* **2016**, *127*, 2534–2541. [CrossRef] [PubMed]
57. Falla, D.; Gallina, A. New insights into pain-related changes in muscle activation revealed by high-density surface electromyography. *J. Electromyogr. Kinesiol.* **2020**, *52*, 102422. [CrossRef]
58. Gallina, A.; Garland, S.J.; Wakeling, J.M. Identification of regional activation by factorization of high-density surface EMG signals: A comparison of Principal Component Analysis and Non-negative Matrix factorization. *J. Electromyogr. Kinesiol.* **2018**, *41*, 116–123. [CrossRef]
59. Drost, G.; Stegeman, D.F.; van Engelen, B.G.; Zwarts, M.J. Clinical applications of high-density surface EMG: A systematic review. *J. Electromyogr. Kinesiol.* **2006**, *16*, 586–602. [CrossRef]
60. Cheng, R.; Crouzier, M.; Hug, F.; Tucker, K.; Juneau, P.; McCreedy, E.; Gandler, W.; McAuliffe, M.J.; Sheehan, F.T. Automatic quadriceps and patellae segmentation of MRI with cascaded U2-Net and SASSNet deep learning model. *Med. Phys.* **2022**, *49*, 443–460. [CrossRef]
61. Yao, J.; Yang, B.; Niu, W.; Zhou, J.; Wang, Y.; Gong, H.; Ma, H.; Tan, R.; Fan, Y. In vivo measurements of patellar tracking and finite helical axis using a static magnetic resonance based methodology. *Med. Eng. Phys.* **2014**, *36*, 1611–1617. [CrossRef]
62. Robert, B.; Boulanger, P. Automatic Bone Segmentation from MRI for Real-Time Knee Tracking in Fluoroscopic Imaging. *Diagnostics* **2022**, *12*, 2228. [CrossRef]
63. Reddy, S.; Fox, J.; Purohit, M.P. Artificial intelligence-enabled healthcare delivery. *J. R. Soc. Med.* **2019**, *112*, 22–28. [CrossRef] [PubMed]
64. Bisson, L.J.; Komm, J.T.; Bernas, G.A.; Fineberg, M.S.; Marzo, J.M.; Rauh, M.A.; Smolinski, R.J.; Wind, W.M. How accurate are patients at diagnosing the cause of their knee pain with the help of a web-based symptom checker? *Orthop. J. Sports Med.* **2016**, *4*, 2325967116630286. [CrossRef] [PubMed]
65. Dagneaux, L.; Allal, R.; Pithioux, M.; Chabrand, P.; Ollivier, M.; Argenson, J.-N. Femoral malrotation from diaphyseal fractures results in changes in patellofemoral alignment and higher patellofemoral stress from a finite element model study. *Knee* **2018**, *25*, 807–813. [CrossRef] [PubMed]
66. Ho, K.-Y.; Keyak, J.H.; Powers, C.M. Comparison of patella bone strain between females with and without patellofemoral pain: A finite element analysis study. *J. Biomech.* **2014**, *47*, 230–236. [CrossRef]
67. Islam, K.; Duke, K.; Mustafy, T.; Adeeb, S.M.; Ronsky, J.L.; El-Rich, M. A geometric approach to study the contact mechanisms in the patellofemoral joint of normal versus patellofemoral pain syndrome subjects. *Comput. Methods Biomech. Biomed. Eng.* **2015**, *18*, 391–400. [CrossRef]
68. Liao, T.-C.; Keyak, J.H.; Powers, C.M. Runners with patellofemoral pain exhibit greater peak patella cartilage stress compared with pain-free runners. *J. Appl. Biomech.* **2018**, *34*, 298–305. [CrossRef]
69. Liao, T.-C.; Powers, C.M. Tibiofemoral kinematics in the transverse and frontal planes influence the location and magnitude of peak patella cartilage stress: An investigation of runners with and without patellofemoral pain. *Clin. Biomech.* **2019**, *62*, 72–78. [CrossRef]
70. Liao, T.-C.; Yang, N.; Ho, K.-Y.; Farrokhi, S.; Powers, C.M. Femur Rotation Increases Patella Cartilage Stress in Females with Patellofemoral Pain. *Med. Sci. Sports Exerc.* **2015**, *47*, 1775–1780. [CrossRef]
71. Pal, S.; Besier, T.F.; Gold, G.E.; Fredericson, M.; Delp, S.L.; Beaupre, G.S. Patellofemoral cartilage stresses are most sensitive to variations in vastus medialis muscle forces. *Comput. Methods Biomech. Biomed. Eng.* **2019**, *22*, 206–216. [CrossRef]
72. Graf, E.S.; Stefanyshyn, D. The effect of shoe torsional stiffness on lower extremity kinematics and biomechanical risk factors for patellofemoral pain syndrome during running. *Footwear Sci.* **2012**, *4*, 199–206. [CrossRef]
