12

Recognition of Posture and Gait Disturbances in Patients with Normal Pressure Hydrocephalus Using a Posturography and Computer Dynography Systems

L. Czerwosz[1], E. Szczepek[1,2], B. Sokołowska[1],
J. Jurkiewicz[1,2] and Z. Czernicki[1,2]
[1]*Mossakowski Medical Research Centre, Polish Academy of Sciences, Warsaw,*
[2]*Warsaw Medical University, Warsaw,*
Poland

1. Introduction

There are great difficulties in clinical practice to differentiate between normal pressure hydrocephalus (NPH) and brain atrophy (Tans 1979, Galia at al. 2005). The consequences of inaccurate diagnosis are serious therefore we observe steady searching of new non-invasive or minimal-invasive diagnostic methods.

The purpose of this study is to quantify the characteristics of the postural sway and locomotion in NPH patients in two states: before and after shunt implantation and to compare posture and gait features among: NPH, brain atrophy patients and healthy persons.

Assessment of stability and balance system consist in quantitatively measuring and analysing movements of the centre of foot pressure (COP). Position of COP steadily changes due to the so called postural sways, and of course due to voluntary moves. Enlarged sways, observed in normal pressure hydrocephalus, are not however specific and cannot give simple diagnosis. Postural balance can be impaired due to pathology in various organs including vestibular and cerebellar disorders and various forms of ataxia (Mohan at al. 2009), Parkinsonism (Bloem at al. 1995, Stolze at al. 2001, Jagielski at al. 2006), multiple sclerosis (Kessler at al. 2011) and even alcohol dependence (Wöber at al. 1998) and muscle fatigue or aging (Błaszczyk and Michalski 2006).

Evaluation of gait relates to postural stability in standing upright position. The gait disturbance is probably the most prominent clinical feature of NPH and it is often the first NPH symptom to develop (Radvin 2008). Gait disturbances are part of so called Hakim triad (Hakim & Adams 1965). NPH gait disturbances are very characteristic and rely on shuffling manner of walking, without raising the feet as if they were glued to the floor. This kind of gait is called also magnetic. Gait disturbances are still not fully described quantitatively due to lack of reliable, specific parameters measuring most typical features of gait in NPH.

Some papers related to postural stability and gait evaluation in NPH have already been published by Szczepek and Czerwosz (Szczepek at al. 2008, Czerwosz at al. 2008, 2009). The current study is trying to summarize some of our results.

2. Methods

Recently rapid development of precise methods of quantitative measurements of body position while standing or walking has been observed. Two techniques used by us in our investigations should be discussed here:

1. static posturography – measurement of body sways while standing on a force plate,
2. dynography – measurement of gait.

In both systems the resultant force – feet pressure acting on the horizontal surface (XY) is calculated on the basis of some number of pressure sensors. The most important is the point of application of this force. This point is called Centre of foot/feet Pressure (COP). In static conditions the COP point is a projection of the Centre of Gravity (COG) position – on the XY horizontal plane. COM and COG signals are highly correlated (Błaszczyk 2008). It has been documented that COG signal can be extracted from COP by low-pass filtering (Benda et al. 1994). The high frequency component comes in dynamic and realistic conditions from inertia forces that influence COP instantaneous location. Inertia forces arise from accelerations of the body while it is swaying or moving – losing and recovering balance (Newton's second law of motion).

2.1 Posturography

The instantaneous COP xy position can be calculated on the basis of instantaneous values of $p_1(t)$, $p_2(t)$, $p_3(t)$, $p_4(t)$ forces measured on four corners of the square plate; d is a length of it's side. In case of our device: d= 40 cm.

$$\begin{cases} x(t) = \frac{d}{2}(-p_1(t) + p_2(t) + p_3(t) - p_4(t)) / (p_1(t) + p_2(t) + p_3(t) + p_4(t)) \\ y(t) = \frac{d}{2}(+p_1(t) + p_2(t) - p_3(t) - p_4(t)) / (p_1(t) + p_2(t) + p_3(t) + p_4(t)) \end{cases} \quad (1)$$

To obtain the exact position of COP, the p_n forces must be reduced by tare weights measured independently on each corner. The real force plate is shown on **Figure 1**; p_n forces are pointed and orientation of xy plane is given by X and Y axes. All $p_n(t)$ values, and therefore x(t) and y(t) change in time. In practice we collect them in 0.01 seconds intervals (sampling frequency 100 Hz) in digital form with 12 bit accuracy. Data were low-pass filtered (15 Hz cut-off frequency). Trajectory can be observed on-line and off-line in an analogue way on a chart called posturogram or stabilogram.

A single measurement on a force plate takes usually 30-60 seconds. The resultant time had to be reduced due to some artefacts related to unsolicited activity of the patient such as his movement or speaking influencing the outcomes. Removing artefacts is still an unresolved problem in posturography due to questionable difference between unsolicited movement and essential balance restoration, especially in case of large sways.

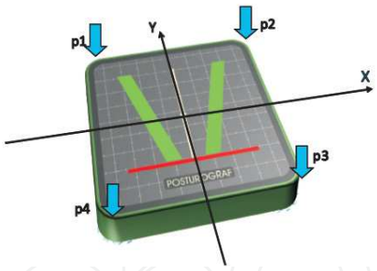


Fig. 1. Force plate.
There are four sensors measuring forces on each corner: p1, p2, p3, p4.
Y represents forward-backward, anterior-posterior sways, in sagittal plane,
X represents left-right, mediolateral sways, in frontal plane.

2.2 Examples of posturographic measurements

Figure 2 shows six examples of posturographic measurements with eyes open (EO) or closed (EC). The two first trajectories belong to NPH patient in acute state, before shunt

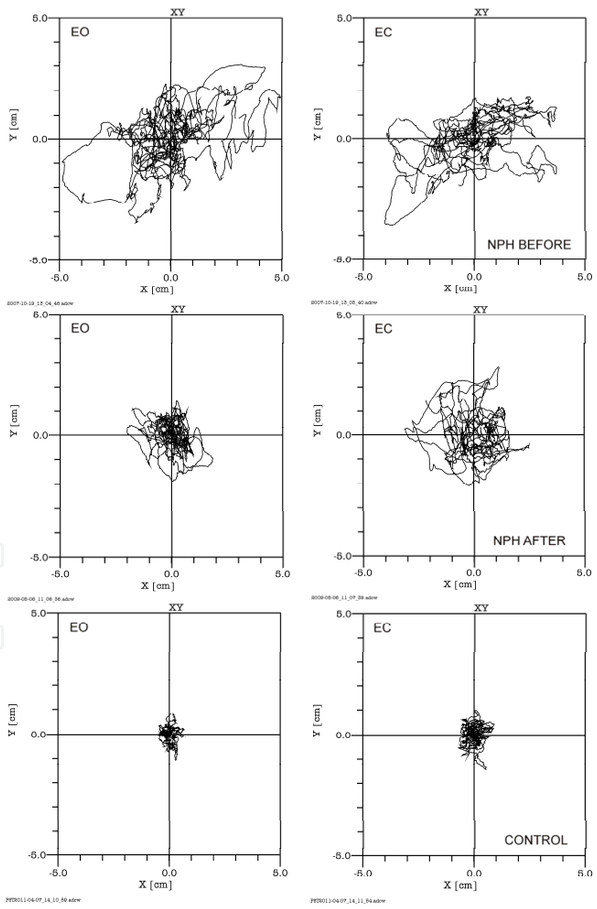


Fig. 2. Examples of measurements – from top: NPH BEFORE – NPH patient before shunt implantation measured with eyes open (EO – left) and closed (EC- right), NPH AFTER – NPH patient after surgery. CONTROL – healthy person.

implantation. The next two were measured after surgery; the last two belong to a healthy person. As one can see, there are big differences in the shapes of the trajectories, especially NPH patient before surgery demonstrates very large sways – both, with eyes open and closed. Sways of the NPH patient are very large both for EO and EC. After surgery sways are reduced but they are still larger than in a healthy person.

2.3 Posturography parameters

COP trajectory represents sways of an object standing in upright position for some time. There is some number of various metrics developed that evaluate average or typical "behaviour" of the curve in many aspects (Baratto at al. 2002, Raymakers at al. 2005).

The starting point of our analysis was to define the global parameters expressing the "size" of sways. We have taken into consideration:

- R – average COP sway Radius,
- A – Area of developed surface of COP trajectory, AS – Area Speed
- L – Length of COP trajectory, V – Velocity.

An average Radius of sway is a simple average of distances between curve samples and (0,0) point on XY plane – coordinate origin. Actually all points of the curve have been shifted by $(\bar{x},\bar{y})$ vector beforehand and thus (0,0) turns into the "centre of gravity" of all samples ($\bar{x}$ denotes average value of all x_i). This simple way of calculating R has been applied by Czerwosz and Szczepek in their papers (Czerwosz at al. 2008, 2009, Szczepek at al. 2008) and also Mraz at al. 2007, Bosek at al. 2005, Kubisz at al. 2011.

Calculation of developed area bases on all available samples. The developed surface consists of triangles created from every two consecutives COP positions sampled every 0.01 second and the coordinate origin (0,0). Let's compare this surface to wooden pencil shavings when sharpening a pencil. **Figure 3** shows the idea of the calculation on a piece of COP curve. The area depends on the number of samples – thus it depends on measurement duration. It is easy to normalize it dividing the area by measurement duration. In this way we are obtaining Area Speed (AS) in mm^2/sec.

The length of COP trajectory is calculated as a simple sum of consecutives segments between COP positions sampled every 0.01 second. Length after division by measurement duration becomes a Velocity (V) in mm/sec.

