Clinical measurements of proprioception, muscle strength and laxity in relation to function in the ACL-injured knee

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Abstract

A knee injury with ACL rupture may cause deficits in proprioception, increased laxity and decreased muscle strength. Although it may be common knowledge that these factors affect knee function, only a few studies have been performed where this has been investigated in the clinical situation and the results are not conclusive. The purpose of this study was therefore to investigate how and to what extent proprioception, laxity and strength affect knee joint function and evaluate if the methods commonly used for estimating these factors clinically seem to be relevant.

The study encompassed 36 patients with ACL deficiency. A single-leg hop test for distance and subjective rating of knee function were defined as dependent variables and analyzed separately in stepwise linear regression models where proprioception, knee joint laxity, hamstrings and quadriceps strength, age and sex were defined as independent variables.

Higher threshold values (poorer proprioception), increased side-to-side difference of anterior laxity and poorer strength significantly predicted shorter length of the hop test. Higher rating of subjective function corresponded to female gender, lesser side-to-side difference of anterior laxity and better proprioception.

Key words: Knee injuries · Anterior cruciate ligament · Knee joint · Proprioception · Laxity

Introduction

Mechanoreceptors located in the joint capsule, knee joint ligaments and menisci may be affected by a knee injury involving ACL rupture and disturbances of the afferent activity may occur [21-24].

Proprioceptive measurements have been performed in clinical situations for a couple of decades with an increase the past 10-15 years. A number of measurement methods have been used [3, 5, 6, 8-10, 12, 16, 20, 25, 27, 32] but few have been tested for relevance – i.e. is the proprioceptive defect found related to knee function? There is also a lack of consensus of which method is preferable and in what situation – what modality of proprioception, joint position sense or kinesthesia, should be used.

The proprioceptive system is complex and encompasses both spinal and cortical projections and reflective pathways [23] why it can not be taken for granted that the perception of movement or joint position in clinical measurements reflects the status of the whole system, or that measured proprioceptive defects are connected to functional disability. The ability to consciously perceive proprioceptive signals may differ, and be dependent on many factors, such as distraction during the measurement session, regardless of the actual proprioceptive activity [2]. The relevance of the sometimes small proprioceptive alterations found after injury have been questioned and the few studies we have found examining this are not unanimous [7-9].

The relevance of clinical measurements of laxity and muscle strength and their relative influence on the outcome after injury also seem to be unclear [9, 11]. We therefore performed the present study with our previously used methods to assess these factors, proprioception, laxity and strength, in relation to knee function.

Materials and Methods

Patients

The study included 36 patients, 18 women, with a history of recreational sports activities from the Orthopedic Department, Lund University Hospital. The patients were recruited from the Dept. of physiotherapy where they all went for rehabilitation. All patients had a total ACL rupture verified by arthroscopy, in most cases within 10 days after injury, which was the routine at the Department at that time. The patients in this study were not classified according to associated lesions - i.e. meniscal, chondral or collateral ligament injuries. This is the case in most studies where knee joint proprioception is examined and may be a limitation since some previous studies have shown that different injury morphology may affect patients differently with regard to proprioceptive ability [18, 30]. However, in this study the objective was to examine an unselected group of patients according to both injury morphology and function. The distribution of significant associated injuries is presented in table 1. The mean age was 26 (women 24.7, range 17-35, and men 27.1, range 16-35) years. The mean time since injury was 3.8 years (women 3.8, range 0.5-11, and men 3.75, range 0.5 – 11) years. On a patient satisfaction scale, VAS analogue scale, range 0-100, where 100 indicates good knee function, as that before injury, and 0 was total disability, the patients had a mean score of 58.9 (women 65.9, range 12-94, and men 51.8, range 12-95). All patients were initially treated conservatively, which was the routine for recreational sportsmen/women without specific demands, and the mean rehabilitation time was 7 months (range 0-24). The rehabilitation program encompassed intensive neuromuscular rehabilitation program where hamstring strength and coordination were emphasized and has been described in detail elsewhere [30]. Time of physiotherapy for each patient is presented in table 1. The median Tegner activity level was 4 (women 4, range 1-9, and men 4.5, range 1-9), equal to semi-heavy labour or sports activities such as cycling or jogging on even ground at least twice a week.).