73. Diekfuss, J.A.; Grooms, D.R.; Nissen, K.S.; Coghill, R.C.; Bonnette, S.; Barber Foss, K.D.; Dudley, J.A.; Berz, K.; Logan, K.; Gubanich, P. Does central nervous system dysfunction underlie patellofemoral pain in young females? Examining brain functional connectivity in association with patient-reported outcomes. *J. Orthop. Res.* **2022**, *40*, 1083–1096. [CrossRef] [PubMed]
74. Ho, K.-Y.; Liang, J.N.; Budge, S.; Madriaga, A.; Meske, K.; Nguyenton, D. Brain and Spinal Cord Adaptations Associated with Patellofemoral Pain: A Systematic Review and Meta-Analysis. *Front. Integr. Neurosci.* **2022**, *16*, 4. [CrossRef] [PubMed]

75. Foss, K.D.B.; Slutsky-Ganesh, A.B.; Diekfuss, J.A.; Grooms, D.R.; Simon, J.E.; Schneider, D.K.; Jayanthi, N.; Lamplot, J.D.; Hill, D.; Pombo, M. Brain Activity During Experimental Knee Pain and Its Relationship with Kinesiophobia in Patients With Patellofemoral Pain: A Preliminary Functional Magnetic Resonance Imaging Investigation. *J. Sport Rehabil.* **2022**, *31*, 589–598.
76. Callaghan, M.J.; McKie, S.; Richardson, P.; Oldham, J.A. Effects of patellar taping on brain activity during knee joint proprioception tests using functional magnetic resonance imaging. *Phys. Ther.* **2012**, *92*, 821–830. [CrossRef] [PubMed]
77. Pattyn, E.; Verdonk, P.; Steyaert, A.; Van Tiggelen, D.; Witvrouw, E. Muscle functional MRI to evaluate quadriceps dysfunction in patellofemoral pain. *Med. Sci. Sports Exerc.* **2013**, *45*, 1023–1029. [CrossRef]
78. Slutsky-Ganesh, A.B.; Diekfuss, J.A.; Grooms, D.R.; Simon, J.E.; Anand, M.; Lamplot, J.D.; Jayanthi, N.; Wong, P.K.; Lyle, M.A.; Myer, G.D. A preliminary investigation of the effects of patellar displacement on brain activation and perceived pain in young females with patellofemoral pain. *J. Sci. Med. Sport* **2022**, *25*, 385–390. [CrossRef]
79. Te, M.; Baptista, A.F.; Chipchase, L.S.; Schabrun, S.M. Primary motor cortex organization is altered in persistent patellofemoral pain. *Pain Med.* **2017**, *18*, 2224–2234. [CrossRef]
80. Ebrahimi, N.; Rojhani-Shirazi, Z.; Yoosefinejad, A.K.; Nami, M. The effects of virtual reality training on clinical indices and brain mapping of women with patellofemoral pain: A randomized clinical trial. *BMC Musculoskelet. Disord.* **2021**, *22*, 900. [CrossRef]
81. Vicenzino, B.T.; Rathleff, M.S.; Holden, S.; Maclachlan, L.; Smith, B.E.; de Oliveira Silva, D.; van Middelkoop, M.; Group, P.C.; Collaborators, I.G. Developing clinical and research priorities for pain and psychological features in people with patellofemoral pain: An international consensus process with health care professionals. *J. Orthop. Sports Phys. Ther.* **2022**, *52*, 29–39. [CrossRef]
82. Botanlioglu, H.; Kantarci, F.; Kaynak, G.; Unal, Y.; Ertan, S.; Aydingoz, O.; Erginer, R.; Unlu, M.C.; Mihmanli, I.; Babacan, M. Shear wave elastography properties of vastus lateralis and vastus medialis obliquus muscles in normal subjects and female patients with patellofemoral pain syndrome. *Skelet. Radiol.* **2013**, *42*, 659–666. [CrossRef]
83. Engelina, S.; Robertson, C.J.; Moggridge, J.; Killingback, A.; Adds, P. Using ultrasound to measure the fibre angle of vastus medialis oblique: A cadaveric validation study. *Knee* **2014**, *21*, 107–111. [CrossRef] [PubMed]
84. Jeon, H.; Donovan, L.; Thomas, A.C. Exercise-Induced Changes in Femoral Cartilage Thickness in Patients with Patellofemoral Pain. *J. Athl. Train.* **2023**, *58*, 128–135. [CrossRef] [PubMed]
85. Sjoerdsma, M.; Caresio, C.; Tchang, B.; Meeder, A.; van de Vosse, F.; Lopata, R. The feasibility of dynamic musculoskeletal function analysis of the vastus lateralis in endurance runners using continuous, hands-free ultrasound. *Appl. Sci.* **2021**, *11*, 1534. [CrossRef]
86. Shark, L.-K.; Chen, H.; Quan, W.; Goodacre, J. Acoustic emission and angular movement variations from early adulthood healthy knees to late adulthood osteoarthritic knees. In Proceedings of the 2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Orlando, FL, USA, 16–20 August 2016; pp. 2382–2385.
