APPLICATION OF STATISTICAL ANALYSIS AND FUNCTIONAL ASSESSMENT TESTS IN PATIENTS AFTER TROCHANTERIC FRACTURES TREATED SURGICALLY IN AN INDIVIDUAL REHABILITATION PROGRAMME

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Abstract: Physiotherapeutic procedures after surgical treatment of trochanteric fractures of femurs are a very important element of a post-operative management because they have a significant influence on the final result of physiotherapy. This is due to the nature of the fracture and the frequency of its occurrence. The aim of the work is, in particular, to determine the relationship between functional assessment scales in patients after trochanteric fractures treated surgically using extended statistical analysis including regression equations. Statistical analysis included a group of patients, which participated in a specialized programme of a post-operative procedure, called the 'Individual' Group. The matrix of research results, calculations of basic statistical measures, such as position, variability, interdependence, asymmetry and concentration were presented for this group. Regression equations representing the relationships between the considered variables, in particular concerning the applied scales and post-operative tests, were presented. Their purpose, mathematical interpretation, results of calculations and statistical tests were discussed. Attention was paid to the high correlation between the Parker and Mobility tests. The extended statistical analysis makes it possible to create an own system for assessing the treatment results of patients after trochanteric fractures are treated surgically.

Key words: hip joint, rehabilitation, variance analysis, correlation of variables, variation measures

1. INTRODUCTION

The incidence of fractures of the proximal femur is increasing year by year. They account for 7% of all fractures in adults and 24% of fractures in the elderly (Zu-Sheng et al., 2018; Carulli et al., 2017). They mainly concern women over 60 years of age. After surgical treatment, mortality rates are 7–10% after 30 days, 10–20% after 90 days and 20–50% after 1 year (Borges et al., 2019; Lee et al., 2014; Rizk et al., 2016). The progressive age of patients is an independent mortality factor (Pincus et al., 2017).

Clinical analyses indicate that surgical treatment up to 48 h after an injury improves this index (Borges et al., 2019; Moja et al., 2012; Carulli et al., 2017; Forni et al., 2019). On this basis, guidelines were introduced in the USA and Canada to operate up to 48 h after an injury, and some authors even specify a threshold of 24 h as necessary for the procedure (Pincus et al., 2017). It is also indicated to quickly mobilise patients and then to verticalize them as early as possible to minimize the risk of complications associated with staying in a supine position, such as pneumonia, deep vein thrombosis, bleeding, pulmonary embolism, urinary tract infection and decubitus ulcers (Auron-Gomez and Michota, 2008; Bellebarba et al., 2000; Saarenpää et al., 2009; Huddleston and Whitford, 2001; Klestil et al., 2018).

A special group of fractures of the proximal femur are patients with trochanteric fractures. They constitute 31–51% fractures of the proximal femur. It is worth noting that patients with reduced bone mineral density (BMD) are more susceptible to this type of fracture than to the fracture of the femoral neck (Bernstein et al., 2018). In patients with trochanteric fractures, the percentage of patients with concomitant age-related diseases increases, which can significantly worsen the state of health at the time of the injury. Comorbidities cause difficulties in treatment and influence post-operative prognosis (Zu-Shenk et al., 2018; Grau et al., 2018).

Patients with cognitive impairment (dementia) are a significant problem. 0.5% of the world's population suffers from dementia, and it is estimated that in 20 years this value will double. In this group, in addition to the typical factors that increase the risk of fracture (age, sex, comorbidities), we also observe limited physical fitness and a decrease in BMD in comparison to patients without cognitive impairment. This significantly limits the chances of returning to the fitness the patient had before the fracture and increases the risk of subsequent hospitalisations (Yli-Kyyny et al., 2019). Fig. 1 presents the risk factors for the fracture of the hip area (Friedman et al., 2010). It is emphasized that the early diagnosis of cognitive impairment and the treatment of osteoporosis in patients with dementia may reduce the incidence of hip fractures (Friedman et al., 2010; Hao-Kuang et al., 2014; Huang et al., 2015).

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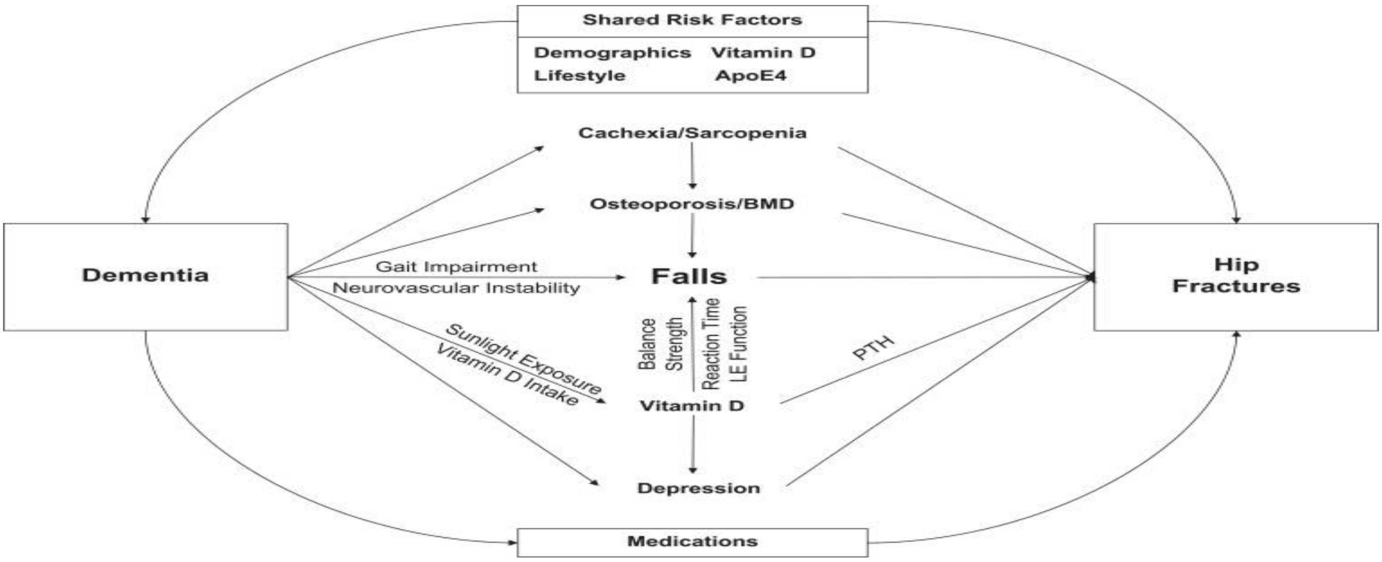

