Review Article

Leg Length Discrepancy—Treatment Indications and Strategies

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Summary

Background: Many people have leg-length discrepancies of greater or lesser severity. No evidence-based studies on the need for treatment are currently available.

Methods: This review is based on publications retrieved by a selective search in the PubMed database, as well as on published recommendations from Germany and abroad and on the authors' own clinical experience.

Results: If the two legs are of different lengths, this is generally because one leg is too short. It is debated whether leg-length discrepancy causes pain or long-term musculoskeletal disturbances. A direct connection to back pain is questionable, but a mildly elevated incidence of knee arthritis seems likely. The evidence base on the indications for treatment of leg-length discrepancy is poor; only informal consensus recommendations are available. There are a wide variety of conservative and surgical treatment options. The final extent of a leg-length discrepancy first noted during the growing years can be estimated with predictive algorithms to within 2 cm. The treatments that can be considered include a shoe insert, a high shoe, or an orthosis, surgically induced slowing of growth by blockade of the epiphyseal plates around the knee joint, or leg lengthening with osteotomy and subsequent distraction of the bone callus with fully implanted or external apparatus. Changes in leg length exert marked mechanical stress on the soft tissues. If the predicted leg-length discrepancy exceeds 5 cm, initial leg-lengthening treatment can already be considered during the patient's growing years.

Conclusion: It must be discussed with each patient individually whether the treatment should be conservative or surgical. The extent of the discrepancy is not the sole determining factor for the mode of treatment. The decision to treat is always elective.

Cite this as:
Vogt B, Gosheger G, Wirth T, Horn J, Rödl R: Leg length discrepancy—treatment indications and strategies. Dtsch Arztebl Int 2020; 117: 405–11. DOI: 10.3238/arztebl.2020.0405

Leg length discrepancy is a common condition with diverse causes. This review focuses on anatomical leg length discrepancy with measurable differences between the lengths of the lower-limb bones, including foot height.

Another term commonly used for leg length discrepancy of less than 2 cm is pelvic obliquity, showing that the finding of a leg length inequality of this extent is frequently not a merely anatomical phenomenon, but can completely or at least partially be the result of functional abnormalities, such as pelvic distortion (1, 2).

Large leg length discrepancy can be as severe as the complete absence of parts of the limb. These cases are typically linked to rare congenital malformations which, in addition to the leg length discrepancy, are associated with complex changes of the entire limb. These patients have unstable joints, vascular malformations, severe malpositioning, and partial or even complete absence of entire bones or toe rays (1, 2).

Despite the widespread occurrence of leg length discrepancy, national or international guidelines for the management of this condition are non-existent. The only exemption is the Pediatric Orthopedic Society of North America (POSNA) which posts on its website a study guide, naming three top contributors (3). However, it remains unclear which consensus-finding procedure was used.

Methods

This review is based on a selective search of the PubMed database, using the search terms "leg length discrepancy" in combination with "scoliosis", "low back pain",

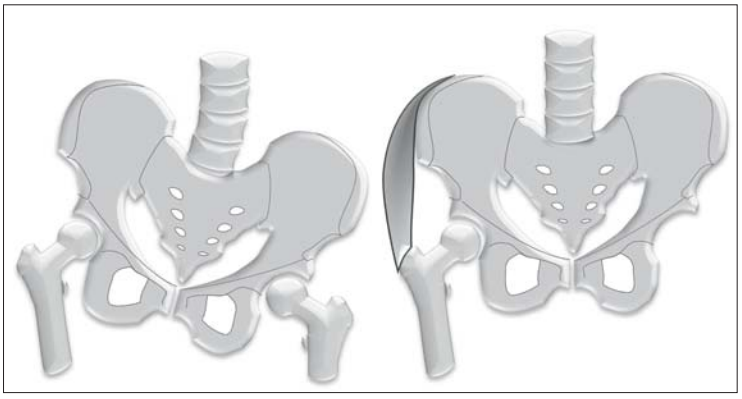

Figure 1:
Left: Double-leg stance with equal weight distribution in the presence of leg length discrepancy.
Right: Single-leg stance with balancing of the pelvis by the gluteal muscles

"osteoarthritis", "gait analysis", "function", "epidemiology", and "ISKD and lengthening or Fitbone and lengthening or Precice and lengthening", as well as national and international recommendations and own experiences.

