Biology of Sport, Vol. 20 N°4, 2003

ANALYSIS OF MAXIMUM FORCE OF TIP PINCH, LATERAL PINCH AND PALMER PINCH IN RELATION TO MAXIMUM HANDGRIP FORCE

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Abstract. The aim of the presented study was to develop a mathematical relationship expressing the pinch forces (tip pinch, lateral pinch and palmer pinch) in relation to handgrip force which will make it possible to determine maximum force for those three pinches in relation to upper limb location and gender. The predictive equation expressing maximum handgrip force in relation to upper limb location and gender has been developed on the basis of accessible data. By adopting the predictive equation of the maximum handgrip force, an analysis of pinch force values in relation to upper limb location was also performed. The developed relationship could be very useful in assessing maximum pinch forces for creating norms in sport, rehabilitation and occupational settings.

(Biol.Sport 20:303-319, 2003)

Key words: Hand forces - Upper limb model - Predictive equation - Rehabilitation

Introduction

An upper limb is, generally speaking, a body part which enables the performing of manipulation tasks by hand activities like grip or pinch. The grip or pinch is the act of taking by hand and keeping a firm hold of any object, tool, lever or instrument. Grips are performed using the whole hand while the pinch involves using the fingers only. Grip and pinch strength are commonly employed indices of strength used in hand evaluations. In studies published so far a few kinds of grip can be distinguished. The broadest area, however, is occupied by research performed for the most common kind of grip, which is transverse grip known as handgrip. However, also pinch forces like tip pinch, palmer pinch and lateral pinch are quite commonly known and studied.

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It is widely accepted that handgrip and pinch strength provide an objective index of the functional integrity of the upper limb. Measurements of maximum grip or pinch forces result in values that can be comprised to establish normative data, which is important in sport settings concerning tennis, weight lifting, baseball, archery, pole valnut etc. Strength parameters are used in sport not only as an estimate of total body strength and to define functional baselines but also for the assessment of the functional effects of hand or wrist injuries and for establishment of treatment goals. Hand and wrist injuries usually affect grip and pinch strength temporarily or permanently, which means that the strength can be measure of progress during rehabilitation and the need for further physiotherapy. Therefore the measurement of grip and pinch strength is commonly performed to document hand function of sportsmen as well as to monitor the success or failure of their treatment programme.

To determine whether an individual has impairment in grip strength is to compare that individual's grip strength with established norms. As from the biomechanical point of view the musculoskeletal load of the upper limb in static conditions depends on upper limb location, force exerted by the upper limb (value, direction, type of grip) and time or repeatability of force exertion [15], guidelines as to proper recommended force values in reference to upper limb location are needed. Therefore, it is necessary to measure grip strength in a body position that is identical to that used in the collection of normative data.

It would be very useful to find out the general relationship between the value of maximum pinch forces and the most important factor which influences this force, like upper limb location and gender. For such a purpose, broad experimental studies are needed. Another way of achieving this is to establish the relationship on the basis of many different data derived from already performed studies of various researchers.

Studies have been performed whose aim was to analyse the maximum forces of the upper limb and most of those studies considered handgrip force. They have revealed that maximum handgrip force strongly depends on upper limb location and on the basis of those studies it has been possible to develop a predictive equation, which expresses maximum handgrip force in relation to upper limb location and gender [16].

There are also a number of studies which consider pinch forces, mostly tip pinch, lateral pinch and palmer pinch in relation to upper limb location. However, the number of the results of those studies is much lower and do not allow for the development of such a relationship. Taking into account that there are not enough studies presenting the results of the maximum force of pinch forces for different

upper limb locations, it is advisable to find a relationship between maximum handgrip force and the most common maximum pinch forces like tip pinch, lateral pinch and palmer pinch.

Finding a relationship between maximum force for handgrip force and maximum pinch forces will make it possible to express pinch forces in relation to handgrip force too. Such an attitude will facilitate, on the basis of a predictive equation of maximum handgrip force in relation to the upper limb location and gender, an expression of maximum force of pinch forces in relation to upper limb location and gender.