Fig. 1. Risk factors for dementia and hip fractures (Friedman et al., 2010)

Non-surgical treatment of this type of fracture is associated with mortality up to 60% during the year, therefore the surgical stabilisation of the fracture is an indication for life, except for terminally ill or incurable patients (Zhengan et al., 2018).

Operational goals include the anatomical reduction of fragments, sTab. anastomosis with minimal blood loss, and shortening the time of surgery (Yousry et al.,, 2015). Treatment is illustrated in Figs. 2a and 2b.

a
b

Fig. 2. (a) Radiogram before the surgery, (b) Radiogram after the surgery

The most commonly used anastomoses are as follows: Gamma type intramedullary nails and DHS, DCS systems (Fig. 3, Zhengan et al., 2018; Ibrahim and Meleppuram, 2017; Carulli et al., 2017). The highest stability of the anastomosis can be obtained after the anastomosis with the Gamma type intramedullary nail.

a
b
c

Fig. 3. Types of bone anastomoses in trochanteric fractures: a) Gamma type intramedullary nail, b) DHS System, c) DCS System [Stryker, Medgal]

Rehabilitation programmes in patients after surgical treatment of trochanteric fractures of the femurs are usually not described in detail. Most often the method and the programme of improvement depends on the skills and equipment of the centre. In addition to general improvement programmes, the element that the authors pay attention to is the quickest verticalisation of the patient with a partial limb loading, because only such a procedure limits the high mortality rate and minimizes disability (Baum Gaertner and Oetegen, 2009; Klestil et al., 2018; Nurul et al., 2019; Seitz et al., 2016; Shibasaki et al., 2018). The difficulty of the problem can be proved by the fact that only about 50% of patients with trochanteric fractures return to their pre-injury performance. In addition, the researchers jointly emphasize that in recent years, the stay of patients in hospitals has been shortened, while the role of long-term rehabilitation/care centres is growing (Tan et al., 2017).

Trying to find a compromise in the methodology of rehabilitation treatment, a research project entitled 'Comparative assessment of the effectiveness of physiotherapy in patients after surgical treatment of trochanteric fractures depending on the psychomotor state' was implemented at the Department of Traumatology and Orthopaedics at the Military Medical Institute in Warsaw in 2015. Many statistical variables resulting from the obtained information were subjected effectiveness assessment (demographic data and assessment of intellectual performance according to the modified Mini-Mental State Examination (MMSE.) Analyzed variables are scales (tests) of the assessment of physical activity and clinical examination. It is worth noting that the authors interchangeably used the concept of tests or scales assuming that both theses properly reflect the meaning of the study (Friedman et al., 2010;Shibasaki et al., 2018; Skoworonek et al., 2017). An important problem that was encountered was the statistical evaluation of the obtained results. The authors were aware that without the proper approach and analysis, the results may turn out to be incorrect and the conclusions unsuccessful. The problem of statistical analysis of research results was undertaken for the first time in the authors' work (Skowronek et al.,2017). The variance analysis used with constraints was a preliminary activity in the statistical evaluation of the presented research. At the current stage, an introduction of the regression analysis is planned, the equations of which will allow a quantitative assessment between variables. The presented calculations concern the patients from Group I, called the Individual Group. Statistical methods of describing the structure of the population were used for calculations. These results will allow characterisation of the examined group in terms of the influence of the examined variables on the results of the applied physiotherapy procedures in the examined group, and after the analysis on the comparison of the other groups involved in the mentioned research project, i.e. Norm (Group II) and Dementia (Group III) (Research project Military Medical Institute, 2015).

Conducting the proposed research will allow to determine and select the best set of statistical variables in terms of tests and scales having the most important meanings to determine the relationship between the variables that determine the progress of physiotherapy. This analysis may also help find relationships representing a statistical mathematical model describing the output variables (e.g. time of survival) as a function of the input variables (e.g. functional tests) representing the results of physiotherapy, which will allow it to be improved and will help to indicate further directions of research.

Getting ready for the publication, very interesting statistical models regarding mechanical strength of the femur or prognosis of fractures in the hip joint were found in the literature (Pottecher et al., 2016; Bredbenner et al., 2015; Bryan et al., 2010). Statistical models for the variables we discuss have been found in the literature only partially (Anunksy et al.,2008; Mizrahi et al.,2008).

The aim of the work is, in particular, to determine the relationship between functional assessment scales in patients after trochanteric fractures treated surgically using statistical analysis including regression equations. A mathematical model, that will allow to select the most crucial elements from the used functional assessment tests of patients, will be proposed, which may result in the creation in the future of the own system for the evaluation of treatment results of patients with trochanteric fractures.