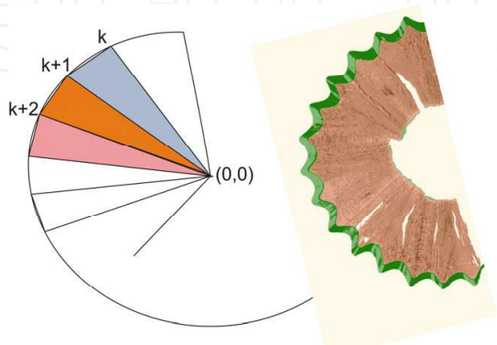


Fig. 3. Graphical explanation of how the developed Area of COP trajectory is calculated. k is a serial number of xy sample – COP position at time t_k, (0,0) is coordinate origin.

Each parameter can relate to two measurement conditions: eyes either open (EO) or closed (EC). In order to express change in value of some parameters due to different conditions one can use simple difference (2). For computational reasons in advanced statistical analysis sum of the same parameters (3) has been introduced.

$$D_x = X_{EC} - X_{EO} \tag{2}$$

$$S_x = X_{EC} + X_{EO} \tag{3}$$

where X can be R, A, AS, L, or V.

A derived parameter – the vision index (4) has been developed on the basis of Radius, Area, Area speed, Length or Speed to express difference of chosen parameter in relation to its mean value. Index is an absolute, dimensionless number with theoretical range [-100%, 100%]. Zero means no difference. One should notice that I_x is bigger for bigger D_x and smaller S_x and vice versa: I_x gets smaller for smaller D_x and bigger S_x. A similar index related to the parameters measured in two different conditions have been introduced by Mraz as ICOP (Mraz at al. 2007).

$$I_x = (X_{EC} - X_{EO})/(X_{EC} + X_{EO}) * 100\% \tag{4}$$

where X can be R, A, AS, L, or V. EC means „eyes closed", EO – „eyes open ", while measurement has been performed. We have made use of vision indices related to radius, area and length. Notice that the index related to area is equal to the index related to area speed ($I_{AS} = I_A$) and the index related to length is equal to the index related to velocity ($I_V = I_L$).

Let's take sight index of radius as an example. Exact way of calculation I_R is given below:

$$I_R = (R_{EC} - R_{EO})/(R_{EC} + R_{EO}) * 100\% \tag{5}$$

2.4 Dynography

Computerized dynography (Infotronic 2007) is a gait analysis system which consists of two soles containing sensors sensible to a foot pressure acting on the ground. These sensors measure the vertical ground reaction forces and their distribution during walking. It's a good alternative to much less quantitative gait scale – for measuring gait impairment of NPH patients (Boon at al. 2007). Another alternative is camera based system but then the only information that is provided are body parts positions and angles without any data related to forces. Walking on a treadmill gives just the speed of gait; to measure more gait features some extra instrumentation should be added. In this study we don't take advantage of forces explicitly, but our system (see below) uses them internally to determine gait phases. Other alternative method of gait evaluation can be performed on two or more joined force plates. This method limits gait to only few steps because of size. It can easily be used for gait analysis in small animals (Voss at al. 2007).

Special boot for dynography is presented in **Figure 4** (on the left side). There are eight sensors inside each sole located as shown in the middle picture. Actually eight histograms are shown here on the sole, not sensors, but they are distributed just as sensors. Histogram height expresses instantaneous or average force acting on a sensor. The picture on the right

shows how the point of application of the resultant ground reaction force is being displaced while stance phase of gait cycle. This point is the Centre of foot/feet Pressure (COP) and its position changes during each step. The overall load, the value of resultant ground reaction changes due to inertia forces as well.

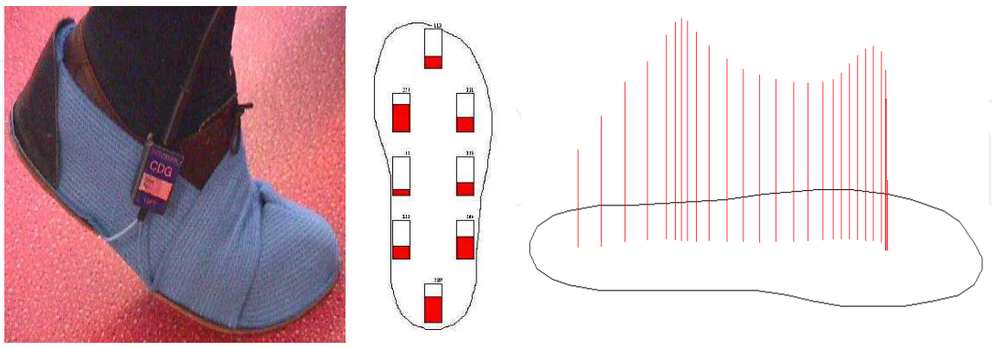


Fig. 4. Left: A boot for dynography with eight sensors inside its sole. Middle: Histograms express instantaneous or average force acting on each sensor. Right: displacement of resultant ground reaction force along a foot. (Pictures from Ultraflex system – Infotronic Company 2007).

The displacement of COP presented in **Figure 4** relates to single foot only. In this case COP position is calculated on the basis of eight sensors. **Figure 5** presents so called gait-lines where successive COP positions of each step are drawn overlapped. Gait-lines of each foot are calculated independently. Pictures on the right side are averaged over all gait cycles of 20 seconds walking. Gait-line represents stance phase of gait from initial contact, while a heel touches the ground till toe off moment (Perry & Burnfield 2010). COP can also be calculated on the basis of 16 sensors enclosed in two soles – from both feet. Cyclogram arises if connecting successive COP positions of each step and drawing the lines overlapped. They are presented in **Figure 6**. Pictures on the right side are averaged over all gait cycles. During double support the COP position lies somewhere between the feet depending on the load ratio and its position changes from one side to another. During single support COP is located within single foot boundary.

Let there be N sensors. N = 8 or N = 16. Let i be the number of a sensor: $1 \le i \le N$. Let the position of sensor i be (x_i, y_i). Let $F_i(t)$ be the force at moment t acting on sensor i.

Coordinates of the COP at moment t can be calculated from equations (6) – see Jeleń at al. 2008.

$$\begin{cases} x(t) = \sum_{i}^{N} F_i(t) * x_i \;/\; \sum_{i}^{N} F_i(t) \\ y(t) = \sum_{i}^{N} F_i(t) * y_i \;/\; \sum_{i}^{N} F_i(t) \end{cases} \tag{6}$$

Equations (6) are very similar to (1) related to force plate, only the number of sensors (N = 4) and its positions are different. The gait-lines and cyclograms are normalised and related to dimensionless foot length, therefore all distances and speed can be calculated only if the

total distance that the person has walked has been entered. Data is sampled with the frequency equal to 100 Hz.

2.5 Examples of dynography measurements

Pictures in **Figure 5** show examples of gait-lines; pictures in **Figure 6** – cyclograms obtained for NPH patient before and after shunt implantation and for healthy person. Gait-lines and cyclograms show gait in compact way. The symmetry of gait and regularity of cycles can

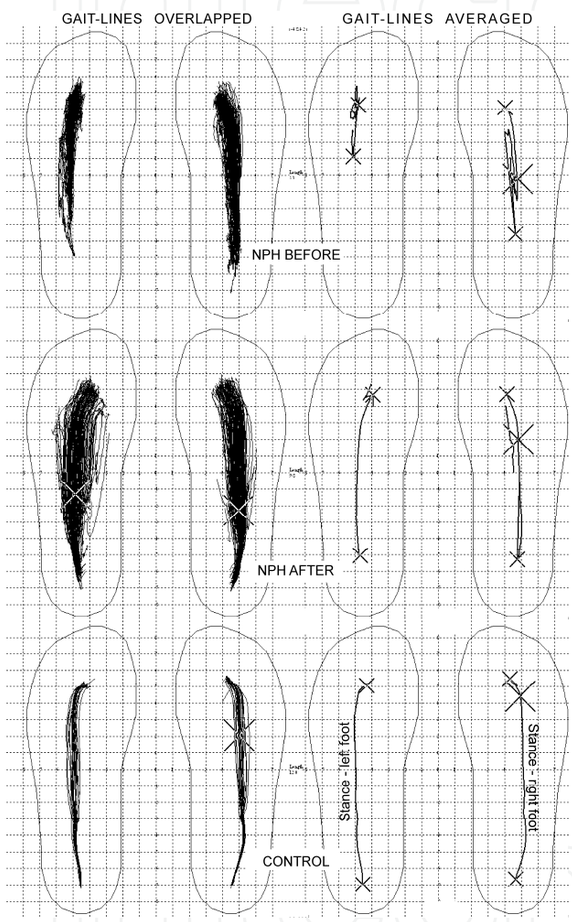


Fig. 5. Examples of gait-lines. The left pictures show overlapping gait cycles measured by 8 sensors in each foot. Pictures on the right side are averaged. The upper gait-lines represent NPH patient before shunt implantation (NPH BEFORE). Gait-lines in the middle belong to NPH patient after surgery (NPH AFTER). Lower gait-lines have been measured in healthy person (CONTROL). Lines representing the Stance gait phase are annotated in the bottom picture.