The aim of the presented study was to develop a mathematical relationship expressing the force of tip pinch, lateral pinch and palmer pinch in relation to handgrip force. Such a relationship will make it possible to determine the maximum force for those three pinches in relation to upper limb location and gender by adopting the predictive equation of male maximum handgrip force in relation to upper limb location and the mathematical relationship of maximum handgrip force between male and female.

An analytical algorithm of the relation between pinch forces and handgrip force

It is advisable to perform a meta-analysis study because an experimental study which would allow for developing the above described relationship is too expensive and time consuming. The study of handgrip has been performed on a much larger population which consider a larger variety of upper limb locations. It could be supposed that for all kinds of grip changes in maximum force, according to upper limb location are proportional. Numerous studies have been performed and their results describe the relationship between handgrip force and various types of pinch for the same group of population in the same experimental conditions [1,6,8,10,12,14,18,20,22]. While analysing those results, it is possible to find a relationship between handgrip force and pinch forces. The result of another study was a predictive equation expressing male maximum handgrip force in relation to upper limb location. The formula for maximum handgrip force has been established on the basis of an extensive study of world literature by implementing a meta-analysis [16].

In the presented study, lateral pinch, also named key pinch, tip pinch, also called pulp 2 pinch, and palmer pinch, also called chuck pinch (Fig. 1) have been considered [7].

TIP pinch

LATERAL pinch

PALMER pinch

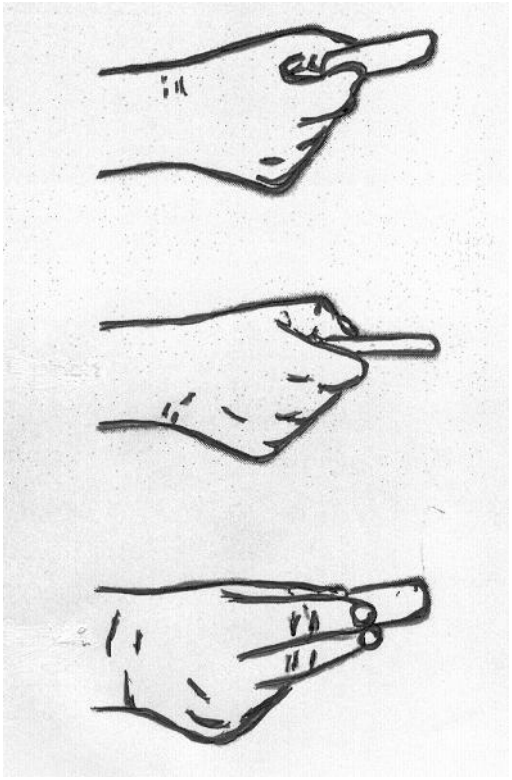

Fig. 1
Illustration of the three kinds of pinch (lateral pinch, palmer pinch and tip pinch)

In the lateral pinch, the force of thumb flexion is opposed by the stability of the radial lateral aspect of the index finger of the partially clenched fist. In the palmer pinch, thumb flexion is opposed by flexion of the index and middle fingers. In the tip pinch, thumb flexion is opposed by the index finger.

The analysis, the aim of which was to establish the relationship between handgrip force and pinch forces, was performed according to the algorithm presented in the diagram below (Fig. 2).

The diagram of the analysis describes the steps necessary to express pinch forces as a function of upper limb location. The mathematical relationship $F_{male}=f(F_{female})$ for handgrip force as well as the predictive equation $F_{handgrip} =f(q_1, q_2, q_3, q_4, q_5, q_6, q_7)$ has been adopted from the study of Roman-Liu [16].