2. MATERIAL AND METHOD

2.1. Material

A group consisting of patients operated on in the Traumatology and Orthopaedic Department of Military Medical Institute performing an individual rehabilitation programme without the control of the physiotherapist team according to the instructions received after the operative treatment. There was no division in this group due to the degree of mental state. The group is conventionally called 'Individual'. From the group originally consisting of 88 people, 26 people were analysed in full. The Individual Group was created as a test group being a reference for the Norm (II) and Dementia (III) Groups, for which the patients were qualified based on the intellectual efficiency assessment using the modified MMSE test.

The method of postoperative rehabilitation in the Individual Group is a typical model of physiotherapy currently functioning in the above-mentioned Department. In the Norm and Dementia Groups, apart from the assessment of the mental state, a rehabilitation consultation was introduced during the control visits at the Traumatology Department as a new element. Physiotherapy was additionally made dependent on the degree of mental state.

2.2. Method

To determine the descriptive characteristics in the form of the statistical measures of position, the calculations of average, mean and classical measures were used Zeliaś (2000), Aczel (2008); Korzyński (2006); Stwora (2019) and Stanisławek (2010). Classical average measures are calculated based on all values of the variable under examination. Average, positional measures are the most recurrent variables. Originally, we chose 13 statistical measures for the calculations (arithmetic mean, standard deviation (STD/ σ), coefficient of variation V, linear correlation coefficient r(Y,X), coefficient of determination r^2(Y,X), minimum value, maximum value, gap, average deviation v_{op}, coefficient of variation of the average deviation, asymmetry coefficient As, concentration coefficient K – kurtosis).

The description of statistical measures is additionally supplemented by a regression analysis which approximates the experimental data. For the available experimental data with the values of independent variables $x_{i,j}$ where: $i = 1, 2, \ldots, N$ (number of experiments), $j = 1, 2, \ldots, K$ (number of independent variables) and the corresponding values of dependent variables y_i, the regression function, that best describes the considered phenomenon in physical terms, is searched. The significance of the fit of the function is evaluated for a given value of the significance level α.

The selection of the type of the regression function is very important for the identification of a given phenomenon. This selection is also very difficult due to the occurrence of disturbances in research as well as in some cases the lack of proper data collected over the years of observation, and which cannot be repeated or supplemented. Often the influence of disturbances is too high compared to the influence of the variation of input variables on the output variables. The significance of the obtained regression function indicates the existence of a correlation between the considered values but it does not have to contain a causal relationship, yet it does not exclude it. Establishing such a regression function that expresses the causal (physical) relationship of a given phenomenon (as far as it is possible with existing experimental data) is the main difficulty in this procedure. It should be emphasised that the determination of high-reliability conclusions based on the established regression equations is very difficult, especially in the assessment of medical problems due to the high variation of factors determining health state assessment. Conclusions obtained as a result of mathematical calculations support the work of the medical team to a large extent, but they cannot replace their knowledge and experience. In definite cases, they can only confirm or help in specifying the assessment of the validity of its constituent elements in the problem under consideration.

3. RESULTS

3.1. Results of calculations of population structure of group I 'individual' for statistical analysis

For the statistical calculations for the 'Individual' group, a measurement matrix of 23 variables characteristic for 26 patients of the studied group was used, and a set of appropriate tests was collected (Skowronek et al., 2017). The analysed variables are, among others: age, gender, range of hip joint motion and functional tests assessing the level of physical fitness of patients after the finished treatment. It is worth noting that the collected values represent the general and partial scores of the used tests. Medical examination with the above-mentioned tests was performed after treatment was completed (about 6 months after surgery). The medical examination took place in the Department or at patient's home.

The results of 26 measurements are presented in Tab. 2, the results of calculating statistical measures in Tab. 3. For a better insight into the research, a detailed description of 23 variables is included in Tab. 1.

Observing the matrix of experiments and the results of calculations of statistical measures, attention is drawn to a large number of data that requires evaluation and proper analysis, and which will be presented in further considerations.

Tab. 1. Physical names of variables considered in an individual improvement programme

Variable x j	Symbol of variable	Name/Description
1	Y	Year of Patient's Birth
2	M / month	Month of Patient's Birth
3	A	Patient's Age
4	R / L	Operated Right / Left Limb L-1 pt., R – 2 pts.
5	M / W	Patient's Gender, Men / Woman K-1 pt. M-2 pts.
6	i	*Indoor* / Indoor Moving
7	o	*Outdoor* / Outdoor Moving
8	c	*Community* / Functioning in Community
9	P	Parker Scale (Parker Mobility Score): indoor moving + outdoor moving + functioning in community, e.g. shopping = Parker max. Maximum number of points 3 + 3 + 3 = 9 pts.
10	n	Walking Aid
11	m	Environmental Mobility
12	M	Mobility- Scale of dependence on walking aid and level of mobility 1. Walking aid: wheelchair (1 pt.), personal assistant (2 pts.), crutches (3 pts.), crutch/walking stick (4 pts.), without orthopedic help (5 pts.) 2. Environmental mobility: indoor moving (1 pt.), outdoor moving (2 pts.), functioning in the community, e.g. possibility of shopping (3 pts.) max. number of points 5 + 3 = 8 pts.
13	V	Scale of Pain Assessment (VAS) from 0 pts to 10 pts.
14	T	Trendelenburg Test 1 pt. - positive test result, 2 pts. - negative test result
15	f	Flexion in a Hip Joint in degrees
16	ex	Extention in a Hip Joint in degrees
17	ab	Abduction in a Hip Joint in degrees
18	ad	Adduction in a Hip Joint in degrees
19	ir	Internal Rotation in a Hip Joint in degrees
20	er	External Rotation in a Hip Joint in degrees
21	HHSm	HHS, score for the range of motion in a hip joint, 0–5 pts
22	HHS	HHS Scale max. number of pts to 100.
23	Tl	Time of Life Since the Operation to the Day of Analysis in years