Epidemiology and etiology

A US study and a Swedish study found that leg length discrepancy of ≥ 1 cm was present in one third of the populations (4, 5). This article focuses on leg length discrepancy of more than 2 cm; however, the prevalence of this extent of leg length inequality is not well established. Among military recruits, leg length discrepancy of >1.5 cm was measured in 4% of cases (5). A frequently cited French study is the only available epidemiological study. It found that one per 1000 population had orthopedic treatment for leg length discrepancy of >2 cm (6).

Anatomical leg length discrepancy can be acquired and congenital. Shortening of a leg can occur primarily as the result of loss of bone or secondarily as the result of traumatic or infectious epiphyseal plate injury in growing patients. In patients with congenital or idiopathic leg length discrepancy, the affected leg is growing continuously slower than the normal leg (1, 2).

This indicates that leg length discrepancy is almost always the result of the shortening of one leg. Leg elongation associated with hemihyperplasia (formerly hemihypertrophy) or partial gigantism is rare, almost always occurring in patients with syndromes or vascular conditions, such as Klippel-Trénaunay-Weber syndrome (1, 2), which are not the subject of this review.

Risks associated with leg length discrepancy

Leg length discrepancy is regarded as a cause of various long-term complications. Assumingly, risks to the

Figure 2:
Measuring leg length discrepancy using the block method: Level pelvis is achieved by equalization with blocks of 4 cm in total height.

TABLE 1

Retrospective studies on lengthening procedures since 2011

Publication	Year	Method 1	Cases	Compl.	Lengthening	Method 2	Cases	Compl.	Lengthening
Krieg et al. (38)	2011	Fitbone	32	30%	37 mm	*	*	*	*
Schiedel et al. (39)	2011	ISKD	69	27%	41 mm	*	*	*	*
Kenawey et al. (40)	2011	ISKD	37	22%	43 mm	*	*	*	*
Mahboubian et al. (e1)	2012	ISKD	11	60%	36 mm	LON	22	45%	41 mm
Lee et al. (e2)	2014	ISKD	35	60%	47 mm	*	*	*	*
Kirane et al. (e3)	2014	Precice I	24	28%	35 mm	*	*	*	*
Shabtai et al. (e4)	2014	Precice I	21	30%	44 mm	*	*	*	*
Schiedel et al. (e5)	2014	Precice I	26	15%	37 mm	*	*	*	*
Horn et al. (e6)	2015	Fitbone	15	26%	35 mm	ExFix	15	60%	38 mm
Kucukkaya et al. (e7)	2015	Fitbone	25	16%	58 mm	*	*	*	*
Wagner et al. (e8)	2017	Precice I + II	32	9%	43 mm	*	*	*	*
Panagiotopoulou et al. (e9)	2018	Precice I + II	15	9%	55 mm	*	*	*	*
Fragomen et al. (e10)	2018	Precice I + II	40	12%	38 mm	LON	22	45%	41 mm
Horn et al. (e11)	2019	Precice II	34	16%	40 mm	Fitbone	16	16%	40 mm

* No comparative method evaluated
ExFix, external fixator; ISKD, intramedullary skeletal kinetic distractor; Compl., complications; LON, lengthening over nails

spine, hip joints and knee joints or painful asymmetries of muscle chains are of particular importance (7). Thus, we will discuss the conceivable negative impact of leg length discrepancy in detail and expand on the evidence from published studies.

Abnormal growth, hip dysplasia and scoliosis

When standing with the weight equally distributed on both legs (position of at attention), patients with leg length discrepancy have their pelvis and sacrum tilted to the side of the short leg, resulting in relative deterioration of femoral head containment and lateral flexion of the spine (1, 2). This gave rise to concerns that leg length discrepancy in growing children could promote the development of hip dysplasia and/or scoliosis. However, in single-leg stance this effect is not present due to the horizontalization of pelvis and sacrum by the gluteal muscles (*Figure 1*). While no data are available on how long per day people in the general population spent in double-leg stance with equal weight distribution, it may be assumed that it is no more than approximately half an hour. Therefore, the notion that half an hour of daily "improper loading" has significant effects on the musculoskeletal system appears to be highly debatable.