To assess the patients' functional status self estimated scores and hop-tests were used. Neither of these methods alone may be adequate to fully assess the patients' knee status since they may capture different aspects of physical performance and function [13]. We chose not to use instability episodes as a single measurement of outcome. In our opinion, a functional test like the hop-test has advantages over registration of the number or occurrence of instability episodes, which may be another way to estimate success of treatment. A patient with instability may learn to avoid these events by modification of his or her activity and thus the absence of instability episodes is not equal to good knee function. This may be captured using self estimated scores or functional test like hop tests.

For estimation of subjective estimation of extremity function, a VAS graded from 0 to 100 mm was used, whereby 0 was *as if the knee had been recently injured* and 100 was *perfect* [32] that is, higher values indicate better function. The VAS has been shown to be a valid and reliable measure of function in patients with knee injuries [14], to highly correlate with functional status [11] and to identify patients with good function and those with poor function [11, 36].

The Research Ethics Committee at Lund University Hospital approved the study and all subjects gave their written informed consent to participation.

We randomized the starting leg and testing was performed in the following order:

1. Laxity test.
2. Proprioception test.
3. Single leg hop test.
4. Muscular peak torque measurements.

Table 1.

Distribution of associated injuries in the knee joint and months of physiotherapy for each patient.

Patient no.	No ass. injuries	Med/Lat. meniscus	MCL/LCL injuries	Cartilage injuries	Physio. months
1	X				6
2		L			8
3		M			4
4		L	MCL		3
5	X				4
6		L	MCL		10
7		L+M			6
8		M			1
9	X				4
10				tibia	5
11		M			8
12		L	MCL		6
13		L+M			12
14		L+M			12
15	X				3
16	X				1
17				femur	6
18		L+M			6
19	X				12
20	X				14
21		M		patella	24
22	X				5
23		L+M		tibia+femur	6
24	X				8
25		L+M	MCL		6
26	X				3
27	X				4
28	X				5
29		L			22
30		M+L		femur	1
31		L+M	MCL		4
32			MCL		6
33		L			6
34	X				7
35	X				8
36		L			0

Laxity

Anterior and posterior displacement of the tibia relative to the femur were recorded in millimetres using a KT-1000 arthrometer (MEDmetric Corp, San Diego, Calif) with an 89-N force, according to the manufacturer's manual. The arthrometer was fixed to the limb according to the manufacturer's specifications, with the knee flexed between 20° and 30°. The registered anterior displacement (mm) was measured for both legs and the side-to-side difference, injured-uninjured side, was used for statistical analysis. We chose to use the 89-N force, instead of maximal force, for standardised reproducible measurements which has been used frequently before [26, 33-35, 37].

Proprioception

Such measurements have been described in detail in our previous investigations [15-18, 31, 32]. In this study we chose to use a "proprioceptive index" as the value for statistical analysis. This proprioceptive index is the sum of the four threshold values towards extension and flexion from 20° and 40°. This index was constructed to obtain a single overall proprioceptive value for each patient, which make individual comparisons between the patients easier, simplify the analysis and interpretation of the results but may also reduce the risk of multicollinearity problems in the statistic model.

Single-leg hop test

We used a modified version of the one-leg hop test with the arms free and aiming at a more functional execution of the hop, thus making it easier to balance the body [38]. The subjects were told to hop as far as possible, taking off and landing on the same foot. The test was performed three times with each leg, alternating the right and left leg, the hop distance being measured from toe to toe. The patients first did a trial one-leg hop before we made the measurements. They wore shoes- e.g. sneakers. The best value of the three consecutive hops was used for the analysis. We used this test to estimate extremity function since it has been found reproducible and valid [13].