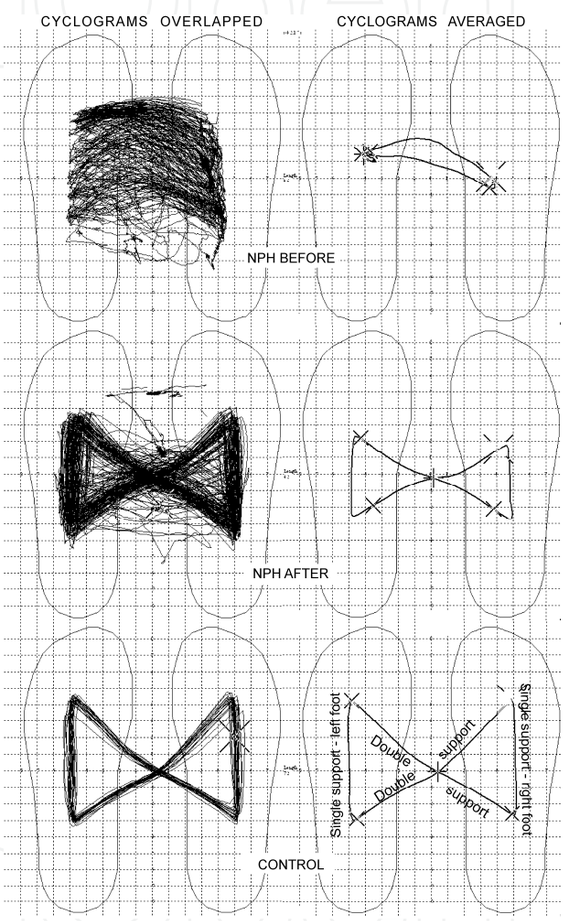


Fig. 6. Examples of cyclograms. The left pictures show overlapping gait cycles measured by 16 sensors in both feet. Pictures on the right side are averaged. Successive panels are: NPH patient before shunt implantation (NPH BEFORE), NPH patient after surgery (NPH AFTER), healthy person (CONTROL). Lines representing the Single and Double Support gait phases are annotated in the bottom picture.

easily be observed. One can notice shuffling gait of NPH patient (before surgery) – there is almost no single support phase – the patient only slightly rises his feet. The whole stance phase is consisting of double support.

2.6 Dynography parameters

After data collection CDG software recognizes gait phases and calculates gait parameters. Gait was described in our research as a duration of a single (SSUP) and double support (DSUP) and duration of a stance phase (STANCE). These measures relate to the left and right leg independently. The phases are shown in **Figure 7**.

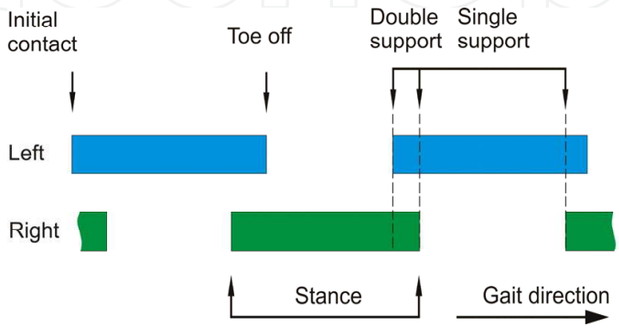


Fig. 7. Phases of gait cycle.

2.7 Hardware and software usage

For posturographic measurements Pro-Med (Poland) force plate (Olton & Czerwosz 2006) was used by us. The software for data collection and analysis has been written by the author (Leszek Czerwosz).

For measurement of ground reaction forces in walking we used the Ultraflex Computer DynoGraphy system from Infotronic Company (Netherlands). Applications of CDG system in NPH are not aware. Explanations of usefulness of this system are provided by Bhargava at al. 2007, Majumdar at al. 2008, Jeleń at al. 2008.

2.8 Statistical methods

Wilcoxon matched pairs test for intragroup and Mann-Whitney U test for between-group comparisons were performed in our studies (Czerwosz at al. 2008, 2009, Szczepek at al. 2008). Non-parametric ANOVA Kruskal-Wallis test (Kruskal & Wallis 1952) was used while comparing more cohorts and then Bonferroni correction (Dunn 1961) for post-hoc comparisons.

There is much confusion related to the application of corrections if performing post-hoc comparisons, especially if testing schema is a priori established. It is hard to accept the fact that the result of one statistical test, i.e. while comparing statistically the NPH and CONTROL groups, can be influenced by other tests, while collecting some extra data, for example ataxia group and by performing other comparisons. We will of course change the level of significance required for rejection the null hypothesis to $p<0.016$ in case of three group analysis that we perform in this study. And we are introducing pattern recognition methods for differentiation of groups to avoid purely academic arguments.

All the nonparametric analyses were conducted using Origin software (OriginLab Corporation) and PASW Statistics (IBM-SPSS Statistics).

We applied pattern recognition algorithms – two advanced statistical methods: Dicriminant Analysis (DA) and k-Nearest Neighbour method (K-NN) (Devijver and Kittler 1982, Duda at al. 2001). DA calculations were performed by means of PASW Statistics. For K-NN calculations (Jóźwik at al. 2011, Sokołowska at al. 2009) a computer programme developed by Adam Jóźwik was used.

The K-NN classifier is a pattern recognition algorithm for recognizing classes of objects. Objects are just vectors of features which values can be measured in patients. Thus an object represent a patient in n-dimensional space, where n is a number of features – measured parameters for each patient. The k-NN algorithm requires a reference set of objects with known class membership. Class means the same as patient group. Any new object, from outside the reference set, is assigned to the class most frequently represented among its k nearest neighbours, searched in the reference set. The leave-one-out method is used to experimentally establish the best value of k giving minimal misclassification rate.

The DA and K-NN methods differ absolutely because DA is a strictly parametric method related closely to the analysis of variance (ANOVA) and produces, among other, linear combination of features (parameters or variables). There is a fundamental assumption that all independent variables have to be normally distributed. In our case – there is no proof for normal distributions, therefore DA outcomes may not be reliable. For the K-NN method it is not important whether distributions are normal.

Pattern recognition methods have already been used in relation to some gait parameters (Bertrani at al. 1999). They should not be mixed with the pattern recognition of gait (Maduko). Discriminant analysis and neural networks were used for gait classification (Kaczmarczyk at al. 2009).

3. Material

After ethical approval by a local Ethics Committee, posturographic and dynographic recordings were taken from NPH patients and from healthy volunteers. Patients with brain atrophy were also recorded to obtain a comparison group to test the power of calculated parameters and statistical methods in differentiation NPG and atrophy (Tans 1979, Galia at al. 2005).

NPH diagnosis was based on the following criteria

1. Enlargement of brain ventricles seen on CT or MR – Evans' ratio above 0.3 (Evans 1942),
2. Neurological symptoms (Hakim triad – minimum two of three symptoms),
3. Mean intracranial pressure ≥ 10 cmH_2O,
4. Resorption resistance R ≥ 11mmHg/ml/min.

Infusion test (Śliwka at al. 1984, Czernicki at al. 1984, Czosnyka at al. 1988) is performed on the basis of cerebrospinal intracranial fluid pressure measurement with simultaneous infusion of physiological saline in L4, L5, and S1 regions. Infusion test seems to be the most important and limitative qualification for shunt implantation.

In all cases balance disturbances and impairment of gait was observed.

The ATROPHY group has been formed according to the following inclusion criteria:

1. Enlargement of brain ventricles seen on CT or MR (Evans' ratio above 0.3),
2. Both subcortical and cortical atrophy,
3. No characteristic neurological symptoms,
4. Mean intracranial pressure < 10 cmH_2O,
5. Resorption resistance R < 11 mmHg/ml/min.

Balance disturbances and some impairment of gait were observed in atrophy patients.

Posturography and dynography evaluations were performed in NPH cases before shunt implantation and shortly after the surgery (within seven days).

3.1 Subjects for posturography study

There were 18 NPH diagnosed patients with spontaneous postural sways measured (9 males and 9 females, range: 32-82 y. o., mean: 64.1 ± 13.2 y. o.). The same group was evaluated twice: before and after shunt implantation forming two cohorts: NPH BEFORE and NPH AFTER.

CONTROL group consisted of 47 healthy subjects, aged 60-69, mean: 59.9 ± 7.0 y. o. The data have been collected by Katarzyna Dmitruk (doctor thesis 2005, partially published in Czerwosz at al. 2009).

ATROPHY group was composed from 36 patients (32-75 y. o., mean: 57.0 ± 14.1 y. o.)

3.2 Subjects for dynography study

CDG measurement was performed in 15 patients with the NPH (8 males and 7 females, age range: 32-82 y. o., mean: 63.1 ± 14.3 y. o.) The same group was evaluated twice: before and after shunt implantation forming two cohorts: NPH BEFORE and NPH AFTER but they are not identical with posturography groups, only 11 patients were examined by two methods.

CONTROL group consisted of 24 healthy subjects (5 males, 19 females).

ATROPHY group was composed from 35 patients (21 males, 14 females, range: 32-79 y. o., mean: 64.1 ± 12.3 y. o.).

4. Results

A number of results have been obtained in the posture and gait study. Posturography and dynography results will be reported separately because so far no joined analysis has been made.

4.1 Simultaneous comparison of three groups – posturography

To compare three groups: NPH BEFORE, ATROPHY, and CONTROL non-parametric ANOVA Kruskal-Wallis test was used. The results are in **Table 1**. The groups differ significantly for all parameters. This allows post-hoc comparisons in pairs of groups, applying Bonferroni correction.

NPH AFTER group was not taken into account in above comparison because it is the same group as NPH BEFERE but evaluated in different condition and it should be compared to NPH BEFERE group by means of paired test.

Parameter		χ^2 K-W	p
Radius	Radius – eyes open R_{EO}	55.9	< 0.001
	Radius – eyes closed R_{EC}	45.2	< 0.001
	Sum of radiuses S_R	55.0	< 0.001
	Difference of radiuses D_R	9.8	< 0.007
	Vision index related to radius I_R	10.5	< 0.005
Area speed	Area speed – eyes open AS_{EO}	59.9	< 0.001
	Area speed – eyes closed AS_{EC}	48.0	< 0.001
	Sum of area speeds S_{AS}	56.8	< 0.001
	Difference of area speeds D_{AS}	7.7	< 0.021
	Vision index related to area I_A	10.2	< 0.006
Velocity	Velocity – eyes open V_{EO}	57.5	< 0.001
	Velocity – eyes closed V_{EC}	41.3	< 0.001
	Sum of velocities V_L	50.6	< 0.001
	Difference of velocities D_V	8.6	< 0.014
	Vision index related to velocity I_V	11.6	< 0.003

Table 1. Results of non-parametric ANOVA Kruskal-Wallis test for three groups: NPH BEFORE, ATROPHY, and CONTROL. The significance p was reported as <0.000 in the original SPSS results meaning that only subsequent, not displayed decimal digits can differ from zero; to avoid confusion the true outcome has been approximated to 0.001.