A study assessing young adults after conservative neutralization of leg length discrepancy which had been present since childhood found a reduction in scoliotic lateral flexion, but also persistent rotational components (8). From this observation it was concluded that leg length discrepancy in growing children may contribute to the development of scoliosis (2). In contrast to this study, the same working group examined young adults with leg length discrepancy of more than 3 cm due to injuries sustained after skeletal maturity and no correction of the leg length inequality with a shoe lift over a period of 10 years. Based on the radiographs obtained, the development of scoliosis could be ruled out (9).

Function, limping and athletic ability

The functional characteristic of leg length discrepancy is the shortening limp (1, 2). Gait analyses have shown that leg length discrepancy of >1 cm can result in gait asymmetry. As the discrepancy increases, the asymmetry also increases and limping becomes noticeable (10).

In German sports for the disabled, permanent leg length discrepancy of ≥4 cm or ≥7 cm, depending on the type of sports, are considered a disability, making the athlete eligible for participation in the Paralympic competition (11). According to the authors, disabled athletes with leg length discrepancy of <5 cm should always practice their sports activities without equalization of leg length by means of conservative measures. Shoe lift, in particular, can completely change the performance of sports shoes, at times making it impossible to engage in the sports activity.

Back pain and osteoarthritis

The multifactorial complexity of back pain is well known and in most cases no single causative factor can be identified. Numerous studies have evaluated potential risk factors for back pain, but leg length

TABLE 2

Leg length discrepancy in the German social welfare and insurance law

	≤ 1 cm	>1 cm ≤ 2 cm	>2 cm ≤ 2,5 cm	>2,5 cm ≤ 3 cm
Personal accident insurance	Normal	1/20 Leg value	2/20 Leg value	2/20 Leg value
Statutory accident insurance	Normal	< 10% MdE	< 10% MdE	10% MdE
Disability law	Normal	< 10% GdB	< 10% GdB	10% GdB

GdB, degree of disability ("Grad der Behinderung"); MdE, reduction in earning capacity („Minderung der Erwerbsfähigkeit")

TABLE 3

Guide to the treatment of leg length discrepancy

Length	Treatment
0–1 cm	No treatment
1–2 cm	Reduce to 1 cm with conservative measures
2–4 cm	Conservative, shortening osteotomy, epiphysiodesis, lengthening
4–5 cm	Conservative, epiphysiodesis, lengthening
>5 cm	Conservative, multi-step lengthening/combined with other measures

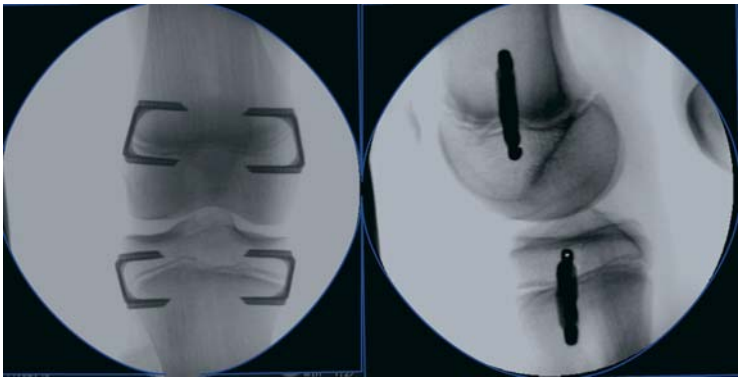

Figure 3: Growth arrest by physeal stapling

discrepancy was not identified as a factor promoting the development of back pain in any of these studies (12). Nevertheless, there are, of course, individual patients who experienced improvements in back pain after they were prescribed shoe lifts. However, whether the change in biomechanics during double-leg stance with equal weight distribution was a major contributor to this effect could not be clarified (4).

A cohort study with more than 3000 participants showed that leg length discrepancy was associated with an increased likelihood of osteoarthritis of the knee. For leg length discrepancy of more than 1 cm, an increased osteoarthritis risk was found for both the longer leg and the shorter leg compared to legs of equal length. However, this risk did not increase with increasing leg length discrepancy (13).