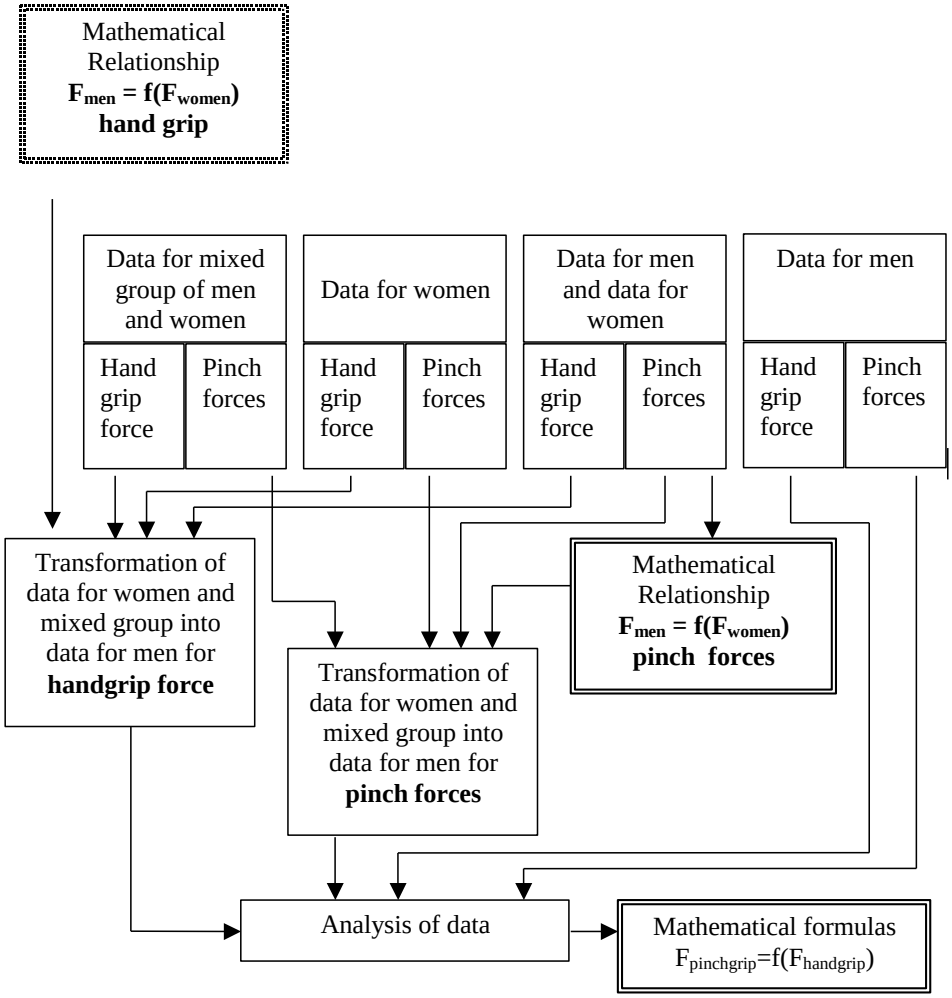

Fig. 2
Diagram of an analysis performed to develop a relationship between maximum pinch forces and maximum hand grip force

As available results of studies considered the force for the population of man or the population of women as well as a mixed population of men and women, the first step was an assessment of the relationship between maximum pinch force (tip, lateral, palmer) for men and women. Some of the studies [1,2,3,4,6,12,22]

presented values of maximum pinch force performed for a population of men and a population of women in the same experimental conditions and for the same upper limb locations. Those studies were accepted for analysis. On the basis of the analysed results of those studies, the relationship between data for men and for women have been established. Fig. 3 presents a relationship between maximum force for men and for women for tip pinch, lateral pinch and palmer pinch. The data derived from various studies are presented in Table 1.