Similar three-group analysis was done for NPH AFTER, ATROPHY, and CONTROL. These groups differ significantly for parameters provided in **Table 2**. There are no significant differences for D_R, D_A, and D_L differences as well as for the vision indices: I_R, I_A, I_L. This is quite obvious if you compare left and right columns in each pair of columns in CONTROL, ATROPHY, and NPH AFTER groups in **Figure 8** – in the upper column chart. Only one chart – the radius chart is presented here. The lower column chart shows vision indices. Indeed CONTROL, ATROPHY, and NPH AFTER columns are very similar.

Parameter		χ^2 K-W	p
Radius	Radius – eyes open R_{EO}	38.0	< 0.001
	Radius – eyes closed R_{EC}	26.9	< 0.001
	Sum of radiuses S_R	32.8	< 0.001
Area speed	Area speed – eyes open AS_{EO}	42.5	< 0.001
	Area speed – eyes closed AS_{EC}	32.2	< 0.001
	Sum of area speeds S_{AS}	38.1	< 0.001
Velocity	Velocity – eyes open V_{EO}	42.8	< 0.001
	Velocity – eyes closed V_{EC}	33.2	< 0.001
	Sum of velocities V_L	38.0	< 0.001

Table 2. Results of non-parametric ANOVA Kruskal-Wallis test for three groups: NPH AFTER, ATROPHY, and CONTROL. Other parameters differentiate not significantly.

4.2 Comparison of groups in pairs – posturography

All collected posturographic data related to the Radius are exhibited in **Figure 8**. There are four groups here; each one consists of EO and EC measurements. Individual values of the Radius in EO and EC measurements are shown overlapped to respective columns.

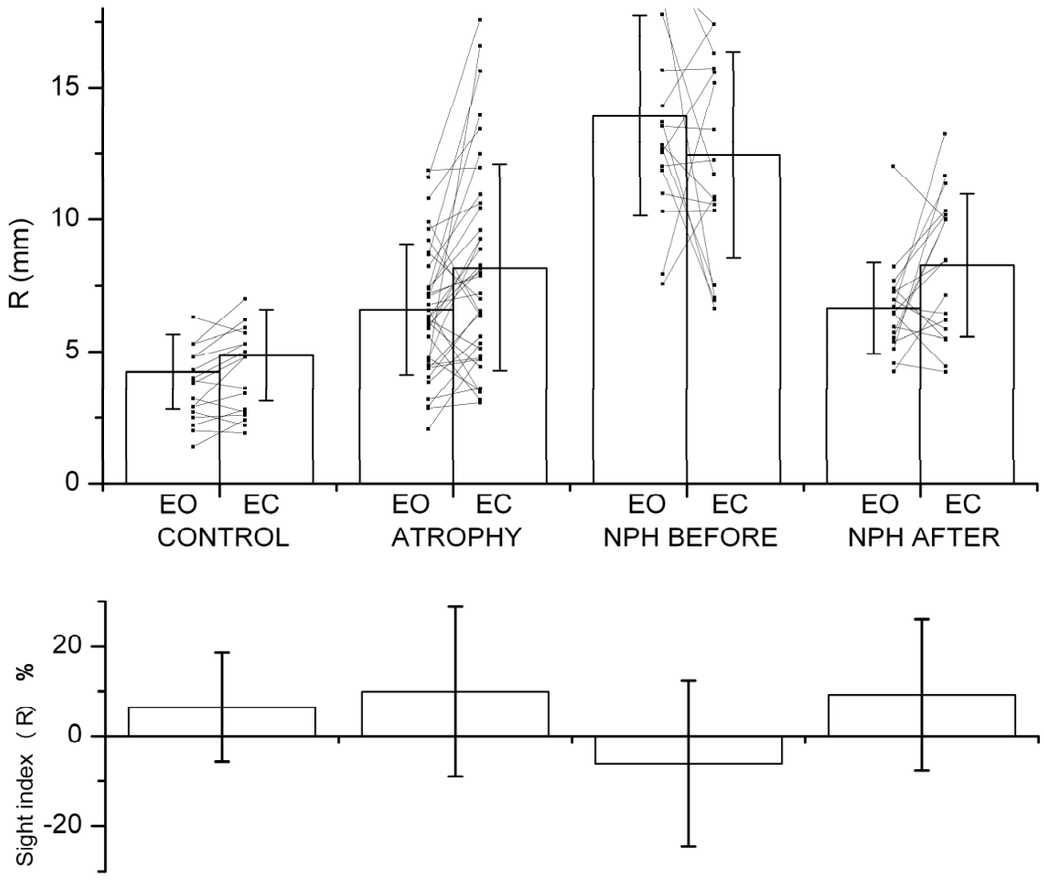


Fig. 8. Upper column chart: Sway Radius – R in CONTROL, ATROPHY, and NPH groups – in patients before and after shunting. Individual values of the Radius are also shown – the lines connect measurements performed with eyes open (EO) or closed (EC). The lower chart expresses vision indices related to radius. Columns represent mean values. Standard deviations are shown as vertical lines.

For comparisons among three groups in pairs see **Tables 3**, **4**, **5**, **7**, and **8**. Nonparametric Mann-Whitney U test with Bonferroni correction was used.

One can notice that NPH BEFORE patients reach largest sways, both with EO and EC (see **Table 3** and **4** respectively). CONTROL group exhibits the smallest sways, both with EO and EC. The same effect can be observed on sums of corresponding parameters (S_X, where X can be R, AS, or V, see **Table 5**). All tested differences of X_{EO}, X_{EC}, and S_X parameters are significant but only V_{EC} and S_V parameters do not differentiate NPH BEFORE and ATROHY pair of groups (**Tables 4** and **5**).

EO		CONTROL	ATROPHY	NPH BEFORE
Radius R_{EO}	AV ± SD mm	4.2 ±1.4	6.6 ± 2.5	13.9 ± 3.8
	CONTROL		p < 0.001	p < 0.001
	ATROPHY			p < 0.001
Area speed AS_{EO}	AV ± SD mm^2/sec	13.3 ± 10.2	56.1 ± 84.5	159.5 ± 104.65
	CONTROL		p < 0.001	p < 0.001
	ATROPHY			p < 0.001
Velocity V_{EO}	AV ± SD mm/sec	9.2 ± 4.4	23.2 ± 23.4	35.5 ± 17.7
	CONTROL		p < 0.001	p < 0.001
	ATROPHY			p < 0.001

Table 3. Comparisons among three groups in pairs; measurements were performed with eyes open. Average values(AV) with standard deviations (SD) and significances p of Mann-Whitney U test are given in appropriate table cells. All groups differ in respective pairs of groups.

EC		CONTROL	ATROPHY	NPH BEFORE
Radius R_{EC}	AV ± SD mm	4.9 ± 1.7	8.2 ± 3.9	12.4 ± 3.9
	CONTROL		p < 0.001	p < 0.001
	ATROPHY			p < 0.008
Area speed AS_{EC}	AV ± SD mm^2/sec	22.7 ± 22.6	107.8 ± 175.6	140.8 ± 92.2
	CONTROL		p < 0.001	p < 0.001
	ATROPHY			p < 0.011
Velocity V_{EC}	AV ± SD mm/sec	13.5 ± 8.7	33.5 ± 32.0	35.2 ± 17.4
	CONTROL		p < 0.001	p < 0.001
	ATROPHY			n.s.

Table 4. Comparisons among three groups in pairs of groups; measurements were performed in eyes closed condition. All EC parameters but one differentiate these groups. Only average velocity V_{EC} is similar in NPH BEFORE and ATROHY groups.

Sums		CONTROL	ATROPHY	NPH BEFORE
Radius S_R	AV ± SD mm	9.1 ± 2.9	14.7 ± 5.7	26.4 ± 6.3
	CONTROL		p < 0.001	p < 0.001
	ATROPHY			p < 0.001
Area speed S_{AS}	AV ± SD mm^2/sec	36.1 ± 30.3	163.8 ± 255.1	300.3 ± 152.9
	CONTROL		p < 0.001	p < 0.001
	ATROPHY			p < 0.001
Velocity S_V	AV ± SD mm/sec	22.8± 12.6	56.8 ± 54.1	70.7± 31.8
	CONTROL		p < 0.001	p < 0.001
	ATROPHY			p < 0.020 =n.s.

Table 5. Comparisons among three groups in pairs of groups. All sums of parameters but one differentiate the groups. Only the sum of average velocities S_V is similar in NPH BEFORE and ATROHY groups.

4.3 Effect of shunt implantation on posturography parameters

One can see in **Figure 9** that radius of sways measured in both conditions: EO and EC in a NPH group before shunt implantation treatment exceeded corresponding values measured in the same patients after surgery.

There is a full set of parameters included in **Table 6** – average values, standard deviation and significance level of nonparametric Wilcoxon paired test. The NPH BEFORE and NPH AFTER groups differ in relation to almost all parameters. The most powerful is radius with EO (R_{EO}) – see also **Figure 9**.

Sways with eyes opened before shunting is much bigger than after surgery.