Tab. 2. Matrix (database) of experiments in an individual improvement programme (Results of medical research (N = 26) – Individual Group)

	Y	M	A	RL	WM	i	o	c	P	n	m	M	V	T	f	ex	ab	ad	ir	er	HHSm	HHS	TI
No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1.	27.	3.	87.	1.	2.	2.	2.	2.	6.	4.	3.	7.	0.	1.	100.	-20.	30.	0.	0.	0.	4.40	86.40	2.475
2.	19.	1.	95.	1.	.2.	1.	0.	3.	3.	1.	4.	0.	2.		100.	-20.	20.	0.	0.	20.	4.70	71.70	2.491
3.	36.	9.	78.	1.	1.	3.	3.	3.	9.	5.	3.	8.	0.	2.	100.	-20.	20.	0.	0.	20.	4.70	91.70	2.546
4.	37.	1.	77.	2.	1.	2.	2.	2.	6.	4.	2.	6.	1.	1.	100.	-15.	25.	0.	0.	20.	4.40	86.40	2.502
5.	41.	10.	73.	1.	1.	3.	3.	3.	9.	5.	3.	8.	0.	1.	100.	-20.	20.	0.	0.	20.	4.70	48.70	.457
6.	49.	4.	65.	1.	1.	3.	3.	3.	9.	5.	3.	8.	0.	2.	120.	0.	20.	15.	15.	30.	5.00	100.00	2.872
7.	24.	5.	90.	2.	1.	1.	1.	0.	2.	1.	1.	2.	1.	1.	100.	-20.	20.	15.	0.	0.	4.55	52.55	2.669
8.	26.	5.	88.	2.	1.	2.	2.	2.	6.	3.	1.	4.	2.	1.	100.	0.	20.	20.	-10.	10.	4.75	33.75	2.604
9.	34.	3.	80.	1.	1.	2.	2.	2.	6.	3.	3.	6.	2.	1.	100.	-30.	20.	0.	0.	30.	4.70	57.70	2.968
10.	30.	10.	84.	1.	2.	2.	2.	2.	6.	4.	2.	6.	0.	1.	100.	-20.	10.	5.	0.	0.	4.20	69.20	2.491
11.	35.	3.	79.	1 .	1.	2.	2.	2.	6.	3.	2.	5.	0.	1.	100.	-20.	10.	5.	0.	0.	4.20	69.20	2.650
12.	38.	9.	76.	2.	1.	2.	2.	2.	6.	3.	1.	4.	0.	1.	100.	-20.	10.	5.	0.	0.	4.30	66.30	2.757
13.	52.	3.	62.	2.	2.	2.	2.	2.	6.	4.	3.	7.	1.	1.	70.	-20.	-20.	20.	0.	0.	3.15	68.15	2.880
14.	39.	3.	75.	2.	1.	2.	2.	2.	6.	4.	3.	7.	2.	1.	100.	-20.	20.	0.	0.	0.	4.40	69.40	2.869
15.	25.	5.	89.	1.	1.	3.	3.	3.	9.	5.	3.	8.	0.	2.	110.	0.	20.	10.	0.	0.	4.65	99.65	2.724
16.	22.	12.	92.	1.	1.	2.	2.	2 .	6.	3.	2.	5.	1 .	1.	100.	-20.	20.	15.	-10.	20.	4.85	67.85	2.645
17.	51.	4.	63	.1.	2.	0.	0.	1.	1.	2.	2.	2.	5.	1.	60.	-45.	-20.	20.	20.	20.	3.30	19.00	2.689
18.	48.	4.	66.	1.	2.	2.	2.	1.	5.	3.	1.	4.	5.	1.	100.	-20.	15.	0.	0.	0.	4.35	52.32	2.568
19.	33.	2.	81.	2.	2.	3.	2.	3.	8.	4.	3.	7.	1.	1.	110.	0.	30.	0.	0.	0.	4.55	81.55	3.042
20.	28.	4.	86.	2.	2.	2.	2.	2.	6.	3.	1.	4.	2.	1.	100.	-20.	20.	-20.	-10.	10.	4.75	50.75	2.601
21.	23.	9.	91.	2.	1.	0.	0.	0.	0.	1.	1.	2.	2.	1.	90.	-20.	20.	20.	20.	20.	4.70	6.70	.986
22.	45.	12.	69.	2.	1.	2.	2.	2.	6.	3.	3.	6.	0.	1.	90.	-20.	20.	20.	20.	20.	4.70	62.70	2.568
23.	40.	5.	74.	1.	1.	3.	2.	3.	9.	5.	3.	8.	0.	1.	120.	0.	20.	15.	15.	30.	5.00	88.00	2.905
24.	26.	3.	88.	1.	1	3.	3	3.	9.	5.	3.	8.	0.	2.	110.	-10.	30.	0.	0.	0.	4.55	99.55	2.667
25.	55.	11.	59.	2.	1.	3	.3.	3.	9.	5.	3.	8.	0.	2.	120.	0.	20.	0.	0.	0.	5.00	100.00	2.590

Tab. 3. Results of calculations for Group I (Individual) 7 statistical measures of 23 variables