Table 1
Values of maximum force of tip pinch, lateral pinch and palmer pinch for man and women (values in bold italics have been calculated on the basis of the formulas presented in Fig. 3; some of studies comprise a few data according to different age groups and different upper limb location)

References	Tip pinch [N]		Lateral pinch [N]		Palmer pinch [N]	
	M	W	M	W	M	W
Mathowetz *et al.* [12] (different age groups)	80.44	49.05	115.76	78.48	118.70	76.52
	81.42	52.97	118.70	78.48	115.76	78.48
	78.48	55.92	117.72	83.39	109.87	86.33
	80.44	51.99	117.72	73.58	116.74	77.50
	79.46	51.01	113.80	74.56	108.89	75.54
	84.37	58.86	114.78	78.48	106.93	80.44
	81.42	55.92	117.72	74.56	105.95	77.50
	73.58	51.99	107.91	69.65	105.95	71.61
	70.63	45.13	103.01	68.67	98.10	65.73
	75.54	47.09	103.99	66.71	95.16	63.77
	61.80	45.13	86.33	64.75	80.44	64.75
	62.78	43.16	91.23	55.92	83.39	53.96
	75.54	50.03	108.89	71.61	103.99	72.59
Mathowetz *et al.* [13] (upper limb locations)			***108.60***	75.71		
			105.95	73.49		
Mathowetz *et al.* [11]	***74.07***	50.78	***113.89***	76.62	***117.43***	84.17
Palanisami *et al.* [14]	47.87	***32.37***	89.27	***59.06***	69.16	***45.13***

Crosby *et al.* [2]	84.66	62.39	120.27	89.07		
Lamoreaux and Hoffer [10] (different upper limb locations)			***68.96***	***41.50***		
			71.81	***43.95***		
			80.83	***51.80***		
Dempsey and Ayoub [3] (different upper limb locations)	55.62	37.18	86.03	51.50	73.77	49.83
	50.91	34.53	79.95	46.50	67.79	43.95
	41.40	28.15	69.45	39.83	53.07	33.94
	47.77	32.86	79.95	45.42	66.41	43.65
	51.21	34.43	80.34	45.42	66.02	43.46
Hallebeck and McMullin [6] (different upper limb locations)			77.11	63.77		
			84.17	67.00		
			94.86	76.62		
			85.84	68.18		
			73.28	59.84		
Boathright *et al.* [1] (different age groups)			95.35	70.83		
			51.99	32.86		
Young *et al.* [21]			113.11	71.22		
Werner and Flanzblau [17]			113.80	***80.25***		
Imhram [7] (different upper limb locations)	69.65	***47.68***	96.14	***64.94***	94.18	***65.24***
	49.05	***33.16***	83.39	***53.96***	72.59	***47.87***
	49.05	***33.16***	77.50	***48.95***	67.69	***43.95***
	49.05	***33.16***	75.54	***47.09***	66.71	***43.07***
	41.20	***27.66***	63.77	***37.08***	53.96	***32.77***
Williams *et al.* [18]	***39.63***	26.49	***75.34***	47.09		
Fernandez *et al.* [4,5] (different upper limb locations)	62.39	46.89	93.98	62.69	89.17	62.29
	61.12	46.50	90.74	59.74	84.27	61.51
	56.11	***43.36***	86.23	57.19	76.22	52.19
	57.39	36.98	85.84	55.82	76.42	48.76
	50.42	36.00	77.20	48.76	65.24	39.14
Woody and Mathiowetz [19] (different upper limb locations)	***114.19***	81.52	***117.03***	77.89		
	115.27	82.40	***107.62***	74.85		

Josty *et al.* [8] (different upper limb locations)	***140.28***	103.01
	148.23	109.87
	156.18	116.74

