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Review

How proprioception changes before and after total knee arthroplasty: A systematic review

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ABSTRACT

Background: Proprioception is one of the most significant factors in balance, joint stability, graceful movement, coordination, and injury prevention. It involves a wide set of receptors located within joints, muscles, and tendons. Given the neurophysiological processes involved in proprioception response are multiple and complex, there is not one single method to measure it. Particularly, proprioception of the knee joint, whether it is healthy, affected by osteoarthritis, or after replacement, is the most investigated by in literature.
Research question: This review addresses the analysis of proprioception in the knee joint before and after total knee arthroplasty (TKA). The aim is to obtain an overview of the proprioceptive skills in subjects who suffered from osteoarthritis and were subjected to knee replacement, evaluating changes in proprioception before and after the surgery.
Methods: The research was conducted within four databases: Web of Science®, PubMed Central®, Cochrane®, and PEDro®, between January 2008 and February 2018. Accurate exclusion criteria and selection strategy were applied to screen the 170 articles found.
Results: Ultimately, 13 papers were fully evaluated and included in this review, divided into two classes: i) works directly measuring proprioception, ii) studies indirectly evaluating proprioception. Contrasting results emerged from the analysis, and no consensus was found in the literature about the improvement or worsening in proprioception before and after TKA.
Significance: Since currently there is high variability in methods, protocol and parameters used to evaluate knee proprioception, further investigations based on a consistent dataset, a well-defined protocol, measurable outcomes, timeline follow-ups, and rehabilitation programs should be performed in order to obtain reliable results on the effects of TKA on knee proprioception and balance.

1. Introduction

Deriving from the combination of the Latin words “proprius” (*i.e.*, “one’s own,”) and “percipere” (*i.e.*, “to collect information”), the proprioception concept includes both the ideas to have a sense of body orientation and position, and a sense of body and limb motion [1]. Generally, proprioception is defined as the ability to sense the position of a joint in space [2].

Proprioception can be divided into two key aspects of joint homeostasis: joint position sense, and joint kinaesthesia, which are the static and the dynamic sense of movement, respectively. [3]. The definition of proprioception, however, is controversial and some authors added a third key aspect which is the sensation of force [4].

Proprioception is one of the most significant factors in balance, joint stability, graceful movement, coordination and injury prevention. [5]. It involves a wide set of receptors located within joints, muscles (*e.g.*, spindle muscles related to changes in muscle length), and tendons (*e.g.*, Golgi tendon receptors sense changes in muscle tension). These mechanisms/structures play a fundamental role in providing information on muscle dynamics to the central nervous system [6].

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Since the neurophysiological processes that are involved in proprioception response are multiple and complex, there is not a single method to measure it. Summarizing the most common protocols to evaluate knee proprioception in clinical settings [1,7,8], proprioception can be evaluated as:

- Passive joint position detection (PJPD), or joint position sense (JPS): the subject has to recognize an established position when reproduced passively.
- Active joint position detection (AJPD), or joint position reproduction (JPR): the subject has to actively reproduce an established position.

These are types of static proprioception, where the difference between a target angle set by the clinician and a reproduced knee angle performed by the patient is measured as an error angle [8]. Analogously, dynamic proprioception can be assessed through the following tests:

- Passive motion detection threshold (PMDT): the subject has to detect a minimum threshold at which he can identify a moving state from the stationary position.
- Passive motion direction discrimination (PMDD): the subject has to discriminate between different movement directions and one or more axes of rotation.
- Active movement extent discrimination assessment (AMEDA): the participant has to perform and to distinguish between different preset active flexion positions.

Although a broad variation in the literature on adopted methods, tested joints and sampled populations was identified, the most commonly used protocols were AJPD or PJPD, followed by PMDT and PMDD [1].

Furthermore, a distinction between direct measures and indirect measures can be proposed. While direct measures are generally based on one of the abovementioned protocols, indirect measures can be derived from instrumental assessment, such as force platforms or other rehabilitation devices for static or dynamic postural stability assessments

1.1. proprioception in OSTEOARTHRITIS knee and total knee ARTHROPLASTY

The knee resulted in the most investigated joint for proprioception assessment [1]. Joint position sense declines with age in healthy subjects [9] and further deteriorates when knee osteoarthritis (OA) occurs [10]. Proprioception resulted impaired in established OA, while no difference was found between early OA and age-matched control subjects, in terms of repositioning error of knee position sense [11]. Reduced proprioception in elderly and OA subjects may be even responsible for the initiation or advancement of knee degeneration [9].

When subjects present advanced OA, generally unresponsive to pharmacological treatments, the total knee replacement (TKR), or total knee arthroplasty (TKA), is the surgical procedure considered as the gold standard [12]. The surgical option aims to alleviate pain, correct the deformities, restore the ROM and locomotor function, provide a rapid and substantial reduction of pain [13–15] and increase patient satisfaction. Reduction of pain, which is the main aim of TKA, was also taken into account among studies because a decrease of pain contributes to increasing postural control and stability, as proved by the improved results of sensorimotor control test (SCT) during follow-up visit [16,17].

Nevertheless, controversial results were reported in literature about the effect of this type of surgery. Even if OA has already altered proprioception abilities, the TKA procedure can further affect proprioceptors [18]. Some studies demonstrated that TKA slightly improved knee JPS, kinaesthesia, and balance [9,19]. Conversely, other researchers did not observe any improvement at all [17,20]. It is worthy to point out that the type of used prosthesis also affects proprioceptive capacity. In fact, if it is true that intracapsular mechanoreceptors in the native articulation, present in structures such as LCA and meniscus, are fundamental to provide proprioceptive information, it is also true that these tissues are usually sacrificed during total knee arthroplasty surgery with the possibility of compromising post-operative proprioception.