No. v.	Name v.	$\bar{X}$	V=(SDT/$\bar{X}$) 100[%]	r(y,x)	r(x,y)^2 100[%]	Vop=(op/ $\bar{X}$) 100[%]	As asym.	K coef. kurtosis
1	Y	35.34615	28.81796	0.125	1.570	23.395	0.287	1.912
2	m	5.53846	61.96632	−0.401	16.043	52.350	0.624	1.908
3	A	78.65385	12.95047	−0.125	1.570	10.513	−0.287	1.912
5	WM	1.30769	35.99324	0.193	3.741	32.579	0.786	1.567
6	i	2.15385	38.71671	0.212	4.482	27.198	−1.069	3.932
7	o	2.03846	40.40746	0.144	2.084	25.399	−0.892	3.580
8	c	2.03846	47.01392	0.191	3.659	32.656	−0.859	2.819
9	P	6.26923	40.49333	0.199	3.950	28.929	−0.798	2.981
10	n	3.65385	32.78952	0.137	1.879	27.044	−0.551	2.514
11	m	2.26923	38.53378	0.160	2.544	34.681	−0.515	1.459
12	M	5.846615	35.11952	0.128	1.632	29.555	−0.521	1.937
13	V	0.96154	148.48580	0.026	0.070	107.692	1.650	5.089
14	T	1.26923	35.64366	0.152	2.310	31.002	0.981	1.925
15	f	100.76920	13.43859	0.151	2.272	7.986	−1.062	4.866
16	ex	−15.38462	−72.33601	0.188	3.517	−56.731	−0.137	3.046
17	ab	16.92308	70.94695	−0.100	0.995	43.881	−2.088	7.066
18	ad	7.11538	142.17970	0.020	0.039	120.790	−0.338	2.753
19	ir	2.69231	320.50950	−0.133	1.773	239.560	0.791	2.752
20	er	10.76923	104.80300	−0.194	3.776	93.956	0.338	1.493
21	HHSm	4.52115	9.93199	−0.110	1.220	6.789	−1.678	5.692
22	HHS	69.20077	35.97741	0.464	21.551	27.116	−0.667	2.868
23	T	2.54185	22.18227	1.000	100.000	11.648	−2.662	9.482

3.2. Final characteristics of treatment results

The essence of the final assessment of the treatment of patients with trochanterian fractures in addition to radiological control is the scale of pain assessment and the assessment of mobility (Skowronek et al., 2017; Tjun Huat Chya et al., 2013; Wamper et al., 2010). The latter one is performed in a clinical examination with functional tests.

For a physiotherapist, this is the basic measure of the outcome of treatment. Therefore, for the detailed statistical evaluation of 23 variables, 7 were selected. They include age, gender, Parker test/scale (Tab. 4) and VAS pain assessment scale, Trendelenburg test, the scale of dependence on walking aid and the mobility level – working name Mobility (Tab. 5) and the HHS scale. The scores of the tests were assessed as a whole without detailed evaluating of their components.

Tab. 4. Scoring of the Parker Test (Parker Mobility Score) and marking of its symbols (Skowronek et al., 2017; Tjun Huat Chya et al., 2013; Wamper et al., 2010)

Mobility	Without difficulty	With the help of orthopedic equipment	With the help of another person	Lack of activity
Indoor moving	3 pts.	2 pts.	1 pt.	0 pts.
Outdoor moving	3 pts.	2 pts.	1 pt.	0 pts.
Functioning in community e. g. shopping	3 pts.	2 pts.	1 pt.	0 pts.

Parker Test= indoor moving + outdoor moving + functioning in community e. g. shopping

Tab. 5. Scoring of the scale of dependence on walking aid and level of mobility(Skowronek et al., 2017; Tjun Huat Chya et al., 2013; Wamper et al., 2010)

System of scoring	Result
Walking aid	
Wheelchair	1 pt.
Personal assistant	2 pts.
Walking frame, crutches	3 pts.
Crutch, walking stick	4 pts.
Moving without help	5 pts.
Environmental mobility	
Indoor moving	1 pt.
Outdoor moving	2 pts.
Functioning in community, e.g. shopping	3 pts .

Scoring of the scale of dependence on walking aid and level of mobility= walking aid + environmental mobility

3.3. List of statistical measures

The results of the adopted statistical measures of the selected variables are summarised in Tab. 6. Each of the analysed variables and scales was subjected to the presented innovative statistical analysis. It facilitates the assessment of mutual links between variables. The applied test in the assessment of mutual correlations was first of all the linear correlation coefficient. The correlation was assessed according to the following assumptions (Skowronek et al., 2017; Zeliaś, 2000).

Correlation assessment:
- 0.0 – no correlation
- $0.0 < r_{(x,\,y)} \le 0.2$ – very small (practically no linear connection),
- $0.2 < r_{(x,\,y)} \le 0.4$ – clear but small,
- $0.4 < r_{(x,\,y)} \le 0.7$ – moderate,
- $0.7 < r_{(x,\,y)} \le 0.9$ – significant,
- $0.9 < r_{(x,\,y)} \le 1.0$ – very strong,
- $r_{(x,\,y)} = 1.0$ – functional linear relationship between the variables y, x.

For a better insight into the assessment of the obtained results, coloured markings according to the attached legends were introduced. A list of the results of the calculations of statistical measures is shown in Tab. 6 and a list of correlation coefficients between the output values and the successive variables xi in regression equations for the specified medical tests is shown in Tab. 7. In order to determine the relationship between these tests, regression equations in the form of the third-degree polynomial were adopted. Finally, the form of regression equations and the results of their testing are given after presenting the statistical measures and the correlation coefficients.