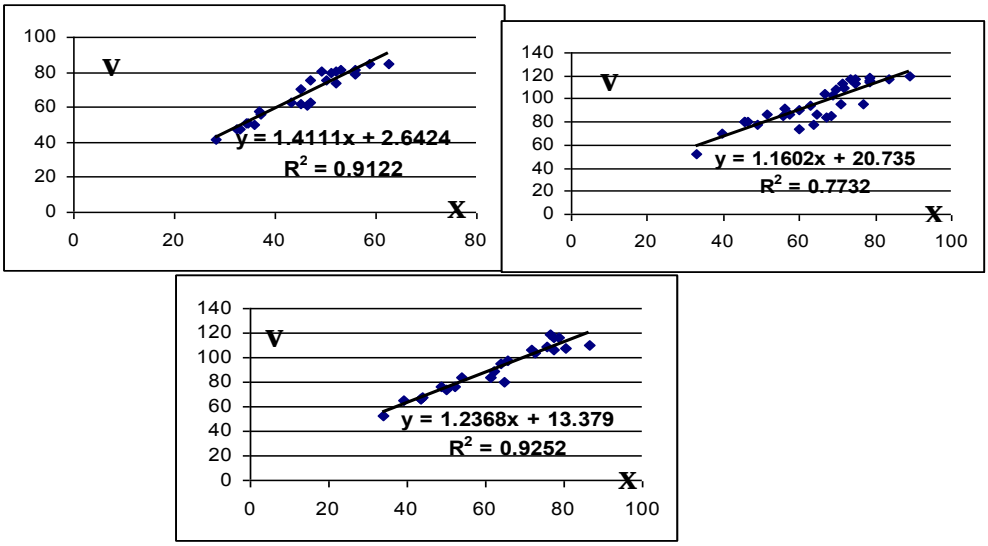

Fig. 3
Regression line for maximum force between values for men (y) and women (x): a) tip pinch, b) lateral pinch, c) palmer pinch

The relationships presented in Figure 3, allowed for transferring data for women and mixed group into data for man. The next step was an analysis of the results for handgrip force and pinch forces. The data for tip pinch, lateral pinch and palmer pinch which were taken into consideration are presented in Table 2.

The relationship has been established only in those cases where there was correlation between maximum handgrip force values of and one of the pinch forces (tip, lateral or palmer).

As a result of this analysis a mathematical relationship between maximum force for pinches considered in the study (tip, lateral and palmer) and handgrip has been developed. The kind of relationship that has been applied is the one with the highest correlation co-efficient. The relationship between handgrip force and pinch force is expressed by the linear relationship (1), (2) and (3) for tip pinch, lateral pinch and palmer pinch respectively.

$F_{tippinch} = 0{,}0986*F_{handgrip} + 29{,}338$ (1)
$F_{lateralpinch} = 0{,}1727*F_{handgrip} + 33{,}934$ (2)
$F_{palmerpinch} = 0{,}1441*F_{handgrip} + 37{,}838$ (3)

Table 2
Values of maximum force of man handgrip, tip pinch, lateral pinch and palmer pinch in relationships $F_{tippinch}=f(F_{handgrip})$, $F_{lateralpinch}=f(F_{handgrip})$ and $F_{palmerpinch}=f(F_{handgrip})$

References	hand grip [N]	tip pinch [N]	lateral pinch [N]	palmer pinch [N]
Mathowetz *et al.* [12]	538.57	80.44	115.76	118.70
Mathowetz *et al.* [12]	537.59	81.42	118.70	115.76
Mathowetz *et al.* [12]	543.47	78.48	117.72	109.87
Mathowetz *et al.* [12]	532.68	80.44	117.72	116.74
Mathowetz *et al.* [12]	520.91	79.46	113.80	108.89
Mathowetz *et al.* [12]	490.50	84.37	114.78	106.93
Mathowetz *et al.* [12]	506.20	81.42	117.72	105.95
Mathowetz *et al.* [12]	450.28	73.58	107.91	105.95
Mathowetz *et al.* [12]	399.27	70.63	103.01	98.10
Mathowetz *et al.* [12]	406.13	75.54	103.99	95.16
Mathowetz *et al.* [12]	335.50	61.80	86.33	80.44
Mathowetz *et al.* [12]	293.32	62.78	91.23	83.39
Mathowetz *et al.* [12]	464.99	75.54	108.89	103.99
Mathowetz *et al.* [13]	498.54		112.52	
Mathowetz *et al.* [13]	481.47		109.19	
Mathowetz *et al.* [11]	510.12	74.07	113.89	117.43
Palanisami *et al.* [14]	338.94	47.87	89.27	118.70
Crosby *et al.* [2]	467.64	84.66	120.27	
Josty *et al.* [8]	452.24		140.28	
Josty *et al.* [8]	512.08		148.23	
Josty *et al.* [8]	526.80		156.18	
Lamoreaux and Hoffer [10]	267.03		68.96	
Lamoreaux and Hoffer [10]	187.08		71.81	
Lamoreaux and Hoffer [10]	181.29		80.83	