Among studies that found positive results by performing TKA, findings are contrasting between the retention or the sacrifice of the posterior cruciate ligament (PCL). According to Rajgopal et al. [21], PCL in TKA seemed to be a good option for better kinematics, stability, and proprioception. Posterior cruciate ligament retaining designs have been in fact postulated to be advantageous to patients, and contributes to a more normal gait and “feel” of the knee after total knee arthroplasty based on its neurosensory properties [19].

Moreover, even the mode in which the surgery is performed seems to significantly affect the postoperative proprioceptive recovery. It has been reported that the dynamic equilibrium is better in the case of minimally invasive implant techniques (with a surgical navigator) compared to conventional techniques [22].

Finally, the rehabilitation program also influences considerably the post-operative result to reacquire the lost autonomy. As always, only an optimal collaboration between surgery and subsequent rehabilitation can guarantee excellent results from the point of view of the recovery of movement function and resolution of the pain.

1.2. Aim

This review paper aims to provide an overview of the proprioceptive skills in subjects who suffered from knee OA and were subjected to TKR, evaluating proprioception before and after the surgical procedure. In particular, this paper provides a review of the methods currently applied to evaluate proprioceptive abilities related both to knee OA and TKR, and the main parameters measured to quantitatively assess such abilities. Since proprioception is a complex concept with different aspects, the following paper also analyses and discusses both studies about the direct measurement of proprioception, as well as studies that provide an indirect measure of it focusing on balance assessment.

2. Material and methods

2.1. Data sources

An electronic database search was performed on March 1, 2018, using Web of Science®, PubMed Central®, Cochrane®, and PEDro® databases to identify articles concerning the assessment of proprioception in people that underwent TKA due to OA. According to the PRISMA statement [23], an additional manual search was performed, however no work resulted relevant for inclusion in this paper.

2.2. Search terms

The terms and keywords used for the literature research were ('*Propriocept**') AND ('*total knee arthroplasty*' OR '*TKA*' OR '*TKR*') located within the title and/or abstract and/or keywords. The authors used the wildcard character * mainly to include in the research both the terms *proprioceptive*, *proprioception*, and *proprioceptors*.

Table 1
Papers in which proprioception is directly assessed.

Ref.	AIM	Participants	Instruments	Outcomes	Protocol	Results / Findings
[16]	To assess the impact of joint degeneration due to advanced gonarthrosis and the effect of arthroplasty on proprioception and sensorimotor system performance of the knee	62 AG (68.8y ± 7.4y), 74 CG (67.5y ± 6.6y).AG evaluations: pre-surgery (PRE), 8 days post-surgery (P1), 100 days (P2) post-surgery both in operated and healthy limb (HL).	BOSCH DWM-40 L digital protractor, Saunders' digital inclinometer	6-point Likert scale (0-5) to evaluate Sensorimotor Control Test (SCT); degrees to reach the target position for Joint Position Sense (JPS)	Patient sitting on a high couch. SCT: the knee and hip in 90º flexion, the foot of the examined limb rested on a rubber exercise ball (75 cm diameter). The patient had to keep the ball under the foot. The examiner pushed on the ball in different directions (30 s). JPS: the starting position of the knee was 45º flexion and the test was performed as an open kinetic chain, with the patient's eyes closed. TASK: to place the knee in a requested position after several free movements of the joint.	SCT: CG = 4.9, PRE = 3.1, P1 = 2.9, P2 = 4.5. Significant differences ($p < 0.001$) in SCT between: CG/PRE, CG/P1, CG/P2 ($p = 0.015$), PRE/P2, P1/P2. JPS: CG = 3.9° ± 2.9°, AG_HL = 8.1° ± 5.7°, PRE = 10.5° ± 7.7°, P1 = 9.5° ± 6.0°, P2 = 3.9° ± 3.1°. Significant differences ($p < 0.001$) in JPS between: CG/AG_HL, CG/PRE, CG/P1, PRE/AG_HL ($p = 0.023$), P2/ AG_HL, PRE/P2, P1/P2. Proprioception deficits in AG compared to CG. Patients at P2: improved JPS, range of extension, SCT scores, reduced pain.
[32]	To compare post-operative quadriceps and hamstring muscle strength, position sense, and physical performance in patients who underwent either BKA or TKA.	11 OA patients (15 knees) who received BKA (54.8y ± 5.6y); 13 OA patients (16 knees) who received TKA (65.7y ± 6.7y); 10 CG for BKA (57.7y ± 3.6y); 10 CG for TKA (67.3y ± 5.0y). Evaluations: pre-TKA (PRE), 6 months post, 12 months post (POST)	Isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA).	Isokinetic knee muscle strength, knee position sense (as degrees from the target position), physical performance	Assessment in open kinetic chain as JPR. After seating the patient on a dynamometer the examiner maintained the target knee angle of the patient for 5 s each (3 times). Then, the knee was moved back to the starting position. TASK: to reproduce the target angle from the starting position and stop at the angle believed to be the target one. Several angular settings with different starting and target positions (0°–60°, 30°–60°, 90°–30°, and 90°–60°), were established	Proprioception results (mean ± SD in deg): [0°–60°] PRE 4.6 ± 3.2; post-TKA 3.9 ± 3.4; CG 3.0 ± 1.9. [30°–60°] PRE 2.6 ± 2.4, post-TKA 4.4 ± 4.7, CG 3.6 ± 1.6. [90°–30°] PRE 6.6 ± 7.6, post-TKA 3.9 ± 2.9, CG 3.0 ± 1.8. [90°–60°] PRE 4.7 ± 3.5, post-TKA 4.6 ± 4.7, CG 2.4 ± 1.6. No significant differences among PRE/POST/and CG.
[28]	To investigate the falls risk and the occurrence of falls in knee OA people before/following KR	35 AG (67.4 ± 7.3 y). Evaluations: before surgery (PRE), and 12 months post-surgery (POST)	Not specified	Self-administered Assessment of QoL (AQoL); Western Ontario and McMaster Universities Osteoarthritis (WOMAC); Incidental and Planned Activity Questionnaire (IPAQ); Short Falls Efficacy Scale International (FES-I); number of falls; PPA included proprioception	Proprioception measured during sitting by matching the position of the legs on either side of a clear plastic sheet with the eyes closed. Any error in matching the limbs was recorded in degrees. 2 practice trials and 5 recorded trials.	Proprioception results (mean ± SD in deg): PRE 1.8 ± 1.0; POST 1.8 ± 1.0. No significant differences PRE/POST
[33]	To assess balance, strength, vision, proprioception, fear of falls, QoL, and physical activity in knee OA people before/after KR, comparing to CG	35 AG (67 ± 7y, 45-81y); 27 CG (65 ± 11y, 48-86y). Evaluations: before surgery (PRE), and 4 months post-surgery (POST)	Not specified	AQoL; WOMAC; IPAQ; FES-I; PPA (risk of fall included proprioception)	Proprioception measured during sitting by matching the position of the legs on either side of a clear plastic sheet with the eyes closed. Any error in matching the limbs was recorded in degrees. 2 practice trials and 5 recorded trials.	Proprioception results (mean ± SD, range in deg): AG PRE 1.8 ± 1.0, 0.4–4; AG POST 1.8 ± 1.1, 0.2–4.8; CG 1.3 ± 1.3, 0.2–5. Significant differences between AG/CG both in PRE and in POST. No significant differences PRE/POST within AG.