Tab. 6. List of statistical measures in the Individual Group

Analyzed variables and scales	$\bar{X}$	V	Vop	As	K
Age	78.65385	12.95047	10.513	-0.287	1.912
MW/Gender	1.30769	35.99324	32.579	0.786	1.567
Parker	6.26923	40.49333	28.929	-0.798	2.981
"Mobility"	5.84615	35.11952	29.555	-0.521	1.937
VAS	0.96154	148.48580	107.692	1.650	5.089
Trendelenburg	1.26923	35.64366	31.002	0.981	1.925
HHS	69.20077	35.97741	27.116	-0.667	2.868

$\bar{X}$ – arithmetic mean, V – coefficient of variation (differentiation) , Vop – coefficient of variation of average, A – asymmetry coefficient, K – kurtosis)

Legend:
- (red) for v and v_{op}, red means the most homogeneous result
- (blue) for v and v_{op}, blue means the least homogeneous result
- (red) for As, red means the right-sided asymmetry (As > 0)
- (blue) for As, blue means the left-sided asymmetry (As < 0)
- (red) for K, red means values with higher concentration around averages (K > 3)
- (blue) for K, blue means values with lower concentration around averages (K < 3)

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Tab. 7. List of linear correlation coefficients between the used tests

Group/correlation	Variable x	Variable x^2	Variable X^3
Parker - HHS	0.79026	0.75639	0.72633
Mobility - HHS	0.81212	0.79995	0.77084
VAS - HHS	-0.65303	-0.62278	-0.57586
Trendelenburg -HHS	0.63291	0.73003	0.77755
Parker - Mobility	0.91384	0.88861	0.86245
VAS - Mobility	-0.58886	-0.57327	-0.55357
Trendelenburg - Mobility	0.47708	0.53140	0.57330
VAS - Parker	-0.55986	-0.55186	-0.52961
Parker - Trendelenburg	0.45685	0.45685	0.45685
VAS - Trendelenburg	-0.41687	-0.41687	-0.41687

Description of correlation	Graphic interpretation
0.0 - no correlation	
$0.0 < r_{(x,y)} \leq 0.2$ – very small	
$0.2 < r_{(x,y)} \leq 0.4$ – clear but small	
$0.4 < r_{(x,y)} \leq 0.7$ – moderate	
$0.7 < r_{(x,y)} \leq 0.9$ – significant	
$0.9 < r_{(x,y)} < 1.0$ – very strong	
when $r_{(x,y)} = 1.0$ – linear function	

3.4. Models of regression equations, research observations

After analysing the linear correlation coefficients, the statistical models in the form of the third-order regression equations were used in the next stage. The best ones were selected and presented. An additional goal of these activities was to improve research in the future by reducing the number of the currently performed tests which contain common features of elements related to physical and intellectual efficiency or other important features affecting the outcome of treatment.

In the exploratory research, the polynomial model was adopted in the following form:

$$\hat{y} = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \quad (1)$$

where: $\hat{y}$ - output variable of the regression equation, ai - regression coefficients, i = 1, 2, 3 x - input variable.

Below the selected calculation results, that were obtained using a standard IBM multiple-step regression programme, are presented. This programme was supplemented with the data necessary to select the best set of regression equations. This programme allows to match the assumed mathematical models to the experimental data according to the principle of the minimum sum of squares of deviations of differences between experimental points, and relevant points of the calculated mathematical models. The significance of the statistical fit of the mathematical model to the experimental data was tested with the F – Fischer Snedecor test, while the significance of individual coefficients of regression equations was tested with the t – Student test at the assumed significance level of α = 0.05 in both cases. The significance level α = 0.05 corresponds to the level of confidence (probability) p = 1−α = 0.95. The final form of regression equations was chosen by adopting the criterion of the execution of the applied tests at the significance level α ≤ 0.05. The test results are given in Tab. 8.

Tab. 8. Results of testing the significance of regression equations and regression coefficients regarding the dependences between the used tests

No.	Dependence of tests	Step of calculations	Multiple correlation coeff. *R*	No. of freed. deg.; no. & nam. *n-k-1,*	*k*	Value of F – Fisher function *F*	Critical value F_{kr} (α, n-k-1, k)	$\frac{F}{F_{kr}}$	Value of t – Student function *t*	Critical value $t_{kr\,(\alpha,\,n-1)}$	$\frac{t}{t_{kr}}$
1	P-HHS	1	0.780	24	1	39.917	4.262	9.365	t_1= 6.318	2.064	3.061
		2	0.791		2	19.244	3.430	5.610	t_1=1.819 t_2=0.297	2.064 2.069	0.879 0.135
		3	0.835	22	3	16.830	3.056	5.507	t_1=2.770 t_2=2.884 t_3=2.262	2.064 2.069 2.074	1.335 1.397 1.091
2	M-HHS	1	0.812	24	1	46.492	4.262	10.98	t_1=6.819	2.064	3.304
		2	0.814	23	2	22.615	3.430	6.598	t_1=2.166 t_2=0.482	2.064 2.069	0.483 0.233
		3	0.815	22	3	14.537	3.056	4.757	t_1=0.758 t_2= -0.339 t_3=0.395	2.064 2.069 2.074	0.365 0.163 0.190
3	V-HHS	1	0.653	24	1	17.845	4.262	4.422	t_1=-4.224	2.064	2.046
		2	0.656	23	2	8.707	3.430	2.538	t_1=2.002 t_2=0.420	2.064 2.069	0.968 0.203
		3	0.686	22	3	6.526	3.056	2.135	t_1=0.857 t_2=1.334 t_3=-1.291	2.064 2.069 2.074	0.413 0.622 0.643
4	T-HHS	1	0.778	24	1	36.696	4.262	8.610	t_3=6.058	2.064	2.935
		2	0.816	23	2	22.923	3.43	6.683	t_3=3.026 t_2=-2.055	2.064 2.069	1.462 0.993
		3	0.827	22	3	16.012	3,056	5.239	t_3=2.080	2.064	1.006