Another cohort study with 3067 participants examined the association between leg length discrepancy of ≥ 2 cm and the development of hip and knee joint symptoms as well as osteoarthritis of the hip and knee. While the risk of developing osteoarthritis of the knee increased numerically, the only statistically significant association was found for progressive knee osteoarthritis (14).

Diagnosis

In a clinical setting, leg length discrepancy can be determined with an accuracy of ± 1 cm (15). Using measuring blocks with defined height, the shortening is gradually corrected until the pelvis is level; from the total height of the blocks, the leg length discrepancy can be inferred (16) *(Figure 2)*. In order to radiographically determine the difference in leg lengths a standing full-leg radiograph with leg length equalization using blocks is obtained. However, this is only required at the time surgical correction of the leg length discrepancy is planned.

Indication for treatment

There is a lack of robust evidence on which to base the decision to initiate treatment of leg length discrepancy. Neither prospective nor retrospective studies comparing the natural course with a therapeutic intervention or different treatment approaches among each other have been published. Only the various techniques of leg lengthening surgery have been compared retrospectively *(Table 1)*.

A guideline which is based on a transparent consensus-finding procedure is not available. One of the reasons for this shortcoming is the weak evidence base for late complications, such as back pain and osteoarthritis.

A consensus within the guidelines for the assessment of invalidity in the German social welfare and insurance law is only indirectly identifiable *(Table 2)* (17). The authors think that from this an indication for treatment in patients with a leg length discrepancy of ≥2 cm can be derived. This is also the threshold for initiation of treatment in the POSNA study guide (3). Whether a leg length discrepancy should be treated at all—be it conservatively or surgically—54should be decided on an individual basis, balancing the potential risks and benefits for the patient. The mere presence of a leg length discrepancy does not automatically constitute an indication for treatment. Consequently, treatment decisions are always elective.

By clearly communicating the above-mentioned basic considerations to the patient, each patient should be empowered with an understanding of the facts that enables them to correctly assess their level of suffering and their individual reasons for seeking medical advice, such as concerns about back pain or late complications, or to properly evaluate current symptoms and to make a decision based on this understanding.