Muscle strength testing

Measurements of concentric isokinetic strength of the knee muscles were performed with a Biodex Multi-Joint System II isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY) with Biodex Advantage software, version 4.5 (Biodex Medical Systems Inc). The standard Biodex knee unit attachment was used. Subjects were placed in an upright position with 90° of hip flexion on the dynamometer chair and were secured with straps across the chest, pelvis, thigh, and ankle. The resistance pad was placed as distally as possible on the tibia while still allowing full dorsiflexion at the ankle. The center of motion of the lever arm was aligned as accurately as possible with the slightly changing flexion-extension axis of the knee joint. The range of motion of the knee joint was set at 0° to 100°. The subjects gripped the edge of the bench to stabilize the body during the test. Standardized oral instructions and encouragement were given. The subjects were allowed trial tests to familiarize themselves with the equipment and the test procedure before 5 maximal reciprocal concentric isokinetic knee extensions and flexions at an angular velocity of 60 deg.s-1 were made. The sum of the peak torque (Nm) for quadriceps and hamstrings, giving a muscle strength index value (peak torque quadriceps plus peak torque hamstrings), was used in the analysis and has been used previously [1]. This index was constructed since we found it to be the best alternative in this situation to assess muscle strength. The frequently used hamstring:quadriceps ratio has its' obvious limitations. Choosing one group of muscles to use for strength measurements is not easy since poor quadriceps strength has been shown to predict bad knee function and OA and hamstrings are important stabilizers. Analysing them separately adds two extra analyses which is not optimal. Putting them both separately in the same model may cause multicollinearity problems. Using the strength index, for our purpose, may be more logical in this study since we use an index also on the proprioceptive measurements.

Statistics

We used stepwise linear regression models where single-leg hop distance and subjective function were dependent variables in turn, and side-to-side difference of anterior laxity, proprioception, strength, age and sex independent variables. The objective was to estimate how and to what extent the independent variables affect each dependent variable. For all analyses, we used the results of the injured leg of the patients. In this study, as well as in some of our previous studies [16, 31, 32], a few patients had a more marked increase in threshold values than the other patients. Especially one patient had proprioceptive values that differed substantially from the rest of the group. We discussed to exclude this patient but since we have seen these types of extreme values before, and even larger values [16, 32], we decided not to exclude this observation. These patients do exist. It is, however, a fact that this is an influential observation, which does not change the direction of the regression line but increases the slope of the line in the same direction.

We used only the 89N (20 lbs.) value from the laxity test, strength index and proprioceptive index in order to minimize multicollinearity problems in the model. However, there is probably some relation between laxity and proprioception and strength index. Since we considered each of these variables to be essential in the analysis, we included them in the model. Running a stepwise analysis may thus be more appropriate. The correlation matrix showed no value higher than 0.17 between any of these variables. We used Axum 7 for Windows (MathSoft Engineering & Education, Inc. Cambridge, MA) for statistical analysis.

Results

Summary statistics for age, subjective function, laxity test, one leg hop test, proprioceptive threshold index, peak torque for extension, and flexion, and strength index is presented in table 2.

The first stepwise linear regression model showed that increased side-to-side difference of anterior laxity and poorer proprioception significantly predicted shorter hop length. That is, 1 mm increased side-to-side difference of anterior laxity shortens hop length by 8.5 cm (P=0.026) and an increased proprioceptive threshold value by 1° shortens hop length by 11.8 cm (P=0.005). There was also a significant relation between strength index and hop length - an increased strength index by 1 Nm increased hop length by 0.38 cm (P<0.001) (Table 3A, Figures 1A-C).

The second model showed that male gender, increased laxity and poorer proprioception significantly predicted poorer subjective function. That is, female gender increased subjective function by 15.4 units (P<0.001), 1 mm increased side-to-side difference of anterior laxity decreased subjective function by 6.5 units (P<0.001) and an increased proprioceptive threshold value by 1° decreased subjective function by 4.5 units (P=0.009) (Table 3B, Figures 2A-C).

Table 2.

Summary statistics for age, injured leg subjective function, KT-1000 (sagital amplitude for injured leg, uninjured leg and side-to-side difference), injured leg one leg hop test, injured leg proprioceptive threshold index, injured leg peak torque for extension and flexion and injured leg strength index.

	Age (years)	Subj. (0-100)	Ant. laxity inj. (mm)	Ant. laxity uninj. (mm)	Side-to-side diff. (mm)	Hop test (cm)	Thres-hold index (°)	PeakT Ext. (Nm)	PeakT Flex. (Nm)	Strength index (Nm)
Min	16	12	2.5	2.0	-4.5	0	1.8	0	0	0
Max	35	95	11.0	9.0	7	241	14.2	345.5	156.8	502.3
Mean	25.9	58.9	7.1	5.0	2.06	145.9	4.1	174.9	96.1	270.9
STD	5.4	27.4	2.4	1.6	2.4	66.8	2.2	63.8	32.4	94.1

Table 3.