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									t_2= -1.574 t_1=1.182	2.069 2.074	0.759 0.570
5	**P-M**	**1**	0.914	24	1	121.947	4.262	28.519	t_1=11.025	2.064	5.341
		2	0.917	23	2	60.68	3.43	17.691	t_1=2.715 t_2=-0.897	2.064 2.069	1.312 0.433
		3	0.961	22	3	88.509	3.056	28.962	t_1=5.624 t_2=-4.981 t_3=4.48	2.064 2.069 2.074	2.712 2.402 2.160
6	**V-M**	**1**	0.589	24	1	12.74	4.262	2.989	t_1=-3.569	2.064	1.729
		2	0.591	23	2	6.157	3.43	1.795	t_1=-0.8712 t_2=-0.262	2.064 2.069	0.421 0.127
		3	0.594	22	3	4.008	3.056	1.311	t_1=-0.578 t_2=0.424 t_3=-0.401	2.064 2.069 2.074	0.277 0.204 0.193
7	**T-M**	**1**	0.573	24	1	11.75	4.262	2.757	T_3=3.428	2.064	1.661
		2	0.647	23	2	8.294	3.43	2.418	T_3=2.326 t_2=-1.891	2.064 2.069	1.124 0.914
		3	0,734	22	3	8.558	3.056	2.800	T_3=2.905 t_2=-2.641 t_1=2.387	2.064 2.069 2.074	1.401 1.273 1,151
8	**V-P**	**1**	0.457	24	1	10.957	4.262	2.571	t_1=-3.310	2.064	1.604
		2	0.457	23	2	3.033	3.43	0.884	t_1<0.001 t_2<0.001	2.064 2.069	<< 1.0 << 1,0
		3	0.564	22	3	3.415	3.056	1.197	t_1=-0.398 t_2=0.194 t_3=0.227	2.064 2.069 2.074	0.192 0.093 0.109
9	**P-T**	**1**	0.457	24	1	6.33	4.263	1.485	t_1=2.516	2.064	1.219
		2	0.457	23	2	3.033	3.43	0.884	t_1<0.001 t_2<0.001	2.064 2.069	<< 1.0 << 1.0
		3	**no solution in the field of real numbers**								
10	**V-T**	**1**	0.417	24	1	5.048	4.263	1.84	t_1= - 2.247	2.064	1.089
		2	0.417	23	2	2.419	3.43	0.705	t_1<0.001 t_3<0.001	2.064 2.069	<< 1.0 << 1.0
		3	**no solution in the field of real numbers**								

A set of the regression equations representing the effective mathematical models (linear/non-linear) describing the relationships between the selected tests significant in terms of model fit as well as the significance of individual regression coefficients are presented in Eqs. (2)–(11).

Dependence P - HHS $P = 0.69302 + 0.08058\ HHS$
or $P = -3.09728 + 0.42456\ HHS - 0.00706\ HHS^2 + 0.00004\ HHS^3$ (2)

Dependence M-HHS $M = 1.21159 + 0.06697\ HHS$ (3)

Dependence V-HHS $V = 3.55307 - 0.03745\ HHS$
or $V = 2.282 + 0.0975\ HHS - 0.00296\ HHS^2 + 0.00002\ HHS^3$ (4)

Dependence T-HHS $T = 0.73511 + 0.03284\ HHS - 0.00088\ HHS^2 + 0.00001\ HHS^3$ (5)

Dependence P-M $P = -0.33650 + 1.12993\ M$
or $P = -13.48795 + 10.80495M - 2.05105\ M^2 + 0.13140\ M^3$ (6)

Dependence V-M $V = 3.35547 - 0.40949M$ (7)

Dependence T-M $T = 0.91694 + 0.00132M^3$
or $T = -1.39013 + 2.00704\ M - 0.47591\ M^2 + 0.03424\ M^3$ (8)

Dependence V-P $V = 2.93555 - 0.31487P$ (9)

Dependence P-T $P = 3.01504 + 2.56391\ T$ (10)

Dependence V-T $V = 2.63158 - 1.1579\ T$ (11)

Statistical significance of the obtained results is a very important problem. One of the basic activities of statistical inference is verification which means making decisions about the truth or the falsity of statistical hypotheses. Most often it refers to the form of distributions or values of their parameters (Zeliaś, 2000). Here, the hypothesis is any assumption concerning an unknown distribution regarding the examined feature of the population, and about the truth or the falsity, which is deduced from the random test. When carrying out the significance tests, it is required to make such a hypothesis to which there is a greater guess about its falsity than its truth.

The measurement results contain a definite number of experiments of a given statistical measure, e.g.: mean value $\overline{X}$ of the examined feature and coefficients of variation. In many cases there is a need to estimate the population confidence range at the assumed significance level, e.g. $\alpha = 0.05$ substantively justified. When estimating definite population measures based on the performed experiments in the test, the exact value of this measure is not given in this case, but the range is determined, which contains with the assumed probability the unknown missing measure

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value of the parameter being tested. The most commonly accepted value is p = 0.95 (95%), in more detailed studies p = 0.995, and in very exact cases even 0.999 (99.9%).

To determine the confidence ranges for the selected statistical measures, which are characterised by possibly large correlation coefficients r (y, x), a two-sided symmetric distribution of the significance level α = 0.05 was adopted. The adoption of the two-sided distribution of the significance level is justified by the fact that disturbances may appear on the edges of the range of the definite statistical measures. The assumption was made that the tests have the t – Student distribution with n−1 degree of freedom. The mean values of random variables and STDs of the general population are not known.