Table 2
Papers in which proprioception is indirectly assessed.

Ref	AIM	Participants	Instruments	Outcomes	Protocol	Results / Findings
[34]	To evaluate knee stability through novel index of knee joint stability (IKJS)	57 (55f-2 m, aged 42–70y, mean age 58.5 ± 6.1y) CG; 153 patients (aged 53–93y, averaged 68.8 ± 7.1y) who were going to receive TKA (PRE); 55 patients (aged 53–83, averaged 69.4 ± 5.7 years) who received TKA participated in the experiment group 2 weeks after surgery (POST). 27 patients were evaluated both PRE and POST (AG).	system with laser fixed to the leg, target and camera	IKJS	Knee-aiming task: to focus and keep aiming at the target by using the laser pointer on his leg for 60 s.	IKJS resulted in: significant difference between PRE/POST in operated leg in 27 AG. Significant differences among PRE/POST/CG: POST showed higher knee stability than PRE and closer to CG values. IKJS is feasible in quantitatively depicting knee stability (Good repeatability ICC = 0.8 assessed on 12 healthy volunteers).
[22]	To specify the dynamic balancing ability in response to sudden unidirectional perturbation following different surgical techniques during TKA	20 patients into two groups: 10 (4f-6 m) conventional methods of exposure (CONV), 10 (5f-5 m) minimally invasive method (MINI). 45 CG (22f-23 m). Evaluations: pre-TKA (PRE), 6 weeks post (P1), 12 weeks post (P2).	PosturoMed device platform and ZEBRIS CMS10 ultrasound based motion analysis system	Lehr's damping ratio	Provocation test: sudden unidirectional perturbation, to which the subject had to counter with compensatory equilibrium reactions. The platform was moved 20 mm in the ML direction towards the subject's dominant side during the double limb trials and towards the investigated limb during the single limb trials, and locked with the fastening unit. Participants assumed the measuring position and stood still (2 s); the fastening unit was released to perturb the equilibrium; the plate was shifted without warning. 3 times for each position (double-leg, right-leg, and left-leg stance); 60-s resting between measurements.	CONV: Lehr's damping ratio increase at P2, but values significantly lower than CG. MINI: Lehr's damping ratio P1 and P2, significantly higher than PRE, but values significantly lower than CG. Lehr's damping ratios of MINI significantly higher than CONV in post.
[35]	i) to determine postural stability parameters in knee OA patients before and after TKA. ii) To assess the impact of anthropometric and functional characteristics on postural stability.	14 women (60.2 ± 7.6y) with OA in stage III-IV in list to undergo TKA (AG). 10 healthy women (59.5 ± 6.6y) as CG. Follow Up: 1 day before (PRE), 3 (P1), and 6 months (P2) after TKA.	2 stable dynamographic force plates; movement analysis system Elite Clinic and SWAY® software; dynamometer; goniometer	Postural stability: sway displacement in ML and AP directions, Trace speed, COP equivalent Area. Leg extensor muscles strength: maximal voluntary contraction (MVC) force. ROM, Visual Analog Scale (VAS)	Postural stability: to remain as stable as possible standing with right and left leg in different platforms, eyes open (30 s). Muscle strength: seated on a dynamometric chair in horizontal frame, to push the footplate as forcefully as possible for 2-3 s (3 trials, both separated legs, 2 min rest between trials). Before strength testing, the subjects performed a warm-up with exercise bike during 5 min. After TKA subjects performed therapeutic exercises to increase the ROM in the operated knee, to strengthen and stretch the thigh and shank muscles, and to improve postural stability.	VAS decreased significantly at P1 and P2 compared to PRE in AG. ROM significant reduced: at P1 compared to PRE, and at P1 and P2 compared to CG. MCV force in operated leg significantly lower than CG and non-operated leg at PRE, P1 and P2. COP in AP direction for the operated leg significantly higher at PRE, P1 and P2 compared to CG. Compared with CG, only the COP of sway displacement in AP direction is disturbed both PRE and after TKA. Increased postural stability is associated with an increased COP equivalent area.
[27]	To evaluate pre- and post-TKA Single Limb Standing Balance (SLSB) in knee OA patients	11 patients (61.7 ± 7.3y) with radiographic varus deformity and medial compartment degeneration, scheduled for TKA. Evaluations: about 4.5 days prior to surgery (PRE); about 11.3 days after surgery (POST).	Biodex Stability System; horizontal plain stationary force platform (RMI, CEGEDIM)	Dynamic balance: balance index calculated as the amount of time the board spent in a deviated position and the degree of angulation from the neutral centre. Static balance: postural sway of single limb. Prior to TKA: WOMAC, Kellgren/ Lawrence scale, VAS, varus angle while	Prior to TKA: evaluation of maximum isometric peak torque of the quadriceps femoris, balance index, and the postural sway. Peak torque determined by measuring the full isometric contraction of the quadriceps femoris with a 60° adjustment of knee flexion for 5 s. (3 times, at intervals of 15 s, the highest	The mean ± SD of SLSB reduced significantly POST, from 30.3 ± 20.8 cm to 18.5 ± 9.3 cm. Amelioration was in proportion to PRE postural sway. ICC coefficient ranged from 0.7 to 0.8. Patients regained previously impaired SLSB POST in varus knees and these