The results of the multiple regression analysis after stepwise selection with the default setting of P-value of less than 0.15 for entering the model. Single leg hop test length in A and subjective function in B defined as the dependent variable. Coefficient value, with standard error, shows how the length of the hop test in A and rating of subjective function in B is changed, per increased unit of the independent variable. T-value, with corresponding P-value, shows the test result whether the coefficient is significantly different from zero. Multiple R-squared represents the proportion of variance in the dependent variable explained by the model. F-statistic tests whether at least one of the coefficients, excluding the intercept, are significantly different from zero, with the corresponding P-value. Gender = dichotomized variable where men = 0 and women = 1., KT-1000 = results from anterior laxity tests, side-to-side difference, with KT-1000 arthrometer, Strength index = summary of peak torque extension and flexion values (Nm), Threshold index = proprioceptive threshold values.

A.

Hoptest

	Coeff. value	*Std. Error*	*t-value*	*P-value*
Gender	16.9827	10.1592	1.6717	0.1047
KT 1000	-8.5364	3.6424	-2.3436	0.0257
Strength index	0.3818	0.1008	3.7875	0.0007
Threshold index	-11.8314	3.8839	-3.0463	0.0047

Multiple R-Squared: 0.5244
F-statistic: 8.545 on 4 and 31 degrees of freedom, the p-value is 0.00009071

B.

Subjective function

	Coeff. value	*Std. Error*	*t-value*	*P-value*
Gender	15.3825	3.8735	3.9712	0.0004
KT-1000	-6.4706	1.5408	-4.1996	0.0002
Threshold index	-4.5180	1.6306	-2.7712	0.0092

Multiple R-Squared: 0.476
F-statistic: 9.691 on 3 and 32 degrees of freedom, the p-value is 0.000106

Figure 1 and 2.

Graphs 1 and 2 show linear fit plots, with regression line, for y=hop test in figure 1 and y= subjective function in figure 2 and x= laxity/strength/proprioception respectively in A-C.