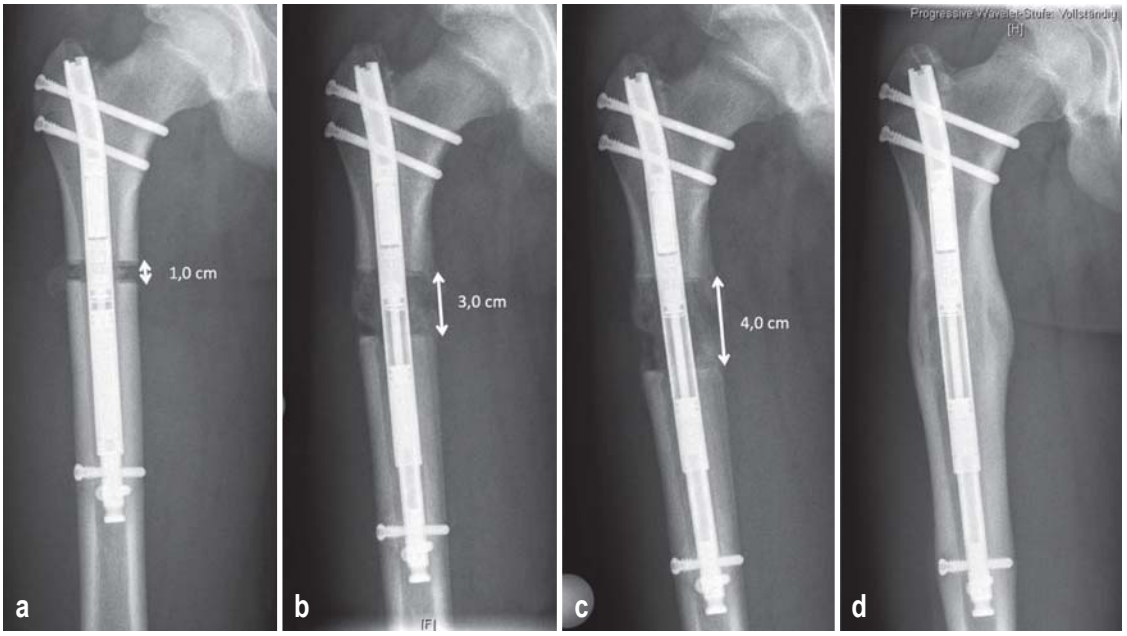

Figure 4: Distraction osteogenesis of the femur with a total length of 4.0 cm, using a magnetically controlled intramedullary lengthening nail:
a) 2 weeks after surgery (distraction 1.0 cm);
b) 4 weeks after surgery (distraction 3.0 cm);
c) 6 weeks after surgery (distraction 4.0 cm);
d) After complete consolidation at 6 months after surgery

In growing children, measuring leg length discrepancy provides only a snapshot, capturing the current situation. Treatment decisions are primarily based on leg length discrepancy after skeletal maturity. In patients with leg length discrepancy due to premature epiphyseal closure, the extent of shortening can be predicted based on the residual bone growth of the contralateral epiphyseal plate (18).

In patients with congenital leg length discrepancy, the prognosis is made using the multiplier method (19, 20). A greater accuracy is achieved by determining the skeletal age. However, there is a residual uncertainty of about 2 cm, depending on the length of the prognostic interval (21). Based on the considerations detailed above and their own experiences, the team of authors has developed a table as an aid to decision making *(Table 3)*.

Conservative treatment

Conservative treatment is typically reserved to patients with moderate leg length discrepancy between 2 cm and 5 cm (1, 2, 22). It is not necessary to seek full leg length equalization. There is good consensus that leg length discrepancy should be corrected to 1 cm and 2 cm residual inequality in growing children and after skeletal maturity, respectively (2, 22).

Insoles and shoe lift

The limiting factor for leg length equalization using insoles is shoe volume. With heel wedge insoles, leg length discrepancy of up to 2 cm can be corrected. With closed shoes, correction of up to 5 cm difference can be achieved by sole lift (22).

Orthosis

Shoe lifts of ≥ 5 cm are associated with increasing instability so that the use of an orthosis becomes indispensable. Orthotic treatment always leads to relative equinus and loss of function of the ankle joint (22). Most patients with leg length discrepancy <10 cm cannot be treated with a functionally superior orthoprothesis since it is very difficult to use a prosthetic foot in this situation for space and cosmetic reasons (23).

Surgical treatment

Alternatively, surgical equalization is a treatment option for patients with leg length discrepancy of ≥ 2 cm (7, 24). For the reasons discussed above, the shortening limp and the reduced shoe functionality resulting from shoe lifts should inform the treatment decision, rather than any assumed late complications (7). When large leg length discrepancies are managed with orthoprosthetic treatment, this functional impairment gets worse.

Growth arrest

In growing children, growth can be arrested by timely surgical intervention blocking the knee-adjacent epiphyseal plates of the longer leg. To do this, the expected leg length discrepancy and the remaining residual growth must be predicted. As a rule of thumb, an annual residual growth of the distal femoral physis of

Key messages

- The indication and the choice of leg length equalization method are always elective and decided by the informed patient.
- Leg length discrepancy between 2 and 5 cm can be equalized. This can be achieved by shoe lift and/or insoles. Alternatively, an intramedullary lengthening nail can be used for leg length equalization.
- In skeletally immature patients, it is possible to treat differences in leg length by growth arrest. With this treatment option it is important to discuss the effect of the procedure on body proportion and height.
- Conservative equalization of leg length discrepancies of more than 5 cm can only be achieved using large aids. Surgical management is typically based on multistage procedures.
- If a leg length discrepancy of considerably more than 5 cm is expected, growing patients should already be informed about surgical treatment options when the existing difference in leg length has reached 5 cm.

0.95 cm and the proximal tibial physis of 0.64 cm can be assumed (25).

The growth arrest can be permanent, effected by ablation of the physis, or temporary, effected by staples *(Figure 3)*, screws or plate-screw systems bridging the epiphyseal plate (26).