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Table 2 (*continued*)

Ref	AIM	Participants	Instruments	Outcomes	Protocol	Results / Findings
				standing, number of painful knee joints.	score was chosen). After warming up, patients were asked to stand on an unstable platform set and to maintain standing balance (20 s) with both arms adducted to the flank, staring forward at a fixed point, and medial ankle surfaces touching (3 trials low difficulty, 3 trials high difficulty).	improvements were proportional to the degree of decreased SLSB.
[18]	To assess the changes induced by the unilateral TKA procedure in human postural control	10 patients, mean age 63.5 y, all suffered from single knee arthritis and had undergone unilateral TKA with the same type of PCL substituting prosthesis. Evaluations: 2 days before surgery (PRE) and 7 days after TKR (POST).	AMTI AccuGait force plate	ML displacement, AP displacement, velocity, ellipse 95 both open eyes and closed eyes	30 s of force platform output, sampling rate 5 Hz. Subjects completed 3 consecutive double-limb standing balance trials on the firm and stable platform with: 1) eyes open (EO), 2) eyes closed (EC). Rest periods of 30-60 s between trials, and at least 1 min rest between each test situation. During the standing tests, subjects stood on their limbs centred on the force platform and with their knee in full extension.	EO POST: insignificant increase of ML displacement (3.4%); significant increase in: AP displacement (23.2%), average velocity (16.8%), Ellipse 95 (33.7%). EC POST: insignificant increase of ML displacement (5.1%); significant increase in: AP displacement (23.9%), average velocity (19.1%), Ellipse 95 (31.5%). Balance control is weaker shortly POST than PRE.
[29]	To evaluate changes in balance among patients with bilateral OA who underwent staged TKA	Unilateral group (UG) (22 patients who did not undergo a second TKA within 24 months of the first TKA), and the bilateral group (BG) (20 patients who had a second TKA within 12 months after initial TKA). Evaluations: preoperatively (PRE), 1-year (1Y), and 2-years post-operation (2Y) in UG; PRE, 1 day before second TKA (1D), and at 1 year after the second TKA (1Y) in BG.	Gravicorder (GS-11; Anima)	2 parameters of gravity center position (GCP): mean GCP in the ML direction [GCP: center 0, initial operative side +, non-operative side -)] and locus length per time (LG) which indicates postural control function by proprioceptive reflex	Postural sway measured for 30 s at 2 min intervals during two-leg standing with eyes open, fixing the gaze at a visual point placed 1 m in front of them at eye level so no moving objects could enter the visual field. Rehabilitation: every day, beginning 1 week after surgery, at least 2 h/day performing: isometric exercises, passive and active-assisted ROM, quadriceps and hamstring strengthening, and gait training (included ascending /descending stairs). Functional electrical stimulation used in all patients.	No significant differences UG/BG in PRE GCP and LG. Significant differences in UG: GCP between PRE/1Y, and PRE/2Y; LG between PRE/1Y. Significant differences in BG: GCP between PRE/1D, and 1D/1Y; LG between 1D/1Y and PRE/1Y. Properly performed rehabilitation after initial TKA, improving postural sway, might attenuate timing for the second TKA
[30]	To evaluate balance changes after TKA in knee OA patients and their relationship with age, pain, ROM in both knees, muscle strength in the quadriceps and hamstrings, and gait velocity	44 patients with severe knee OA who underwent TKA. Evaluation: preoperatively (PRE), 12 months post-surgery (POST)	Manual goniometer; Isometric dynamometry; Gait Mat System II; NeuroCom Balance Master	PRE: Knee Society score (KSS). POST: VAS; knee ROM; muscle strength of the quadriceps and hamstrings; gait velocity; Modified Clinical Test for Sensory Interaction and Balance (mCTSIB). Sit to Stand, 4 recorded values: weight transfer, rising index, sway velocity, and left/right.	3 posturography tests. To walk 4 m distance 5 times at a comfortable pace. Movement measured 3 trials, each 10 s. The test was done: on a firm surface with open eyes (FEO), on a firm surface with closed eyes (FEC), on a foam surface with open eyes (FOEO), and on a foam surface with closed eyes (FOEC). Beginning on postoperative day 1, all patients received 3 weeks of rehabilitation therapy. At 3 weeks, patients who had not achieved 90° of flexion continued in outpatient therapy; those who achieved this ROM were discharged to continue the exercises at home.	No significant difference when comparing CR vs PS. POST: significant increased gait velocity, decreased pain, increased strength of the extensors in both knees, decreased flexion in both knees, and slight improvement in extension of the operated knee. Significant differences in mCTSIB between FOEO and FOEC POST respect to PRE. Age negatively correlated with an improved mCTSIB score. Balance improved significantly POST compared to PRE in FOEO and FOEC
[36]	To establish whether TKR leads to improved static and dynamic balance. To investigate whether improved	62 patients with symptomatic OA (mean age 73 y). Evaluations:	NeuroCom Balance Master	Static balance: Amplitude, direction and speed of movement of COP; mean COP sway speed and mean	Static balance: postural sway in FEO, FEC, FOEO or FOEC (3 trials, each 20 s). Dynamic balance: limits of	Static balance: postural sway in FOEO significantly improved POST. Dynamic balance: RT, MVL, EPE, MXE

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Table 2 (*continued*)