Hallebeck and McMullin [6]	239.27	77.11
Hallebeck and McMullin [6]	294.79	84.17
Hallebeck and McMullin [6]	386.81	94.86
Hallebeck and McMullin [6]	274.39	85.84
Hallebeck and McMullin [6]	227.40	73.28
Boathright *et al.* [1]	543.38	95.35
Boathright *et al.* [1]	337.17	51.99
Young *et al.* [21]	428.70	113.11
Werner and Flanzblau [17]	452.24	113.80

An analysis of pinch forces in relation to upper limb location

To express maximum force in relation to upper limb location a biomechanical model, which allows for a universal definition of upper limb location, has been developed. The system called the Seven Degrees of Freedom Model (SDFM) facilitates defining upper limb location by seven angles.

- angle of arm adduction/abduction (q_1): movement is in transverse plane from -45º (arm directed horizontal towards the body) to 90º (arm directed away from the body);
- angle of arm extension/flexion (q_2): movement is in sagital plane from -50º (arm directed to the back of the body) to 170º (arm straight up);
- angle of medial/lateral rotation along the long axis of arm (q_3): from -60º (upper limb flexed in elbow, the forearm is directed towards the body) to 45º (in the upper limb flexed in the elbow, the forearm is directed from the body);
- angle of flexion in elbow (q_4): from 0º (straight in elbow, arm and forearm are in one line) to 135º (maximum flexion in elbow);
- angle of forearm pronation/supination (q_5): from -85º (palm of upper limb flexed in elbow directed down) to 90º (palm of upper limb flexed in elbow directed up);
- angle of hand adduction/abduction (q_6): from -45º (angle between axis of forearm and axis of hand when hand is bent towards finger) to 30º (angle between axis of forearm and axis of hand when hand is bent towards the thumb);
- angle of hand flexion/extension (q_7): from -90º (angle between inside plane of hand and forearm) to 80º (angle between external plane of hand and forearm);

All the seven angles defining upper limb location are equal to 0° in the natural position of the body, which means in standing upright with upper limbs hanging naturally down.

The SDFM was used to define upper limb location in creating a predictive equation which expresses maximum handgrip force in relation to upper limb location. The formula is expressed as a function of the seven angles. By transferring the formula in step with the relationship between pinch forces and handgrip force, pinch forces can be expressed in relation to upper limb location defined by the above mentioned seven angles.

Maximum pinch force in relation to upper limb location

The predictive equation expressing male maximum handgrip force being the result of the study [16] has been used for calculations of maximum handgrip force for the selected upper limb locations.

An analysis showing the influence of the seven angles defining upper limb location on the value of maximum pinch force (tip, lateral and palmer) have been performed. Fig. 4 shows maximum pinch forces in relation to the seven angles which define upper limb location.

Values in pinch forces according to the angles of limb location are proportional to each other. As far as arm abduction is concerned, the highest value of pinch forces are for q_1 equal to 45°. For angle q_2, (flexion in arm) the lowest value is for 15° and it increases with the increase of the angle. Rotation along the long axis for the arm for both medial and lateral direction causes an increase in the pinch forces. For angle q_4 values of maximum pinch force are on a similar level except for the angle q_4 equal to 45° where the force is a little higher than for the other values of the angle. The lowest value for the angle of pronation/supination is for q_5 equal to 0°, the highest is for q_5 equal to 60° (supination) and above this value the force decreases. For pronation, there is a strong decrease in maximum force value for q_5 equal to -90°. Angles q_6 and q_7 cause a decrease in force value according to an increase in angle value, for q_6 the highest value is for 0°, for angle q_7 it is 15°.