87. Schlüter, D.K.; Spain, L.; Quan, W.; Southworth, H.; Platt, N.; Mercer, J.; Shark, L.-K.; Waterton, J.C.; Bowes, M.; Diggle, P.J. Use of acoustic emission to identify novel candidate biomarkers for knee osteoarthritis (OA). *PLoS ONE* **2019**, *14*, e0223711. [CrossRef]
88. Ozmen, G.C.; Safaei, M.; Lan, L.; Inan, O.T. A novel accelerometer mounting method for sensing performance improvement in acoustic measurements from the knee. *J. Vib. Acoust.* **2021**, *143*, 031006. [CrossRef]
89. Scherpereel, K.L.; Bolus, N.B.; Jeong, H.K.; Inan, O.T.; Young, A.J. Estimating knee joint load using acoustic emissions during ambulation. *Ann. Biomed. Eng.* **2021**, *49*, 1000–1011. [CrossRef]
90. López-de-Celis, C.; Pérez-Bellmunt, A.; Bueno-Gracia, E.; Fanlo-Mazas, P.; Zárate-Tejero, C.A.; Llurda-Almuzara, L.; Cadellans Arróniz, A.; Rodriguez-Rubio, P.R. Effect of diacutaneous fibrolysis on the muscular properties of gastrocnemius muscle. *PLoS ONE* **2020**, *15*, e0243225. [CrossRef]
91. Alentorn-Geli, E.; Alvarez-Diaz, P.; Ramon, S.; Marin, M.; Steinbacher, G.; Boffa, J.J.; Cuscó, X.; Ballester, J.; Cugat, R. Assessment of neuromuscular risk factors for anterior cruciate ligament injury through tensiomyography in male soccer players. *Knee Surg. Sports Traumatol. Arthrosc.* **2015**, *23*, 2508–2513. [CrossRef]
92. Zeinalzadeh, A.; Nazary-Moghadam, S.; Hoseinian, S.H.S.; Ebrahimzadeh, M.H.; Imani, E.; Karimpour, S. Intra-and Inter-Session Reliability of Methods for Measuring Reaction Time in Participants with and without Patellofemoral Pain Syndrome. *Arch. Bone Jt. Surg.* **2021**, *9*, 102.
93. Nazary-Moghadam, S.; Imani, E.; Hosseinian, S.H.S.; Zeinalzadeh, A.; Karimpour, S.; Negahban, H. Visuomotor reaction time difference between patellofemoral pain syndrome and healthy individuals: Cross-sectional study. *J. Bodyw. Mov. Ther.* **2021**, *27*, 274–280. [CrossRef]
94. Lafortune, M.A.; Lake, M.J.; Hennig, E. Transfer function between tibial acceleration and ground reaction force. *J. Biomech.* **1995**, *28*, 113–117. [CrossRef] [PubMed]
95. Raper, D.P.; Witchalls, J.; Philips, E.J.; Knight, E.; Drew, M.K.; Waddington, G. Use of a tibial accelerometer to measure ground reaction force in running: A reliability and validity comparison with force plates. *J. Sci. Med. Sport* **2018**, *21*, 84–88. [CrossRef] [PubMed]

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