The lower limit D and the upper limit G of the confidence range are defined by the dependences:

$$D = \overline{X} - t_{\left(\frac{\alpha}{2}, n-1\right)} \frac{\sigma}{\sqrt{n-1}};$$

$$G = \overline{X} + t_{\left(\frac{\alpha}{2}, n-1\right)} \frac{\sigma}{\sqrt{n-1}}, \ldots\ldots \quad (12)$$

And the relative accuracy degree of the estimation vi [%] of the chosen parameter is determined by the expression:

$$v_i = \frac{t_{\left(\frac{\alpha}{2}, n-1\right)} \sigma}{\bar{x} \sqrt{n-1}} 100\ [\%]$$

The results of the calculations for the selected variables are given in Tab. 9.

Tab. 9. Results of calculations of statistical measures for the selected variables and scales

No.	Variable	Mean value, $\overline{X}$	Stand. deviations., σ	$t_{\left(\frac{\alpha}{2}, n-1\right)}$	Lower limit	Upper limit	Confiden. range	Range length	Estimation degree %
1	**Age [years]**	78.654	10.186	2.060	74.457	82.851	74.7÷82.8	8,394	5.28
2	**MW/Gender**	1.308	0.471	2.060	1.114	1.502	1 ÷ 2	1	14.78
3	**Parker**	6.269	2.539	2.060	5.224	7.312	5 ÷ 8	3	16.99
4	**Mobility**	5.846	2.053	2.060	5.001	6.698	5 ÷ 7	2	14.50
5	**VAS**	0.962	1.427	2.060	0.373	1.358	0 ÷ 2	2	61.11
6	**Trendeleburg**	1.269	0.452	2.060	1.085	1.549	1 ÷ 2	1	14.69
7	**HHS**	69.201	24.897	2.060	58.943	79.458	58.9÷79.4	20.515	14.78

Note: In Tab.9 the A - age variable is given in years, the remaining ranges and length of ranges for the variables are expressed in the appropriate units resulting from the tests and scales

It is worth noting that the best statistical results were obtained in the analysis of the third order regression equations. In order to additionally assess the significance of individual regression coefficients and the significance of mathematical model fit to the experimental data, the t - Student test and the F - Fischer test were analysed. In the analysed dependences, i.e. Parker on Mobility, Mobility on HHS and Parker on HHS, the fit of the mathematical model and the significance of individual regression coefficients were claimed at the significance level $\alpha \leq 0.05$. When analysing complex and difficult issues in research, this is a very good result. The F - Fischer and t - Student tests show that in the conducted analysis the best results are generally achieved in the first-order models.

When assessing the fit of regression equations using the multi correlation coefficient R, the best results are generally achieved in the third-order models. However, in such cases, the statistical analysis (the t - Student test) shows in most cases a considerable loss of significance level of individual regression coefficients at the required level of significance (regression coefficients become irrelevant at the assumed significance level), as well as the reduction of the parameters of the F – Fischer test while maintaining the condition of the specified significance level α.

4. DISCUSSION

The article presents a detailed analysis of the selected tests of functional assessment of patients after trochanteric fractures are treated surgically. Being aware of the time constraints in daily hospital work, a preliminary attempt was made to create an own system that will allow to assess the recovery process quickly and reliably. For the assessment of pain, the Visual Analogue Scale (VAS) was chosen as a proven and easy to use scale, while the mobility test was chosen based on the applied statistical analysis and clinical experience.

Analysing the linear correlation between the applied tests, it was observed that a very strong correlation was obtained between the Parker test/scale and Mobility (r = 0.91384), and a significant correlation was obtained between Mobility and HHS (r = 0.81212). Also significant is the Parker and HHS correlation (r = 0.79026). The remaining relationships between the tests were moderate.

Based on the variation coefficient V and the variation coefficient of the average deviation Vop, it was also found that the results of the above tests proved to be the most homogeneous (reaching the values close to the average) in the 'Individual' Group under study. Trying to confirm the results between the tests, the results of the calculations were compared with the resulting regression analysis. The multiple correlation coefficient R confirmed the high correlation between the tests: Parker and Mobility (0.961), Mobility and HHS (0.815) and Parker and HHS (0.835), which is conditioned by the form of the adopted mathematical model.

The obtained results and the implementation simplicity suggest that it is sufficient to use the Parker or the Mobility tests interchangeably in clinical practice for a full assessment of mobility. The performed analysis allowed to create a model of a fast assessment of the patient's condition. Physiotherapists and doctors are using our experience in the clinical assessment of the patient's condition after hip injuries. They use one functional test (Parker / Mobility interchangeably) and the VAS scale for pain assessment. Previously, 2–3 functional tests were performed, which took twice as much time.

In the literature, we find the tests we used with various statistical calculations (Tjun Huat Chua et al., 2013; Wamper et al., 2010; Shin et al., 2020; Abdullah et al., 2018). However, we did not find any studies that would compare the described tests with the usage of the applied statistical model.

5. CONCLUSIONS

The results from the research on measures and regression equations give the following observations:

– The maximum correlation coefficient was obtained between the Parker and the Mobility tests/scales. Clinical experience confirms the possibility of using one of them in the examination of patients interchangeably.
– The results of the functional assessment regarding the Parker, Mobility, Trendelenburg and HHS tests are the most homogeneous.
– Multiple-step regression effectively supports the statistical analysis in the functional assessment of the 'Individual' Group, thus indicating its usefulness.
– The extended statistical analysis makes it possible to create an own system for assessing the treatment results of patients after trochanteric fractures are treated surgically. The application of the VAS pain assessment scale and the Parker / Mobility interchangeable tests based on clinical experience and statistical calculations allows to assess the patient's condition quickly and reliably.

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