Verification

For verification purposes were accepted the studies of Dempsy and Ayoub [3], Fernandez *et al.* [4,5] and Imhran [7], which were not considered in the development of the relationship between handgrip force and pinch forces. The results derived from the calculations can be compared with experimental data. The studies [3,4,7] were performed for a few different upper limb locations for lataral and palmer pinches. The description of upper limb locations and adequate values of lateral and palmer forces are presented in Table 3.

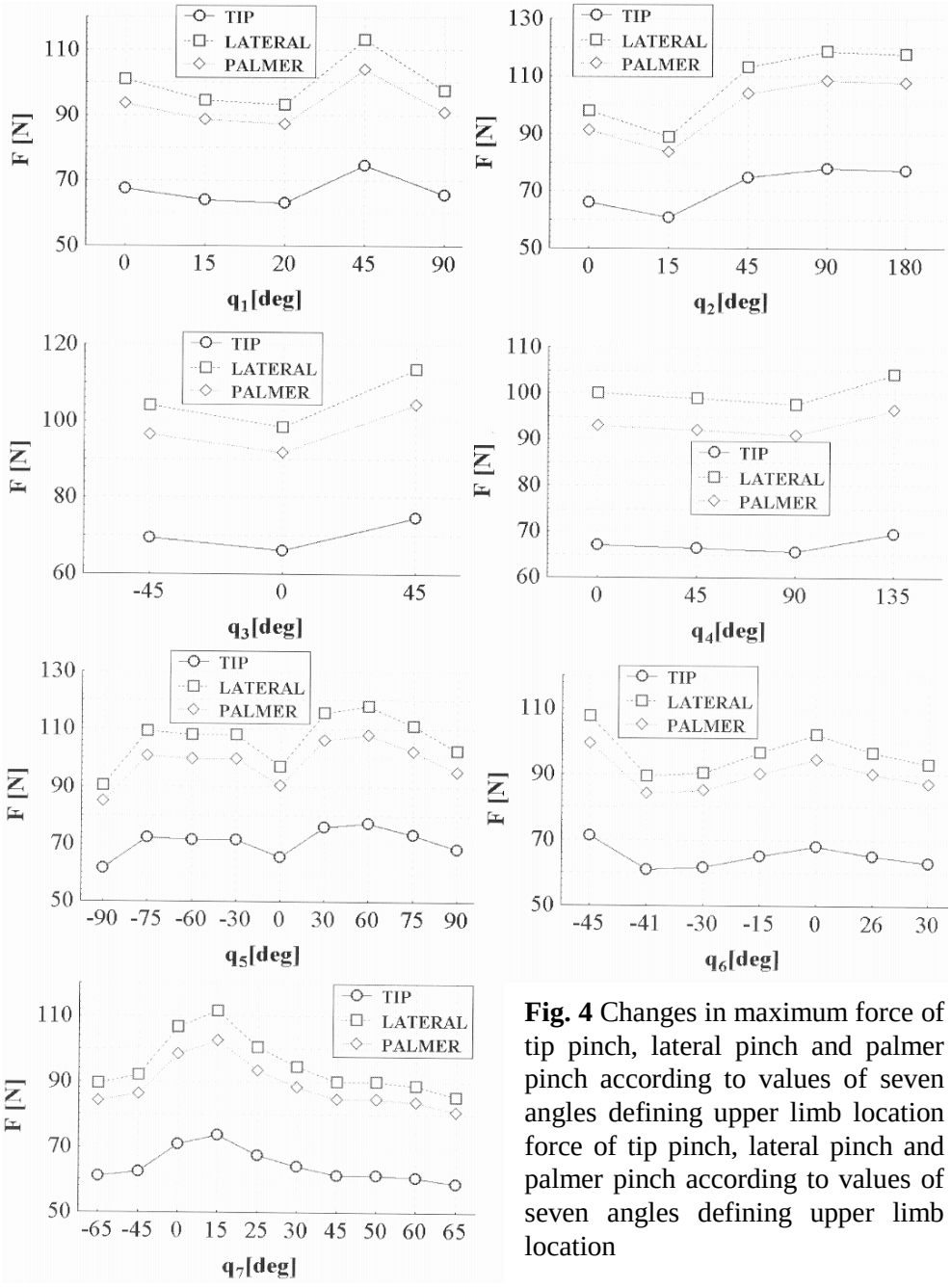

Fig. 4 Changes in maximum force of tip pinch, lateral pinch and palmer pinch according to values of seven angles defining upper limb location force of tip pinch, lateral pinch and palmer pinch according to values of seven angles defining upper limb location

For three out of the seven cases the studies were performed for the same upper limb locations, described as maximum wrist flexion, maximum extension, maximum abduction and maximum adduction. The