Ref	AIM	Participants	Instruments	Outcomes	Protocol	Results / Findings
	balance correlates with functional improvement and/or improved QoL	preoperatively (PRE) and 1 year after surgery (POST)		COP position. Dynamic balance: reaction time (RT), movement velocity (MVL), end point excursion (EPE), maximum excursion MXE), directional control. QoL.	stability (LOS) test to reach a target at the LOS without losing balance (8 trials, max 8 s each). Weight-bearing squat test: stay standing on both legs and then squatting at 30°, 60°, 90°. Self-completed questionnaires. Tests of motor function and dynamic functional balance: four square step test, time up and go test	significantly improved POST. Statistically improved QoL POST.
[31]	To evaluate whether preoperative proprioceptive training would influence postoperative balance and function in ADL in patients undergoing TKA	38 patients scheduled for TKA, randomized in 2 groups: 18 to the Training Group (TG) (mean 72.8y), 20 CG (mean 66.9 y). 3 TG lost to follow-up. Evaluations: 6 weeks before (PRE) and after TKA (POST), TG also one day before surgery (1D)	Biodex Stability System	Balance as SD respect the horizontal plane: ML stability index (MLSI), AP stability index (APSI), and overall stability index (OSI). Gait speed, WOMAC, KSS.	1) Balance (dynamic postural stability): to keep the platform in level position when bilateral stance was assessed at max level over 20 s (1 practice, 2 test trials). 2) Gait: i) walk 60 m on level as fast as possible; ii) to ascend and descend as fast as possible 50 steps, each 16 cm high.	Stance stability improved significantly in OSI and APSI for TG POST. Significant improvement in KSS, WOMAC pain and stiffness in both groups POST. Preoperative proprioceptive training in patients undergoing TKA resulted in improved standing balance (APSI), but no difference in clinical outcome was observed between the 2 groups

2.3. Study Selection Process

Only original, full-text articles published in English, between January 2008 and February 2018, about the assessment of proprioception in patients who suffered from OA and were subjected to primary TKA, were included in this review. First, duplicated references were manually identified and excluded. Then, during the screening procedure, items were excluded if they i) were an abstract, an editorial, a review article, or a chapter from a book; or ii) were not written in the English language. Subsequently, three authors (E.R., G.B., and L.B) independently screened the title and abstract of the remaining papers that were excluded if: i) they did not assess the knee joint; ii) they did not include human *in vivo* studies; iii) their topic did not appear appropriate for this review. Then, the authors full-screened the remaining papers to exclude them if: iv) they included patients who had knee arthroplasty caused by an impairment different from OA; v) they did not provide the proprioception assessment; vi) they involved partial knee replacement; vii) they evaluated proprioception after surgery only. Disagreements about the inclusion/exclusion and classification of the papers were resolved through meetings and discussions among the authors. Ultimately, the selected papers, fully evaluated and included in this review paper, were divided into two groups according to the specific measured outcome (*i.e.*, direct or indirect proprioception evaluation).

2.4. Data extraction

Data were abstracted from each selected paper, as reported in Tables 1 and 2, evidencing the technological solutions used, the experimental aspects, and the performed analysis concerning proprioception assessment. Specifically, the typology of devices used for proprioception assessment, the designed protocol, the subjects involved and, the main findings for each work were detailed.

Papers were divided into two categories: the first one included works which aimed to directly measure proprioception through specific tasks (Table 1), while the second one focused on indirect assessment of proprioception, evaluating not only (or not directly) proprioceptive skills, but assessing also postural sway or muscle strength (Table 2). The presence of a rehabilitation program, as well as the time of follow-ups, were also reported (Tables 3 and 4).

2.5. Data quality assessment

The methodological quality of all studies was evaluated by two independent reviewers (ER, GB). Disagreements were resolved by discussion. If no consensus was met, a third reviewer (LB) made the final decision. A list of methodological criteria recommended by Van Tulder et al. [24] was used to rate the methodological quality of all the works included in this review paper. This methodology is based on 19 items divided into three domains: 11 about criteria for internal validity, 6 for descriptive criteria, and 2 for statistical criteria. Studies were considered to be of high quality if certain criteria were met, in particular, at least six criteria for internal validity, three descriptive criteria, and one statistical criterion. The aforementioned items are reduced to 14 (*i.e.*, 7 for internal validity, 5 for descriptive criteria, and 2 for statistical criteria) for studies without randomized controlled trials, as suggested by Steultjens et al. [25]. These studies were considered to be of sufficient quality if at least 4 criteria for internal validity, 2 descriptive criteria, and one statistical criterion were met as applied by Lim et al. [26].

3. Results

3.1. Literature overview and rating of studies

Overall, 170 articles resulted from the research: 95 obtained from Web of Science®, 17 retrieved from Cochrane®, 51 taken from PubMed Central®, and 7 identified from PEDro®. After removing the duplicated items, 112 references were included in the evaluation procedure. The preliminary screening on the typology of the papers allowed to select 95 references. After the screening of titles and abstracts, 70 papers were identified for full evaluation. Finally, according to the eligibility criteria, only 13 papers resulted, which were adequate for the present work and were included in the final review, as detailed in Fig. 1.

The 13 included papers were analysed according to their main outcome and divided into two classes. The first class included works that tried to obtain a direct measure of proprioception before and after TKA (Table 1), while the second one gathered studies that provided an indirect measurement of proprioceptive skills pre and post-surgery (Table 2). For instance, latter class also includes balance evaluation, since proprioception and balance are strictly related, in fact, impairments in kinaesthesia and proprioception resulted in negative effects on standing balance [19]. Due to the high variability in design research and protocols, details about follow-up timeline and rehabilitation programs are further provided in Tables 3 and 4, respectively. In particular, in Table 3, the timeline of the evaluations is reported for each study. Although all the studies make a preoperative assessment, only six of them reported exactly the time of evaluation, which ranged from 6 weeks to 1 day before the surgery. The time of the first follow-up varied substantially among studies, ranging from a few days [16,18,27], to 1 year [19,28–30]. Finally, only 5 studies proposed a second follow-up for a long-term evaluation of proprioception. Furthermore, in Table 4, the 8 studies that proposed a rehabilitation program were reported. However, little information is reported about time length and frequency of these programs, thus a comparison among the works have low relevance. It could be worthy to highlight that only one study proposed a pre-operative rehabilitation program [31], while all the others focused on post-surgery rehabilitation.