Parameter			NPH BEFORE	NPH AFTER	p
Radius	R_{EO}	mm	13.9 ± 3.8	6.7 ± 1.7	<0.001
	R_{EC}	mm	12.4 ± 3.9	8.3 ± 2.7	<0.002
	S_R	mm	26.4 ± 6.3	14.9 ± 3.6	<0.001
	D_R	mm	-1.49 ± 4.48	1.62 ± 2.78	<0.007
	I_R	%	-6.09 ±18.9	9.26 ± 7.3	<0.008
Area speed	AS_{EO}	mm²/sec	159.5 ± 104.6	37.9 ± 17.1	<0.001
	AS_{EC}	mm²/sec	140.8 ± 92.2	79.4 ± 77.9	n.s.
	S_{AS}	mm²/sec	300.3 ± 152.9	117.2 ± 88.4	<0.001
	D_{AS}	mm²/sec	-18.7 ± 124.6	41.5 ± 70.1	<0.043
	I_{AS}	%	-5.2 ± 34.7	15.6 ± 37.7	<0.025
Velocity	V_{EO}	mm/sec	35.5 ± 17.7	18.3 ± 7.4	<0.002
	V_{EC}	mm/sec	35.2 ± 17.4	26.3 ± 17.1	n.s.
	S_V	mm/sec	70.7± 31.8	44.6 ± 23.1	<0.011
	D_V	mm/sec	-0.3 ± 16.2	8.0 ± 12.5	<0.035
	I_V	%	0.7 ± 21.1	13.3 ± 16.1	<0.035

Table 6. Comparisons between NPH BEFORE and NPH AFTER – all parameters are included. Average values with standard deviations and significances p of nonparametric Wilcoxon paired test are given in appropriate table cells.

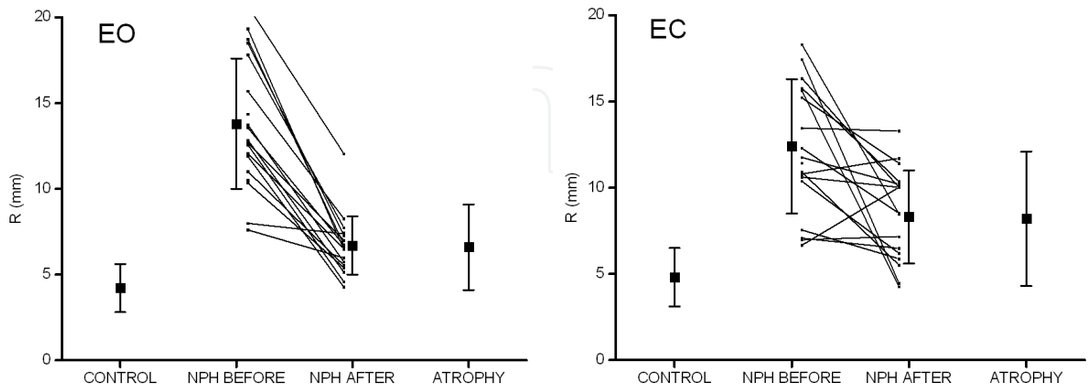


Fig. 9. Mean values of the sway Radius measured with eyes open (EO - left) and closed (EC - right) in NPH patients before and after surgery. Individual R values are given, they are connected with lines. CONTROL and ATROPHY groups are also shown to illustrate effect of shunting against wider background.

4.4 Impact of vision on postural sway characteristics

We introduced EC-EO differences and vision index for explaining in various groups the effect of eye opening or closure on sways. **Table 7** shows D_X and **Table 8** – I_X (where X can be R, AS, or V). The interpretation of differences D_X can be skipped here.

Most interesting features are the vision indices. They differentiate NPH BEFORE group from NPH AFTER and from any other group. **Table 8** shows three comparisons in pairs of groups. The groups NPH BEFORE – ATROPHY significantly differ as well as the NPH BEFORE – CONTROL groups do.

A direct comparison of EO and EC parameters in four groups independently is provided in **Table 9**. Sways with EO and EC seem to be equal in NPH BEFORE group only. In any other group there are significant changes of sways related to the eyes closure. Enlargement of sways is a normal phenomenon after closing eyes, but not in NPH patients in acute state.

Sways of NPH patients do not depend on the sight, they seem to be the same in EO and EC conditions. This observation is the most important result of this study.

4.5 Two dimension analysis – posturography

Much more insight into the data collected is provided in the two dimensional graph. There is four-group scattergram in **Figure 10**. One can see a separation of NPH BEFORE cases and the centroid from all other groups. A separation is statistically significant – see **tables 5** and **8** for NPH BEFORE – CONTROL and NPH BEFORE – ATROPHY data.

Differences		CONTROL	ATROPHY	NPH BEFORE
Radius D_R	AV ± SD mm	0.63 ± 1.19	1.67 ± 3.15	-1.49 ± 4.48
	CONTROL		n.s.	$p < 0.013$
	ATROPHY			$p < 0.008$
Area speed D_{AS}	AV ± SD mm^2/sec	9.4 ± 17.7	51.7 ± 104.4	-18.7 ± 124.6
	CONTROL		$p < 0.031$ = n.s.	n.s.
	ATROPHY			$p < 0.013$
Velocity D_V	AV ± SD mm/sec	4.3 ± 5.7	10.3 ± 14.7	-0.3 ± 16.2
	CONTROL		$p < 0.035$ = n.s.	n.s.
	ATROPHY			$p < 0.007$

Table 7. Comparisons of differences D_R, D_{AS}, D_V among three groups in pairs of groups.

Indexes		CONTROL	ATROPHY	NPH BEFORE
Radius I_R	AV ± SD %	6.5 ± 12.1	9.3 ± 19.4	-6.09 ±18.9
	CONTROL		n.s.	$p < 0.004$
	ATROPHY			$p < 0.005$
Area speed I_{AS}	AV ± SD %	19.8 ± 23.5	22.1 ± 28.2	-5.2 ± 34.7
	CONTROL		n.s.	$p < 0.004$
	ATROPHY			$p < 0.003$
Velocity I_V	AV ± SD %	15.3 ± 13.4	16.3 ± 15.3	0.7 ± 21.1
	CONTROL		n.s.	$p < 0.001$
	ATROPHY			$p < 0.002$

Table 8. Comparisons of vision indices I_R, I_{AS}, I_V among three groups in pairs of groups.

Group	parameter		EO	EC	p
CONTROL	R	mm	4.2 ±1.4	4.9 ± 1.7	< 0.001
	AS	mm²/sec	13.3 ± 10.2	22.7 ± 22.6	< 0.001
	V	mm/sec	9.2 ± 4.4	13.5 ± 8.7	< 0.001
ATROPHY	R	mm	6.6 ± 2.5	8.2 ± 3.9	< 0.004
	AS	mm²/sec	56.1 ± 84.5	107.8 ± 175.6	< 0.001
	V	mm/sec	23.2 ± 23.4	33.5 ± 32.0	< 0.001
NPH BEFORE	R	mm	13.9 ± 3.8	12.4 ± 3.9	n.s.
	AS	mm²/sec	159.5 ± 104.6	140.8 ± 92.2	n.s.
	V	mm/sec	35.5 ± 17.7	35.2 ± 17.4	n.s.
NPH AFTER	R	mm	6.7 ± 1.7	8.3 ± 2.7	< 0.035
	AS	mm²/sec	37.9 ± 17.1	79.4 ± 77.9	< 0.014
	V	mm/sec	18.3 ± 7.4	26.3 ± 17.1	< 0.004

Table 9. Comparison of R, AS, and V parameters measured with EO and EC in CONTROL, ATROPHY, NPH BEFORE and NPH AFTER groups separately.

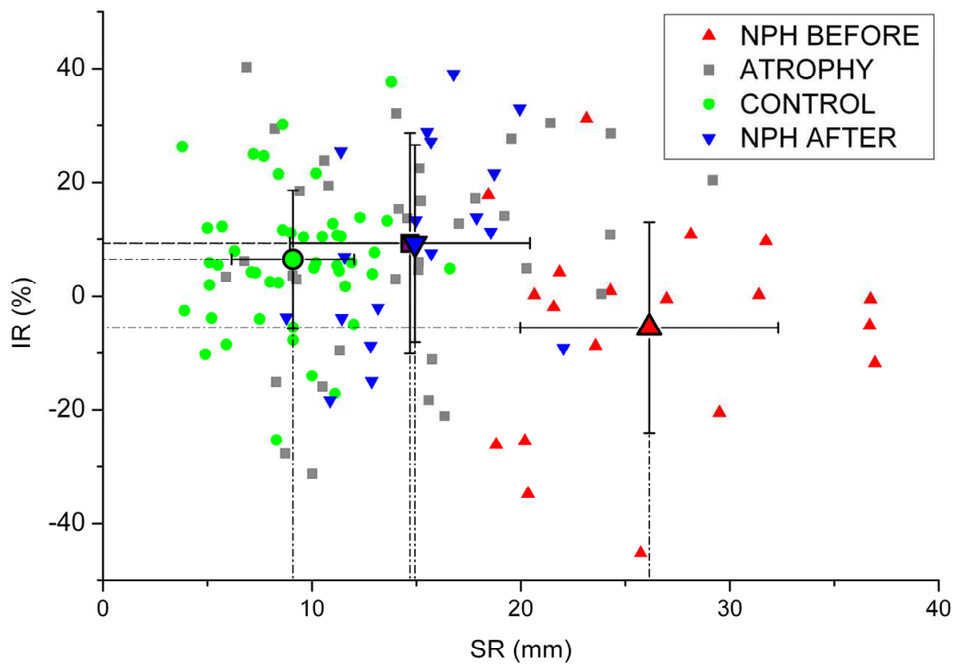


Fig. 10. Scattergram presents all cases in four groups: NPH BEFORE, ATROPHY, CONTROL, and NPH AFTER in I_R (vision index related to radius) versus S_R (sum of R_{EO} and R_{EC}) coordination system. Centroids of the groups are shown with standard deviations. Notice that ATROPHY and NPH AFTER group centroids do overlap.

Two dimensional statistical analysis was performed by means of methods described in the following section.

4.6 k-NN classification of posturografic parameters

All data was analysed by means of two methods: Discrimination Analysis (DA) and k nearest neighbours (K-NN) method. Both methods give similar results for most of classifications.