Figure 1A

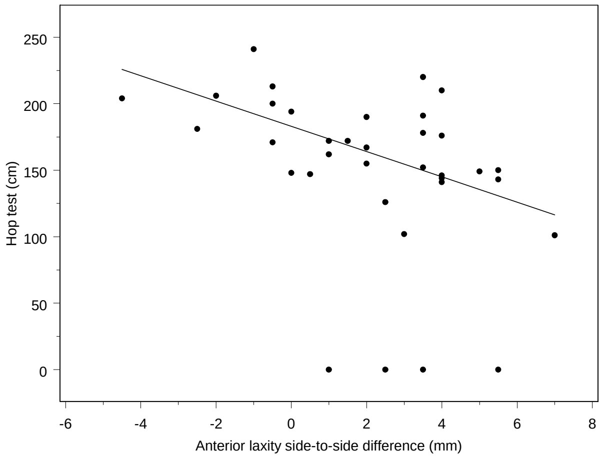


Figure 1B

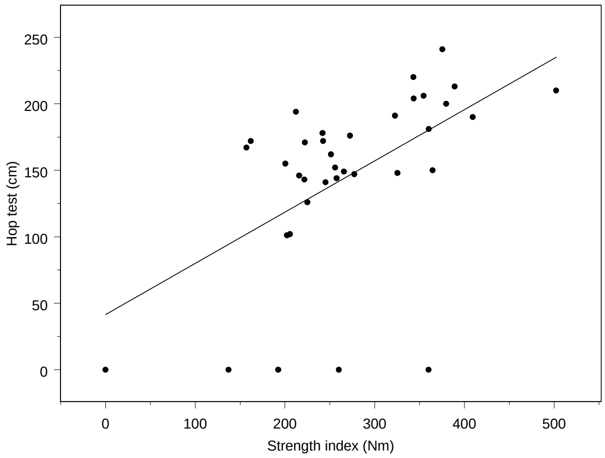


Figure 1C

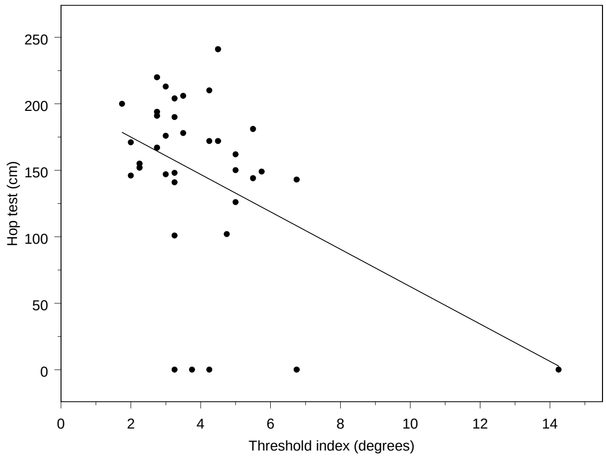


Figure 2A

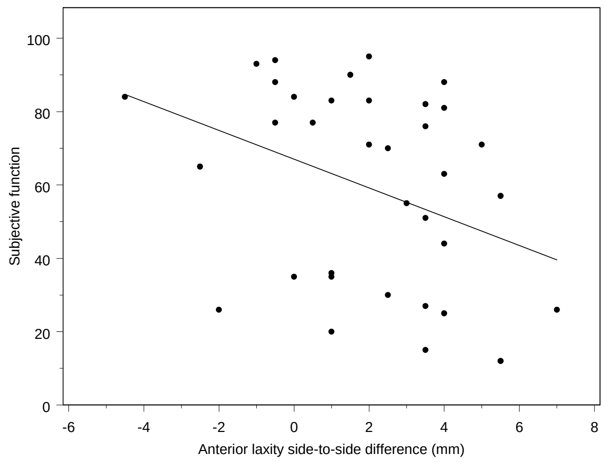


Figure 2C

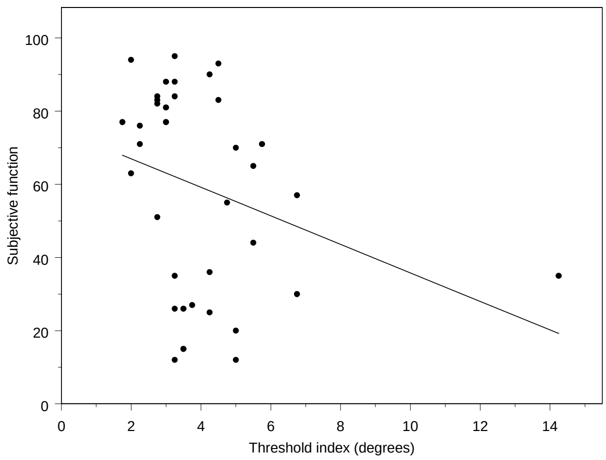
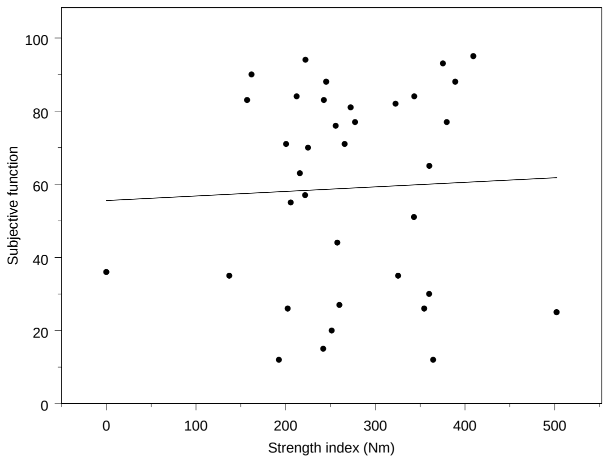


Figure 2B



Discussion

Clinical proprioceptive measurements have become quite frequently used the past 10-15 for patients with knee injuries, and ACL ruptures in particular, and several methods of assessing proprioception has been used [3, 5, 6, 8-10, 12, 16, 20, 25, 27, 32]. Despite this, we have found only a few studies investigating the relation between proprioception and functional testing in ACL-deficient patients. Carter et al. examined joint position sense and performed functional activity tests with a single-leg hop and figure-of-eight run [9]. The results showed that rehabilitation improved the results of the functional testing, but joint position sense was unaffected and was not correlated to functional testing. They thus concluded that the role of joint position sense in relation to the stability of ACL-deficient knees was unclear [9]. Borsa et al. found a significant relationship between single-leg hop distance and proprioception measured as the threshold for the detection of passive motion [8] but concluded in a later study that neither strength, hop length nor proprioception was significantly correlated to patient disability estimated by subjective rating [7].