Moreover, there was only one randomized controlled trial (RCT) [31], which resulted in high-quality methodology according to the criteria list for the methodological quality assessment defined by van Tulder et al. [24], while another RCT was evaluated of sufficient quality [22]. One study described 2 cohorts of patients subjected to different treatments and compared between them [29]. Six works included a patient group and a control group composed of healthy subjects only, used for comparison [16,22,32–35]. Finally, 5 works were observational studies [18,27,28,30,36], where only a patient group is involved and assessed before and after the intervention. Of the 11 studies that are not RCT, the methodology of 4 resulted to be of sufficient quality, while the other 7 were valued of low quality (see Table A1).

Table 3
Length of follow-up protocols and evidence of rehabilitation programs.

Ref.	Preoperative evaluation	Follow-up 1 post-surgery	Follow-up 2 post-surgery	Rehab
[16]	Y (1-2 days before)	8 days	100 days	N
[32]	Y	6 months	12 months	Y
[28]	Y	12 months	n/a	N
[33]	Y	4 months	n/a	N
[34]	Y	2 weeks	n/a	N
[22]	Y	6 weeks	12 weeks	Y
[35]	Y (1 day before)	3 months	6 months	Y
[27]	Y (4.5 days before)	11.3 days	n/a	Y
[18]	Y (2 days before)	7 days	n/a	N
[29]	Y	1 year	2 years	Y
[30]	Y (at least 2 weeks before)	1 year	n/a	Y
[36]	Y	1 year	n/a	Y
[31]	Y (6 weeks before; 1 day before within training group)	6 weeks	n/a	Y

3.2. Direct proprioception assessment

Only 4 works resulted actually able to provide a direct measurement about knee proprioceptive skills, proposing parameters for objective quantification of these skills (Table 1).

Among these, only 2 studies described the experimental tests according to those most proposed in the literature for proprioception evaluation in clinical settings. Slupik et al. examined the recruited patients through a JPS test [16], whereas Chung et al. applied a JPR test [32], requiring the patients to passively or actively reach a target position. In these cases, proprioception was evaluated by directly measuring in degrees the error between the position reached by the subjects and the exact target position required by the examiner. Ultimately, Levinger et al. proposed the assessment of proprioception as sub-task of the Physiological Profile Assessment (PPA) scale, highly linked with risk of falls [28,33].

Contrasting results were obtained from the analysed works. Only Slupik et al., indeed, showed high proprioceptive deficits in patient group (called arthroplasty group – AG) compared to the control group (CG), composed by healthy subjects of control, both in preoperative and early post-operative conditions. They also found a significant improvement of proprioception, according to JPS test results, in post-surgery, such that values for AG measured about 100 days after intervention (second follow-up) were similar to those of CG [16]. Differently, according to Chung et al., any significant differences about proprioception assessment resulted between AG and CG, both in the preoperative stage and during follow-up controls [32]. Finally, Levinger et al. confirmed that proprioception did not significantly improve after TKA [28,33], but proprioceptive skills were highly impaired in AG compared to CG, both in preoperative and post-operative conditions [33], leading to higher risk of falls within the patient group.

3.3. Indirect proprioception assessment

Nine studies proposed the indirect measurement of proprioception abilities before and after TKA (Table 2). These studies mainly evaluated balance.

Different protocols and tests were reported among the studies since each group of researchers proposed the measurement of different parameters to show changes in proprioceptive abilities before and after TKA. For example, Zhou et coll. proposed a novel index of knee joint stability (IKJS) [34], measured following a knee-aiming task. Significant differences were found in the operated leg within AG between pre- and post-surgery. Significant differences appeared also among AG pre-surgery, AG post-surgery and CG. Moreover, the operated leg post-surgery resulted in improved balance, similar to CG.

According to Pethes et al. [22], dynamic balance ability significantly decreased in the early post-operative period, and consequently, also proprioceptive skills decreased. Even if an improvement in balancing abilities was then documented post-TKA (over the first 12 weeks), the dynamic balancing skills in patients while standing were significantly worse than CG [22].

Vahtrik et al. [35] also confirmed significant difference, measured as the centre of pressure (COP) of sway in the anteroposterior (AP) direction, between patients and healthy controls both in pre-operative and post-operative conditions. No other works reported similar differences since a healthy CG was not involved in them.

Improvements in balance post-surgery, reported by several studies [18,22,27,30,31,34,36], were not reasonably caused exclusively by increasing in proprioception, but it can be due also to other factors, such as the decrease in joint effusions, pain and/or inflammation, and changes in ranges of muscle [27]. Nevertheless, balance improvement

Table 4
Timeline of rehabilitation programs, if proposed.