It should be noted that any shortening surgical procedure will also reduce the absolute height. In patients with significant shortening of >5 cm, this can create relevant changes in the proportion of the legs to the trunk (26), because the short leg—as described above—is almost always the abnormal leg (2). The existing proportions can be determined by calculating the ratio of sitting height to subischial leg length (18, 26).

Besides prediction uncertainty, a key risk associated with growth arrest is that secondary axis deviation is created by unbalanced blocking of the epiphyseal plate (2, 26–29). Both risks increase with the extent of the leg length discrepancy requiring correction. The prognosis is all the more uncertain, the younger the child is. Likewise, the earlier the growth arrest is initiated, the longer the abnormal growth can have an effect (26).

Consequently, growth arrest is a technique rather suited for moderate leg length discrepancy between 2 and 5 cm (2, 26, 27).

Acute shortening und acute lengthening

By acute shortening and lengthening, about three to four centimeter change in length are achieved intraoperatively after bone resection, using forced compression or extension (30). This surgical procedure is associated with comparatively large incisions and scars (31). Furthermore, acute shortening or lengthening of a bone is always associated with significant stress on soft tissue (2, 30, 32).

After bone shortening, the soft tissue is relatively too long, resulting in passive muscle failure with loss of strength, even to the extent of observable limping (2, 33). Intensive training can compensate for this loss of strength, but this process may take years, depending on the extent of lengthening. Overall, complications occur in one-third of patients (31).

Limb lengthening is associated with a significant risk of stretch injury to vessel-nerve structures (32). In addition, filling the bone defects created by the lengthening procedure can be very challenging. Frequently, patients have to undergo a second surgical procedure for bone grafting (30, 32, 34).

Continuous lengthening using external fixators and fully implantable intramedullary nails for limb lengthening

The technique of continuous bone lengthening was established in the 1980s, using external fixators. After osteotomy, new bone was grown by distraction osteogenesis. The external apparatus remains in place about one to two months for each centimeter of lengthening (32).

Over the last 20 years, work has been done to reduce the fixator wearing time. By the combined use of intramedullary nails and external fixators (lengthening over nails, LON), the wearing time was reduced by almost half (35). On the other hand, fully implantable intramedullary nails for limb lengthening were developed (36, 37). These create the forces required for the distraction of the callus either by mechanical rotation of the segment forwards or backwards to be extended against each other (intramedullary skeletal kinetic distractor, ISKD) or by electric motors acting inside (Fitbone) or outside of the nail (Precice) (36, 37) *(Figure 4)*. However, the use of these intramedullary nails is limited by the anatomical configuration, including diameter and bone length, as well as open epiphyseal plates.

Continuous slow distraction results in a significant reduction of soft-tissue stress compared to acute lengthening. Nevertheless, soft tissue stress remains a problem; in the experience of the authors, significant difficulties can also be associated with continuous distraction of the femur beyond 8 cm and of the tibia beyond 5 cm.

Typical complications of all of these techniques are inadequate or excessive bone formation, transient and resident joint contractures and even dislocations as well as transient and permanent damage of nerves and blood vessels (28, 34). The use of intramedullary nails for limb lengthening has eliminated the problem of pin infection associated with fixators. Nevertheless, bone lengthening remains a potentially high-risk technique *(Table 1)*.

Conclusion

Technological advances have dramatically improved the possibilities of bone lengthening with regard to the burden on patients. Over the next few years, there will be further advances in the development of implantable lengthening devices. Examples of conceivable

developments are extension plates that can also be used in patients with open growth plates or implants providing biofeedback of the bone regenerate. Nevertheless, bone lengthening will remain a challenging technique, requiring significant experience, especially in controlling potential complications.

Conflict of interest

Dr. Vogt has received reimbursement of conference fees and travel expenses from Merete Medical, Orthofix und Nuvasive. He has received lecture fees from Merete Medical and Nuvasive.

Prof. Wirth has received lecture fees from Orthopediatris (Warsaw, USA). He has received study support from Orthofix (Italy).

Joachim Horn, MD, PhD, is a paid consultant for Nuvasive contributing to teaching programs on surgical techniques.