Feature is a single value of multidimensional vector assigned to any object/case/patient. Groups of patients are called classes within the "classification world". There are 15 features used here as follows: R_{EC}, R_{EO}, AS_{EC}, AS_{EO}, V_{EC}, V_{EO}, S_R, S_{AS}, S_V, D_R, D_{AS}, D_V, I_R, I_{AS}, and I_V, exactly as parameters.

The analysis was performed in several sections. At the beginning every feature was used, one at a time. Then features were grouped into pairs according to the templates: (X_{EO} and X_{EC}), (sums S_X and differences D_X), (sums S_X and vision indices I_X), where X can be R, AS, or V. Features related to R, AS and V were paired separately. Then clusters consisting of six features were applied.

We classified groups/classes in two following schemas – like in traditional analysis: 1) NPH BEFORE, ATROPHY and CONTROL 2) NPH BEFORE and NPH AFTER. Briefing of the classification results is presented below.

Single feature applied individually, classes: NPH BEFORE and NPH AFTER:

There were 15 DA classifications of NPH BEFORE and NPH AFTER classes and 15 K-NN classifications performed. R_{EO} demonstrated the best classification - both methods classified correctly 91.9%/91.9% cases (the first number relates to DA, the second to K-NN). Below there is a list of some best features with outcome better than 75%:

R_{EO}	91.9%/91.9%
S_R	86.5%/89.2%
A_{EO}	86.5%/83.8%
R_{EC}	78.4%/78.4%
S_{AS}	75.7%/78.4%
S_V	75.7%/75.7%

Classification power of vision indices was rather poor; the best was I_R: 67.6%/67.6%.

Two-feature pairs, classes: NPH BEFORE and NPH AFTER:

There were nine DA/K-NN classifications here, the best are:

(R_{EO},R_{EC})	91.9%/94.6%
(S_R,D_R)	91.9%/91.9%
(S_R,I_R)	91.9%/91.9%
(AS_{EO},AS_{EC})	83.8%/83.8%
(S_{AS},D_{AS})	83.8%/78.4%
(S_{AS},I_{AS})	86.5%/83.8%

It is interesting that there are three pairs of features with equal classification power. They relate to the analysis in two dimensions. Notice that (S_{AS},I_{AS}) and (S_{AS},D_{AS}) can be calculated from (AS_{EO},AS_{EC}) using formulas (2),(3), and (4). These dimensions are not completely independent because, for example in the CONTROL group the features R_{EO} and R_{EC} are

correlated (R = 0.73); in other groups the correlation is not as high. An example of two-dimensional approach is shown in **Figure 10**.

Six-feature cluster without and with feature selection, classes: NPH BEFORE and NPH AFTER:

Multi-feature classification by K-NN method was also performed with the following features: S_R, S_{AS}, S_V, I_R, I_{AS}, and I_V. Classification without feature selection (all features forced to enter the analysis) resulted in 89.2% of correctly classified cases. Classification with automatic selection of "best" features resulted in 94.6%. The selected features: S_R and I_{AS}.

Single feature applied individually, classes: NPH BEFORE, ATROPHY, and CONTROL:

Three-group classification (NPH BEFORE, ATROPHY and CONTROL) using single features cannot be good both in DA and K-NN methods. The best results reached AS_{EO} – 77.4% of correct classified cases.

Two-feature pairs, classes: NPH BEFORE, ATROPHY, and CONTROL:

There were nine DA/K-NN classifications here, the best are:

(R_{EO},R_{EC})	75.5%/75.5%
(S_R,D_R)	75.5%/76.5%
(S_R,I_R)	73.5%/74.5%

Other pairs of features are worse. Again there is no difference between classification level among pairs (R_{EC}, R_{EO}), (S_R, D_R) and (S_R, I_R).

Six-feature cluster without and with feature selection, classes: NPH BEFORE, ATROPHY, and CONTROL:

DA/K-NN classifications without feature selection (all features forced to enter the analysis):

R_{EO}, R_{EC}, AS_{EO}, AS_{EC}, V_{EO}, V_{EC}	78.4%/73.5%
S_R, D_R, S_{AS}, D_{AS}, S_V, D_V	78.4%/74.5%
S_R, I_R, S_{AS}, I_{AS}, S_V, I_V	79.4%/73.5%

Classifications with feature selection – DA only:

R_{EO}, V_{EC}	80.4%
S_R, D_R	75.5%
S_R, I_R	73.5%

Features selected automatically during analysis were exactly the same as those selected manually during previous stages.

Classifications with feature selection – K-NN only:

R_{EO}, R_{EC}, AS_{EO}, AS_{EC}, V_{EO}	82.3%
S_R, D_R, D_{AS}, S_V	81.4%
S_R, I_{AS}, S_V	79.4%

Here better results were obtained.

Three-class K-NN classifier consist of three two-class sub-classifiers. The results of sub-classification are also interesting. Single feature: S_R demonstrates 100% correctly classified cases in NPH BEFORE – CONTROL sub- classifier. Selection of three features: R_{EO}, D_{AS} and DV classified correctly 94.6% cases in NPH BEFORE – ATROPHY sub- classifier what proofs the existence of **important difference between NPH and atrophy imbalance.** This observation is also an important result of the present study.

4.7 Analysis of gait parameters

Evaluation of gait is performed by means of five gait parameters: time of single supper (T_{SSUP}), time of double support (T_{DSUP}), time of stance (T_{STANCE}), length of single support (D_{SSUP}), and length of double support (D_{DSUP}). Initially ten parameters were involved; they were related to the left and right leg. Average values with standard deviations were plotted in **Figure 11**. Values of the parameters related to the left and right leg were compared statistically by means of nonparametric Wilcoxon paired test in each group separately. There was no difference found between legs. Therefore the outcomes from the left and right leg were combined – cases are not patients now but legs.

Parameter	χ^2 K-W	p
Time of single support (T_{SSUP}) sec	53.3	< 0.001
Time of double support (T_{DSUP}) sec	84.2	< 0.001
Time of stance (T_{STANCE}) sec	83.2	< 0.001
Length of single support(D_{SSUP})	107.3	< 0.001
Length of double support(D_{DSUP})	80.9	< 0.001

Table 10. Non-parametric ANOVA Kruskal-Wallis test for three groups: NPH BEFORE, ATROPHY, and CONTROL. n = 148.

Non-parametric ANOVA Kruskal-Wallis test was used again to compare three groups: NPH BEFORE, ATROPHY, and CONTROL. The results are in **Table 10**. The groups differ significantly for all parameters. This allows making post-hoc comparisons in pairs of groups, applying Bonferroni correction.

One can notice in **Table 11** that the T_{STANCE} is the biggest in NPH BEFORE group. This means slower gait of patients in acute state; time of stance phase T_{STANCE} is more than 130% longer than in CONTROL group (ratio: 1.61/0.68 = 2.36 of values in NPH BEFORE and CONTROL groups). ATROPHY patients show decreased walking pace compared with healthy people, however they have higher gait velocity than NPH BEFORE.

Duration of single support T_{SSUP} in NPH BEFORE group is 70% longer than in CONTROL group (ratio: 0.65/0.38 = 1.71). Duration of double support in NPH BEFORE group is 180% longer than in CONTROL group (ratio: 0.46/0.16 = 2.87). One can see differences in single and double support distributions. In NPH BEFORE group ratio: T_{SSUP} / T_{DSUP} = 0.65/0.46 = 1.41, in CONTROL group: T_{SSUP} / T_{DSUP} = 0.38/0.16 = 2.37. Double support is much longer not only if measured in seconds, but in relation to single support length. If comparing D_{SSUP} and D_{DSUP}, between NPH and CONTROL groups, one can observe strong reduction of single support length. For single support length D_{SSUP} there is a proportion: 1.64/7.13 = 0.23, for double support length D_{DSUP}: 6.28/11.54 = 0.54. ATROPHY group is always in the middle between NPH BEFORE and ATROPHY.

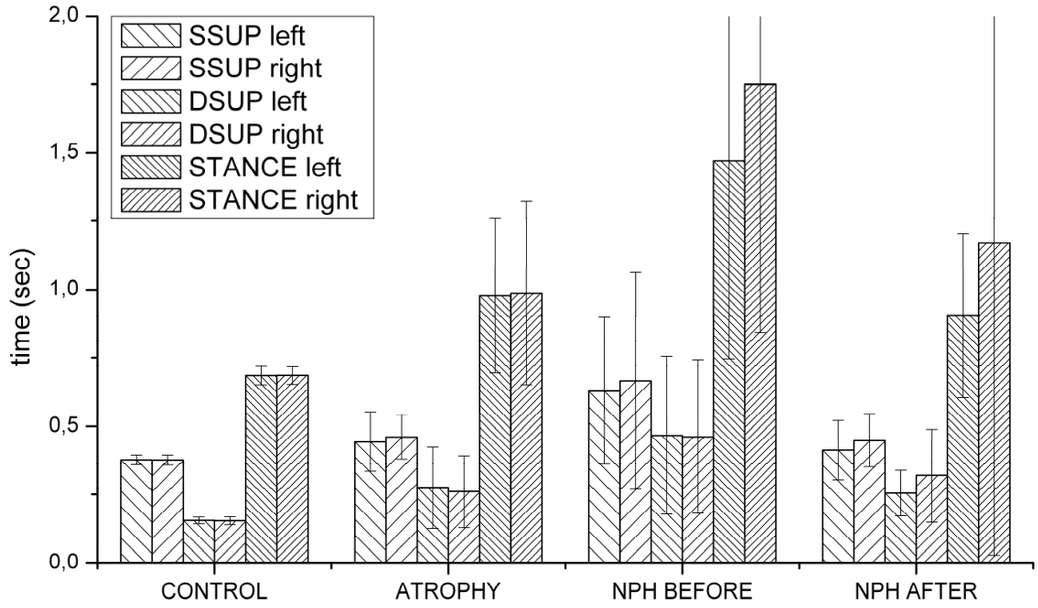


Fig. 11. Average values with standard deviations of times: T_{SSUP}, T_{DSUP}, T_{STANCE} in four groups.