The results of the present study imply that there is a significant relationship between the single-leg hop distance and clinical measurements of proprioception. Thus, impairment of the neuromuscular system seems to cause shorter hopping length, which agrees with the previous findings of Borsa et al. [8]. As noted above, our results are not in agreement with those of Carter et al. [9] but they used a different method of estimating proprioception, i.e. reproduction of passive positioning using a visual analogue goniometer, whereas we used the threshold for detection of passive motion and the studies are thus difficult to compare. In our experience, the threshold for detecting passive motion is more sensitive and reproducible in detecting proprioceptive defects than passive or active reproduction [15-18, 29, 31].

In a previous study by Eastlack et. al, poor correlation between hop length and laxity, anterior laxity at maximum manual force measured by KT-2000 arthrometer, in ACL-deficient patients was found, and non-symptomatic patients did not seem to differ from symptomatic patients in regard to laxity increase [11]. Neither in a recent study by Pollet, any significant correlation was seen between anterior laxity, side-to-side difference measured by Rolimeter, and functional hop tests among patients treated surgically or conservatively for their previous ACL injury [28]. In the present study, increased side-to-side sagital amplitude significantly predicted both shorter hop length and poorer subjective function. In this study, we also assessed proprioceptive capability, which was included in the regression model as a factor of importance for extremity function. It is possible that this explain the difference compared to the study by Eastlack et. al, who also used a regression model but without proprioception [11], and the study by Pollet et. al who used correlation analysis without proprioceptive variables [28].

The results of regression models are of course highly dependent of the variables put into the model. We chose to focus on three main physiological variables with a believed effect on knee function after injury – laxity, strength and proprioception and we have found no other study where all these factors have been analyzed this way, in relation to knee function. Hence, the studies are difficult to compare.

Regarding muscle strength, hamstrings are considered important stabilizers in the ACL-deficient knee and the patients went through an intensive neuromuscular rehabilitation program where hamstring strength and coordination were emphasized [39]. The time since injury, and rehabilitation, in this study show a quite wide range, 0.5-11 years, which should be considered. However, the achieved hamstring strength and ability seem to persist for years [39]. According to previous studies, lower extremity muscular strength is only slightly or moderately related to single-leg hop test performance, implying that other factors are important in extremity function [13], which is supported by the results of the present study.

According to our results, subjective function also seems to be related to proprioception and laxity. Subjective function is a complex measure, which encompasses defined, and probably also undefined, symptoms and abilities. Proprioception and laxity seem to be factors of importance [4], and are in turn related to other variables. This complexity makes it difficult to design models intended to explain only one of the variables, and this must be taken into consideration when interpreting the results and again, the results are dependent of what variables that are incorporated in the analysis.

We have not been able to compare the finding that women were significantly more satisfied with their knees with other studies. Gender differences regarding proprioception and knee function have been discussed [19] and the frequently reported higher incidence of ACL injuries in women, compared with men, has been suggested to be caused by decreased proprioception and increased laxity [33]. Speculations have been made regarding the possibility that women may need longer periods of rehabilitation than men to regain functional stability, or that ACL injury in women results in greater proprioceptive damage [19]. These speculations suggest that women would exhibit a functionally poorer outcome as a result of the injury and would therefore be less satisfied with their knees. Our present results regarding subjective function suggest the opposite. The time factor may be of importance, as the mean time since injury was 3.8 years, which is quite long. It is also possible that recovery/compensation mechanisms, as well as conscious adaptation and lower demands, regarding sporting activities, influence the subjective outcome.

In conclusion, our results show that at an average time from injury of 3.8 years, clinical findings of higher proprioceptive threshold values, increased side-to-side difference of anterior laxity and poorer strength are related to functional impairment in this group of unselected ACL-deficient patients. To our knowledge, no clinical protocol for knee examination has been presented where these factors are assessed together in a standardized way. It will be a future task to develop such a method, considering these factors and also other factors of importance, which can be of clinical use in the individual case. That would hopefully increase our ability to prognosticate the outcome early after ACL injury and thereafter individualize treatment with respect to the morphological and physiological defects.

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