Ref	Rehab	Beginning	Lasting	Frequency
[32]	Y	Post-operative day 1	Not specified	Not specified
[22]	Y	Not specified	Until 12th weeks post-surgery	Not specified
[35]	Y	Post-operative day 1	6 months	Not specified
[27]	Y	Post- as soon as possible	Not specified	Not specified
[29]	Y	1 week post-surgery	Not specified	2 h/day, everyday
[30]	Y	Post-operative day 1	3 weeks	Not specified
[36]	Y	Post-operative 4-6 days	Not specified	Not specified
[31]	Y	6 weeks before surgery	6 weeks	Once/week, 45 min each

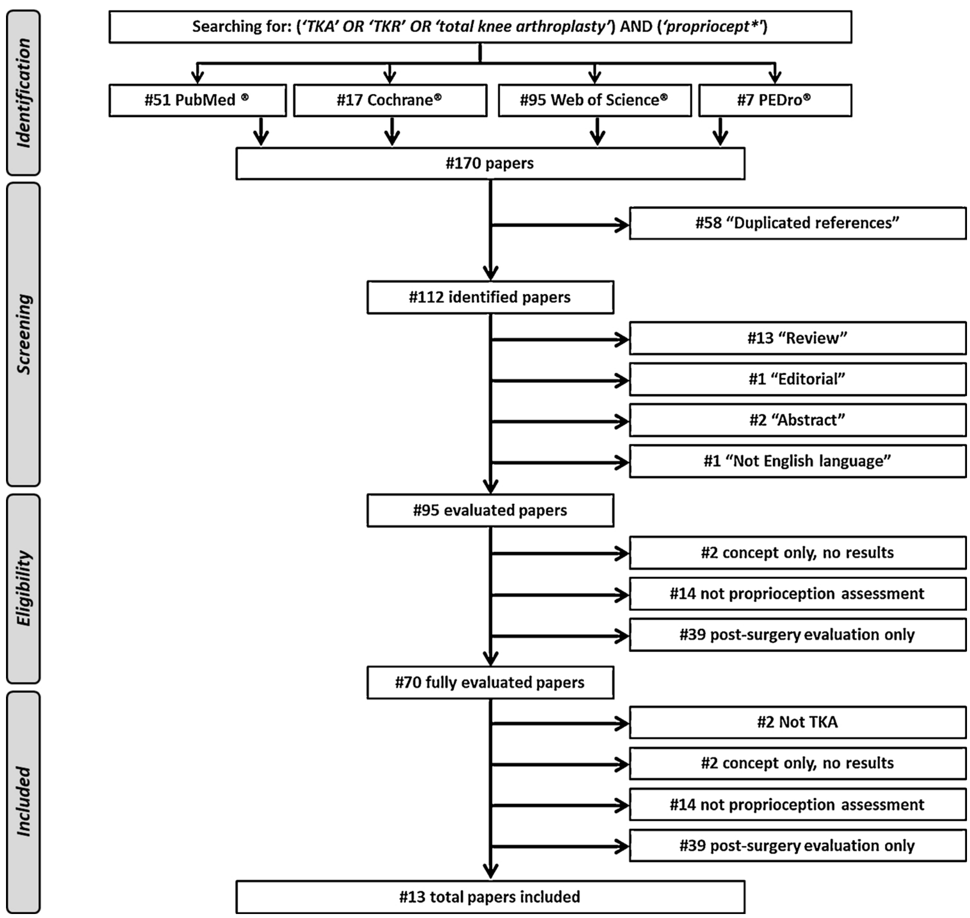

Fig. 1. Selection flowchart according to the PRISMA statement.

has a tangible relevance also in enhancement of patients' quality of life (QoL) [36].

4. Discussion

This review paper analysed studies published during the last decade dealing with knee proprioception before and after TKA, to provide an overview of how proprioception changes in OA patients who underwent knee replacement.

A limited number of papers satisfied the inclusion criteria described in the methodology (see par. 2.3), thus only 13 records out of 170 were included in this paper.

Among the included papers, only 4 works proposed a direct assessment of proprioception, while 9 addressed an indirect evaluation mainly based on balance assessment. Balance, indeed, can be considered as an indirect measurement of proprioceptive function [37], since it is crucial for dynamic postural control [27]. Since TKA did not affect any substantial changes about visual and vestibular elements, the main changes in balance may be attributable to proprioception elements [30].

Contrasting results emerged from the analysed studies concerning the effect of TKA on proprioception, and direct comparison among different works was difficult to discuss because of several differences in research design, methods, tests, measured parameters, length of follow-ups, and rehabilitation [30] (Tables 1–4).

Generally, different results were achieved about the changes in proprioception caused by TKA. In detail, 8 works reported improvement following the surgery [16,22,27,29–31,34,36], four research groups demonstrated that no differences are produced by the TKA [28,32,33,35], and a study even reported worsening in performance after the knee replacement [18]. In fact, this last study observed only an early post-operative period of seven days, during which balance and proprioception can deteriorate, and risk of falls increases [16,22,33,38], but it can be reasonably presumed that longer-time follow-up could confirm improvements in proprioceptive skills.

According to the authors which found an improvement in proprioception after TKA, this can be attributed to the positive effects of TKA on the knee capsule-ligamentous and muscular-tendinous structures, enhancing the perception of joint motion and position [19]. In fact osteoarthritic knees before TKA generally present diminished joint sensation related to a loss of mechanoreceptors, pain, inflammation, laxity, decreased joint space, and patients perform reduced physical activity.

TKA restores joint space and soft tissue tension, reducing pain and chronic inflammation. Furthermore return to a greater daily physical activity and physical therapy sessions could contribute to the proprioception and balance improvement.

Among factors reported by the studies in which no improvement was found after TKA, a role has been imputed to the lack of changes in neurosystem control in terms of knee appropriate muscular activation sequence to maintain postural stability, and also to the possible effects of patients overweight requiring more effort in maintaining postural stability [35]. Also the time of assessment after TKA is relevant since it has be found that 3 months is not sufficient to improve static balance and improvements did not reach statistical significance within 1 year after TKA [28].

Several works pointed out the need to implement a recovery program as soon as possible after TKA [29], to improve proprioception and postural sway, and to decrease the risk of falls [18,35]. However, walking aids should be also recommended during the early post-operative period to safety respond to unexpected conditions [22]. A home-rehabilitation program after TKA, based on balance and proprioceptive exercises, may improve daily activities, such as walking and stair climbing, decreasing the fear of falls as well [39–41].

No evidence was found about the proprioceptive or kinaesthetic effect of PCL retention in TKA in improving postural control after surgery, since posturography changes at 6 or 12-month follow-up did not show differences between groups with or without PCL [19,30]. It has been hypothesized that the absence of changes before and after surgery is due probably to sensory denervation of the posterior cruciate ligament already present in the osteoarthritic knee [19].