Parameter		CONTROL	ATROPHY	NPH BEFORE
T_{SSUP}	AV ± SD sec	0.38 ± 0.02	0.45 ± 0.10	0.65 ± 0.33
	CONTROL		< 0.001	< 0.001
	ATROPHY			< 0.001
T_{DSUP}	AV ± SD sec	0.16 ± 0.01	0.27 ± 0.14	0.46 ± 0.28
	CONTROL		< 0.001	< 0.001
	ATROPHY			< 0.001
T_{STANCE}	AV ± SD sec	0.68 ± 0.03	0.98 ± 0.31	1.61 ± 0.82
	CONTROL		< 0.001	< 0.001
	ATROPHY			< 0.001
D_{SSUP}	AV ± SD cm	7.13 ± 0.53	3.29 ± 1.49	1.64 ± 1.17
	CONTROL		< 0.001	< 0.001
	ATROPHY			< 0.001
D_{DSUP}	AV ± SD cm	11.54 ± 1.85	9.54 ± 1.77	6.28 ± 2.88
	CONTROL		< 0.001	< 0.001
	ATROPHY			< 0.001

Table 11. Comparisons of T_{SSUP}, T_{DSUP}, T_{STANCE}, D_{SSUP}, D_{DSUP} parameters in pairs of groups. Average values with standard deviations and significances p of Mann-Whitney U test are given in appropriate table cells. All differences are significant.

Group	parameter		BEFORE	AFTER	P
NPH n= 15	T_{SSUP}	sec	0.65 ± 0.33	0.42 ± 0.10	< 0.001
	T_{DSUP}	sec	0.46 ± 0.29	0.28 ± 0.14	< 0.001
	T_{STANCE}	sec	1.61 ± 0.82	1.03 ± 0.83	< 0.001
	D_{SSUP}	cm	1.64 ± 1.17	3.55 ± 1.31	< 0.001
	D_{SSUP}	cm	6.28 ± 2.88	8.54 ± 2.96	< 0.001

Table 12. Comparison between NPH BEFORE and NPH AFTER. Average values with standard deviations and significances p of nonparametric Wilcoxon paired test are given in appropriate table cells. All parameters: T_{SSUP}, T_{DSUP}, T_{STANCE}, D_{SSUP}, and D_{DSUP} differentiate significantly NPH stages. All differences are significant.

Parameter			CONTROL n=48	ATROPHY n=35	NPH AFTER n=34
T_{SSUP}	AV ± SD	sec	0.38 ± 0.02	0.45 ± 0.10	0.42 ± 0.10
	CONTROL				< 0.001
	ATROPHY				n.s.
T_{DSUP}	AV ± SD	sec	0.16 ± 0.01	0.27 ± 0.14	0.28 ± 0.13
	CONTROL				< 0.001
	ATROPHY				n.s.
T_{STANCE}	AV ± SD	sec	0.68 ± 0.03	0.98 ± 0.31	1.00 ± 0.78
	CONTROL				< 0.002
	ATROPHY				n.s.
D_{SSUP}	AV ± SD	cm	7.13 ± 0.53	3.29 ± 1.49	3.56 ± 1.28
	CONTROL				< 0.001
	ATROPHY				n.s.
D_{DSUP}	AV ± SD	cm	11.54 ± 1.85	9.54 ± 1.77	8.46 ± 2.79
	CONTROL				< 0.001
	ATROPHY				n.s.

Table 13. Comparisons of T_{SSUP}, T_{DSUP}, T_{STANCE}, D_{SSUP}, D_{DSUP} parameters in group-pairs. Average values with standard deviations and significances p of Mann-Whitney U test are given in appropriate table cells.

Direct comparison of gait parameters between BEFORE and AFTER states in NPH are given in **Table 12**. Because NPH BEFORE and NPH AFTER are paired groups, the Wilcoxon test was used to compare the gait. Differences of all parameters are statistically significant. **Figure 12** shows average values with standard deviations as well as individual values of T_{SSUP}, T_{DSUP}, T_{STANCE} in NPH patients before and after surgery.

After surgery gait of NPH patients resembles gait of patients with atrophy. **Table 13** shows that there is no statistical significant difference between NPH AFTER and ATROPHY groups.

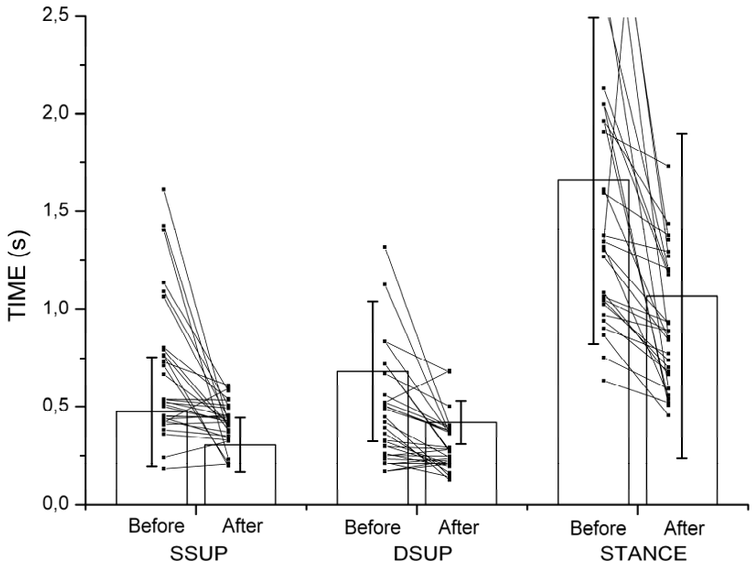


Fig. 12. Mean values of T_{SSUP}, T_{DSUP}, T_{STANCE} in NPH BEFORE and NPH AFTER groups. Individual values of these parameters are given, they are connected with lines. Values for both legs are combined.

4.8 k-NN classification of dynografic parameters

Dynographic parameters were analysed by means of k-NN method in 2008 (Czerwosz at al. 2008). Now the calculations should be repeated with larger number of subjects. Usage of pattern recognition methods can give chance for better evaluation of multi-parameter data.

5. Discussion and conclusions

There are three main theses that come out from this study:

1. Sways in NPH patients before shunting is much bigger than after surgery. This relates mostly to eyes open (EO) condition.
2. Sways of NPH patients do not depends on the sight, they seem to be the same in EO and EC conditions.
3. NPH and atrophy imbalances differ when evaluate by means of more than one parameter (feature). Pattern recognition methods should be used.

There are many proofs of strong relationship between vision and postural control. Vision has a greater influence on standing postural control, resulting in greater sway when individuals are presented with erroneous or conflicting visual cues (Redfern at al. 2001). In impairment of the vestibular system and possibly other sensing systems and probably in cerebellar ataxias, vision can help in balance recovery. In NPH we do not observe any improvement, there is some probability that vision can disturb maintenance of the balance. Interestingly the vision index was slightly negative in NPH BEFORE group, meaning that with eyes closed sways are smaller. Blomsterwall (Blomsterwall at al. 2000) found that healthy individual had a 29% better postural function with open eyes while NPH patients only improved their balance score by 18% with open eye. The impact of vision should be studied farther due to this discrepancy.

6. Acknowledgment

We would like to thank Adam Jóźwik for releasing his K-NN software.

This study was partially supported by grant from the Polish Ministry of Education and Science (Grant No. R13 041 02).

Research support was partially provided by the Biocentrum-Ochota project [POIG.02.03.00-00-003/09 - European Regional Development Fund, the Operational Programme "Innovative Economy" 2007-2013].

7. References

Baratto L, Morasso PG, Re C, Spada G. (2002) *A new look at posturographic analysis in the clinical context: sway-density versus other parameterization techniques.* Motor Control 6(3): 246-70.

Benda, B. J., Riley, P. O., & Krebs, D. E. (1994) *Biomechanical relationship between center of gravity and center of pressure during standing.* IEEE Transactions on Rehabilitation Engineering 2(1): 3-10.

Bertrani A, Cappello A, Benedetti MG, Simoncini L, Catani F. (1999) *Flat foot functional evaluation using pattern recognition of ground reaction data.* Clin Biomech (Bristol, Avon) 14(7): 484-93.

Bhargava P., Shrivastava P., & Nagariya S.P. (2007) *Assessment of changes in gait parameters and vertical ground reaction forces after total hip arthroplasty.* Indian J Orthop 41(2): 158–162.

Bloem B.R., Beckley D.J., Remler M.P. (1995). *Postural reflexes in Parkinson's disease during "resist" and "yield" tasks.* J. Neurol Sci 129: 109-119.

Blomsterwall E., Svantesson U., Carlsson U., Tullberg M., Wikkelsö C. (2000) *Postural disturbance in patients with normal pressure hydrocephalus.* Acta Neurol Scand 102: 284-291.

Błaszczyk J.W. (2008) *Sway ratio - a new measure for quantifying postural stability.* Acta neurobiologiae experimentalis 68 (1): 51-57.

Błaszczyk J.W., Michalski A. (2006). *Aging and postural stability.* Studies in Physical Culture and Tourism 13: 11-14.

Boon AJ, Tans JT, Delwel EJ, Egeler-Peerdeman SM, Hanlo PW, Wurzer HA et al. (1999) *Dutch Normal-Pressure Hydrocephalus Study: the role of cerebrovascular disease*. J Neurosurg 90(2):221-226.

Bosek, M., Grzegorzewski, B., Kowalczyk, A., Lubiński, I. (2005) *Degradation of postural control system as a consequence of Parkinson's disease and ageing.* Neuroscience letters 376(3), 215-20.