Prof. Rödl holds patents and receives license fees/royalties from Merete for Flex Tack and Rigid Tack. He has received reimbursement of travel expenses from Nuvasive, Merete and Smith & Nephew. He has received lecture fees from Nuvasive and Smith & Nephew.

The remaining authors declare no conflict of interest.

Manuscript received on 31 May 2019, revised version accepted on 4 March 2020

Translated from the original German by Ralf Thoene, MD.

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Cite this as:
Vogt B, Gosheger G, Wirth T, Horn J, Rödl R:
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Dtsch Arztebl Int 2020; 117: 405–11.
DOI: 10.3238/arztebl.2020.0405

► Supplementary material

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Leg Length Discrepancy—Treatment Indications and Strategies

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Dtsch Arztebl Int 2020; 117: 405–11. DOI: 10.3238/arztebl.2020.0405

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Questions for the article in issue 22–23/2020:

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cme plus

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Please select the answer that is most appropriate.

Question no. 1

Which observation contradicts the assumption that leg length discrepancy has a negative effect on femoral head containment?

a) People are not frequently in double-leg stance with equal weight distribution and thus this position should no lead to relevant improper loading.
b) Due to the characteristic hypertrophy of the gluteal muscles, sustained pelvic misalignment during double-leg stance is unlikely.
c) The resulting scoliosis supports the correct bio-mechanical balancing of the pelvis.
d) The bilateral femoral head microlesions revealed by computed tomography.
e) The typically hypotrophic muscles of the short leg.

Question no. 2

What is the most common cause of large disparity in leg length?

a) Rare congenital malformations
b) Hip joint contractures
c) Osteomyelitis
d) Femoral head necrosis
e) Knee joint contractures

Question no. 3

When should a standing full-leg radiograph with leg length equalization be obtained?

a) During the initial examination
b) During annual follow-up examinations
c) To fit an orthosis
d) For surgery planning
e) For outcome assessment after completion of treatment

Question no. 4

What is the available evidence on the management of leg length discrepancy like?

a) There are only 3 randomized controlled trials, evaluating leg lengthening using external fixators.
b) Several case-control studies have evaluated the combination of methods for continuous lengthening and shortening.
c) Until now, only retrospective analyses of the various lengthening procedures have been published.
d) In a Cochrane review, the conservative interventions were pooled in a meta-analysis.
e) Several multicenter RCTs have demonstrated the safety and efficacy of growth arrest by physeal stapling.

Question no. 5

What is the functional characteristic of leg length discrepancy?

a) Scissor gait
b) Steppage gait
c) Akinetic-rigid gait
d) Shortening limp
e) Ankylotic limping

Question no. 6

What complications are typically associated with the use of intramedullary nails for limb lengthening or external fixators?

a) Paresthesia of the sole of the foot and the toes
b) Streptococcus pyogenes infection of the surgical wound
c) Fractures adjacent to intramedullary nails
d) Resident joint contractures
e) Improper loading of the lengthened leg

Question no. 7

Which method is used to establish the prognosis of congenital leg length discrepancy?

a) The multiplier method
b) The APACHE system
c) The Simplified Acute Physiology score
d) The modified Cincinnati rating system
e) The SOFA score

Question no. 8

At what point should surgical treatment of leg length discrepancy be considered?

a) Only after the closure of the epiphyseal plates
b) When back pain occurs in the presence of leg length discrepancy.
c) As soon as a child is bullied because of the shoe lift.
d) Starting from a leg length discrepancy of 1 cm which is rated as 1/20 leg value in the personal accident insurance.
e) As soon as a leg length discrepancy of more than 5 cm is present or expected.

Question no. 9

What is a transient consequence of limb shortening surgery?

a) Passive muscle failure
b) Limping of the unaffected leg
c) Toe walking
d) Heel walking of the short leg
e) Duchenne limp

Question no. 10

According to the authors, how should sporting activities always be performed by patients with a leg length discrepancy of <5 cm?

a) Lordosis support
b) With height-correcting insoles
c) With supportive orthotic devices for the ankle joint
d) Without conservative leg length equalization
e) With a custom-made sports shoe