Similarly, no substantial differences were found when comparing patients subjected to TKA and patients underwent bicompartimental knee arthroplasty (BKA) [32], endorsing the idea that cruciate ligaments do not drastically contribute to proprioception.

Regarding the gender, although females are largely the majority of the people recruited for the studies since most of the patients who underwent TKA are women, dynamic balancing activities were not found to be different with respect to males after TKA [22].

The studies included in this review presented some limits: i) sample size reported was small in most of works [18,27,32,35], limiting generalization of findings, ii) high drop-out rate was a common problem [34,36], preventing to accurately compare preoperative and post-operative data of patients; iii) some works did not included a control group [18,27–31,36]; iv) the quality assessment of the included papers revealed that only one [31] resulted in high-quality methodology, being a RCT. Thus, further investigations on a more sizeable dataset, following a well-defined protocol, and agreeing upon measurable outcome, timeline follow-up and rehabilitation program should be performed.

5. Conclusions

This review paper aimed to investigate the effects of TKA on knee proprioception, analysing works that included direct and indirect evaluation of proprioception. Considering the restricted number of papers found to be consistent according to adopted eligibility criteria of this review, proprioceptive impairment in knee OA and the effect of TKR are still understudied and remain complex topics. This review reflects a comprehensive overview of published studies. Unfortunately, these studies are not homogeneous both for methodological quality, assessment instruments, type of TKR implant used, follow-ups, rehabilitation programs, and measured outcomes.

To conclude, though different assessment tools are available to measure proprioception, no standardized comprehensive evaluation protocol presently exists. Contrasting results were found in the literature since some studies found that TKA improves proprioception in knee OA, while others found no difference in proprioception, and one work even reported a worsening condition. Given that different follow up and assessment tools were used, no evidence-based conclusion can be drawn from these studies.

With regards to the training program, there is some evidence that balance and proprioception exercises are effective and should be implemented immediately after TKA in order to obtain best results.

Finally, inconclusive data are available about the implant retaining or substituting PCL, even if cruciate ligaments do not seem severely contribute to proprioception.

It is strongly suggested that further studies in the future be planned in order to better define reliable tools for proprioception measure in knee OA and TKR and for evaluating the effects of rehabilitative programs and surgical interventions.

Conflict of interest statement

The authors declare that they have no conflict of interest.

CRediT authorship contribution statement

Laura Bragonzoni: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Erika Rovini:** Conceptualization, Methodology, Formal analysis, Visualization, Writing - original draft. **Giuseppe Barone:** Formal analysis, Visualization. **Filippo Cavallo:** Supervision, Writing - review & editing. **Stefano Zaffagnini:** Conceptualization, Supervision, Project administration. **Maria Grazia Benedetti:** Methodology, Supervision, Writing - review & editing.

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Appendix A

Table A1
Fulfilled items of methodological quality plus quality criteria for studies.

Ref.	DESIGN	Items positively scored on criteria for "internal validity"	Items positively scored on "descriptive criteria"	Items positively scored on "statistical criteria"	Methodological Quality
Slupik et al. [16]	Controlled Clinical Trial	j, l, n	a, d, m1, m2	o, q	LQ
Chung et al. [32]	Controlled Clinical Trial	g, j, n	d, m2	q	LQ
Levinger et al. [28]	Observational	g, j, l	a, m2	o, q	LQ
Levinger et al. [33]	Controlled Clinical Trial	g, j, l	a, d, m2	o, q	SQ
Zhou et al. [34]	Controlled Clinical Trial	f, l, j	a, d, m1	q	LQ
Pethes et al. [22]	Randomized Controlled Trial	b1, i, f, j, n	a, d, m2	q	SQ
Vahtrik et al. [35]	Controlled Clinical Trial	f, g, l, j, n	a, d, m2	o, q	SQ
DoCho et al. [27]	Observational	g, i, j, l, n	a, k, m1	q	SQ
Stan et al. [18]	Observational	g, j	a, d, m1	q	LQ
Ishii et al. [29]	Controlled Clinical Trial	f, g, n	d, m2	q	LQ
Bascuas et al. [30]	Observational	g, j	a, d, m2	q	LQ
Schwartz et al. [36]	Observational	g, j, l	a, d, m2	q	SQ
Gstoettner et al. [31]	Randomized Controlled Trial	b1, f, g, j, l, n	a, c, d, m1, m2	o, q	HQ

MQ, methodological quality; HQ, high methodological quality; SQ, sufficient methodological quality, LQ, low methodological quality. All studies were scored on items concerning 'internal validity', 'descriptive criteria' and 'statistical criteria'. 'a' indicates a positive score on a description of the eligibility criteria; 'b1 'means that a randomization procedure has been applied, whereas 'b2, 'means that the treatment allocation was concealed; 'c' indicates that groups were similar at baseline; 'd' means that index and control interventions were adequately described; 'e' indicates that the care provider was blinded for allocation of the patients; 'f' indicates that co-interventions were avoid or comparable between the index and the control groups; 'g' means that compliance was acceptable; 'h' means that the patient was blinded for allocation; 'i' means that the assessor of the outcomes measurements was blinded for allocation; 'j' means that the outcome measures were relevant; 'k' indicates that adverse effects were described; 'l' means that withdrawal/ dropout rate was described; 'm1′ means that a short-term follow-up measurement was applied (at the end of the intervention, maximum after 2 weeks), whereas 'm2′ means that a long-term follow-up measurement was applied (after three months or later); 'n' indicates that the timing of outcome assessments was comparable for all groups; 'o' means that the sample size for each group was presented at randomization and for most important outcomes assessments; 'p' means that an intention-to-treat analysis was applied; 'q' means that all point estimates and measures of variability were presented. Criteria 'b1′, 'b2′, 'c', 'e' and 'h' were not scored for NOT RCT studies.

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