Czernicki Z., Szewczykowski J., Kunicki A., Śliwka S., Korsak-Śliwka J., Pawłowski G., Dziduszko J., Mempel E., Jurkiewicz J., Augustyniak B. (1984) *Computerized infusion test II. Clinical use.* Neurol. Neurochir Pol 18 (6): 561-565.

Czerwosz L., Szczepek E., Błaszczyk J.W., Sokołowska B., Dmitruk K., Dudziński K., Jurkiewicz J., Czernicki Z. (2009) *Analysis of postural sway in patients with normal*

pressure hydrocephalus: effects of shunt implantation. European Journal of Medical Research 14 Supl 4: 53-58

Czerwosz L., Szczepek E., Sokołowska B., Jóźwik A., Dudziński K., Jurkiewicz J., Czernicki Z. (2008) *Recognition of gait disturbances in patients with normal pressure hydrocephalus using the Computer Dynography system.* Journal of Physiology and Pharmacology 59, Supl 6: 201-207.

Czosnyka M., Wollk-Laniewski P., Batorski L., Zaworski W. (1988) *Analysis of intracranial pressure waveform during infusion test.* Acta Neurochirurgica (Wien) 93, 3-4: 140-145.

Devijver P.A., Kittler J. (1982) *Pattern recognition: A statistical approach.* Prentice Hall, London.

Dmitruk K. (2005) *Analiza wybranych parametrów posturograficznych u ludzi w różnych grupach wiekowych.* Doctor distertation. Nicolaus Copernicus University, Collegium Medicum. Bydgoszcz (in Polish).

Duda R.O., Hart P.E., Stork D.G. (2001) *Pattern classification.* John Wiley & Sons, New York.

Dunn, O.J. (1961) *Multiple Comparisons Among Means.* Journal of the American Statistical Association 56, 52-64.

Evans W.A. (1942) *An Encephalographic Ratio for Estimating Ventricular Enlargement and Cerebral Atrophy.* Arch. Neurol. and Psych 47 (6): 931-937.

Galia G.L., Rigamonti D., Williams M.A. (2005) *The diagnosis and treatment of idiopathic normal pressure hydrocephalus.* Nature Clinical Practice Neurology 2: 375-381.

Hakim S., Adams R.D. (1965). *The Special Clinical Problem of Symptomatic Hydrocephalus with Normal Cerebrospinal Fluid Pressure.* J. Neurol. Sci. 2: 307-327.

IBM-SPSS Statistics. (n.d.) *PASW Statistics v. 18.(previously SPSS – Statistical Package for the Social Sciences).* http://www-01.ibm.com/software/analytics/spss/products/statistics.

Infotronic Company (2007) *Ultraflex system.* Available from: http://www.infotronic.nl/Brochures/English/Model-English-CEGV2-2007.pdf.

Jagielski J., Kubiczek-Jagielska M., Sobstyl M., Koziara H., Błaszczyk J., Ząbek M., Zaleski M. (2006). *Posturography as objective evaluation of the balance system in Parkinson's disease patients after neurosurgical treatment. A preliminary report.* Neurol Neurochir Pol. 40(2): 127-33. In Polish.

Jeleń P., Wit P., Dudziński K., Nolan L. (2008) *Expressing gait-line symmetry in able-bodied gait.* Dynamic Medicine 7:17.

Jóźwik A., Sokołowska B., Nieboj-Dobosz I., Janik P., Kwieciński H. (2011) *Extraction of biomedical traits for patients with amyotrophic lateral sclerosis using parallel and hierarchical classifiers.* International Journal of Biometrics 3, 1: 85-94.

Kaczmarczyk K., Wit A., Krawczyk M., Zaborski J. (2009) *Gait classification in post-stroke patients using artificial neural networks.* Gait & Posture 30: 207–210.

Kessler N., Ganança M.M., Ganança C.F. Ganança F.F., Lopes S.C., Serra A.P., Caovilla H.H. (2011). *Balance Rehabilitation Unit (BRUTM) posturography in relapsing-remitting multiple sclerosis.* Arq. Neuro-Psiquiatr. 69, 3: 485-490.

Kruskal and Wallis (1952) *Use of ranks in one-criterion variance analysis.* Journal of the American Statistical Association 47 (260): 583–621.

Kubisz L., Werner H., Bosek M., Weiss W. (2011) *Posture Stability Evaluation Using Static Posturography in Patients after Cruciate Ligament Reconstruction*. Acta Physica Polonica 119: 957-960.

Maduko E. *Pattern recognition of human gait signatures.* (n.d.) University of Texas at El Paso. Available from: http://faculty.utep.edu/Portals/1255/Elizabeth.pdf.

Majumdar K., Lenka P.K., Kumar R. (2008) *Variability of Gait Parameters of Unilateral Trans-tibial Amputees in Different Walking Speeds.* Indian Journal of Physical Medicine and Rehabilitation 19 (2): 37-42.

Mohan G., Pal P.K., Sendhil K.R., Thennarasu K., Usha B.R. (2009). *Quantitative evaluation of balance in patients with spinocerebellar ataxia type 1: A case control study.* Parkinsonism and Related Disorders 15 (6): 435-439.

Mraz M., Curzytek M., Mraz M.A., Gawron W., Czerwosz L., Skolimowski T., (2007) *Body balance in patients with systemic vertigo after rehabilitation exercises.* J.Physiol Pharmacol 58 (5): 427-436.

Olton J., Czerwosz L. (2006) *Posturograf firmy Pro-Med,* Acta Bio-Optica et Informatica Medica. Inżynieria Biomedyczna 12: 143. (Article in Polish)

Origin Corporation. (n.d.) *Origin-pro software v. 8.* Available from*:* http://www.originlab.com/index.aspx?go=PRODUCTS/OriginPro.

Perry J., Burnfield J.M. (2010) *Gait Analysis. Normal and Pathological Function.* Slack Inc., Thorofare, New Jersey Second Edition.

Raymakers J.A., Samson M.M., Verhaar H.J.J. (2005) *The assessment of body sway and the choice of the stability parameter(s).* Gait and Posture 21 48–58.

Ravdin L.D., Heather L. Katzen Anna E. Jackson, Diamanto Tsakanikas, Stephanie Assuras, and Norman R. Relkin (2008) *Features of gait most responsive to tap test in normal pressure hydrocephalus.* Clin Neurol Neurosurg. 110(5): 455–461.

Redfern M.S., Yardley L., Bronstein A.M. (2001) *Visual influences on balance.* Anxiety Disorders 15: 81- 94.

Sokołowska B., Jóźwik A., Nieboj-Dobosz I., Janik P., Kwieciński H. (2009) *Evaluation of matrix metalloproteinases in serum of patients with amyotrophic lateral sclerosis with pattern recognition methods.* Journal of Physiology and Pharmacology 60 (suppl 5): 117-120.

Stolze H., Kuhtz-Buschbeck J.P., Drücke H., Jöhnk K., Illert M., Deuschl G. (2001) *Comparative analysis of the gait disorder of normal pressure hydrocephalus and Parkinson's disease.* J Neurol Neurosurg Psychiatry 70:289–297.

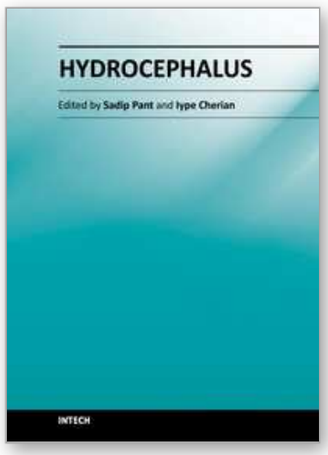
Szczepek E., Czerwosz L., Dąbrowski P., Dudziński K., Jurkiewicz J., Czernicki Z. (2008) *Posturography and computerized gait analysis in the Computer Dyno Graphy system as non-invasive methods for evaluation of normal pressure hydrocephalus progression*. Neurologia i Neurochirurgia Polska 42, 2: 139–152. (Article in polish)

Śliwka S., Pawłowski G., Korsak-Śliwka J., Szewczykowski J., Czernicki Z. (1984) *Computerized infusion test I. The method.* Neurol Neurochir Pol, 18 (6): 553-560.

Tans J.T.J. (1979) *Differentiation of normal pressure hydrocephalus and cerebral atrophy by computed tomography and spinal infusion test.* Journal of Neurology 222, 2: 109-118.

Voss K., Imhof J., Kaestner S., Montavon P.M. (2007) *Force plate gait analysis at the walk and trot in dogs with low-grade hindlimb lameness.* Vet Comp Orthop Traumatol, 20: 229-304.

Wöber C., Wöber-Bingo C., Karwautz A., Nimmerrichter A, Walter H. and Deecke L. (1998). *Aataxia of stance in different types of alcohol dependence – a posturographic study.* Alcohol & Alcoholism 33, 4: 393-402.



Hydrocephalus

Edited by Dr Sadip Pant

ISBN 978-953-51-0162-8

Hard cover, 214 pages

Publisher InTech

Published online 24, February, 2012

Published in print edition February, 2012

Description of hydrocephalus can be found in ancient medical literature from Egypt as old as 500 AD. Hydrocephalus is characterized by abnormal accumulation of cerebrospinal fluid (CSF) in the ventricles of the brain. This results in the rise of intracranial pressure inside the skull causing progressive increase in the size of the head, seizure, tunneling of vision, and mental disability. The clinical presentation of hydrocephalus varies with age of onset and chronicity of the underlying disease process. Acute dilatation of the ventricular system manifests with features of raised intracranial pressure while chronic dilatation has a more insidious onset presenting as Adams triad. Treatment is generally surgical by creating various types of cerebral shunts. Role of endoscopic has emerged lately in the management of hydrocephalus.

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

IntechOpen