theoretical values calculated on the basis of a predictive equation expressing maximum handgrip force in relation to upper limb location [16] and equations (2) and (3) for lateral pinch and palmer pinch were performed. For calculations, maximum values of respective angles, accepted on the basis of a few studies and listed above, were accepted. It should be noted that the values of both lateral and palmer pinches differ between the study of Dempsy and Ayoub [3], Imhran [7] and Fernandez *et al.* [4,5]. The results of numerous studies have revealed that maximum force depends on many factors. The range of strength is highly influenced by specific experimental conditions such as equipment used, testing protocols and examined population.

Theoretical and experimental values for lateral pinch and palmer pinch have been presented in Figs. 5 and 6, respectively.

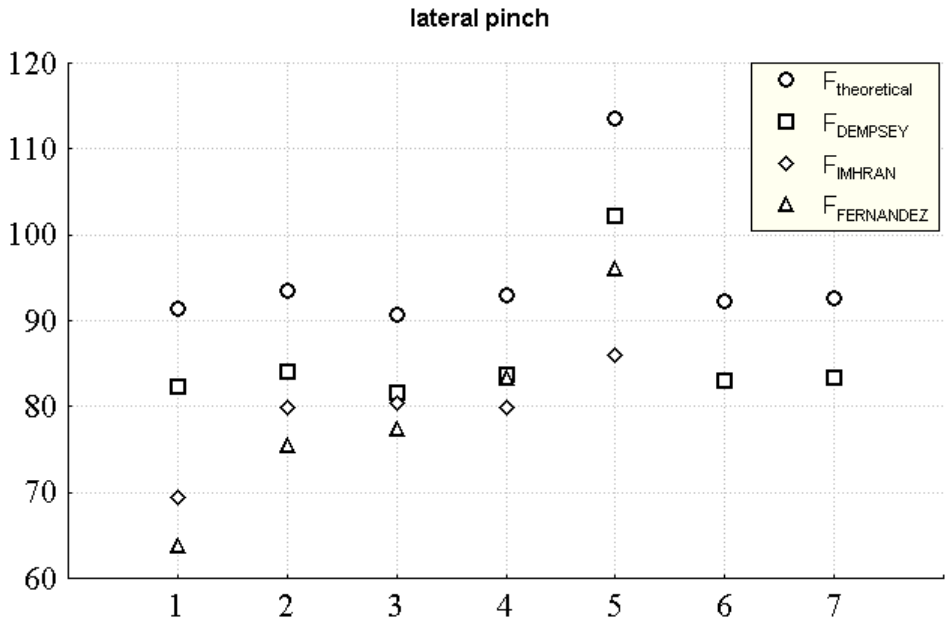

Fig. 5
Theoretical and experimental values of maximum force for lateral pinch (numbers mark upper limb location in Table 3)

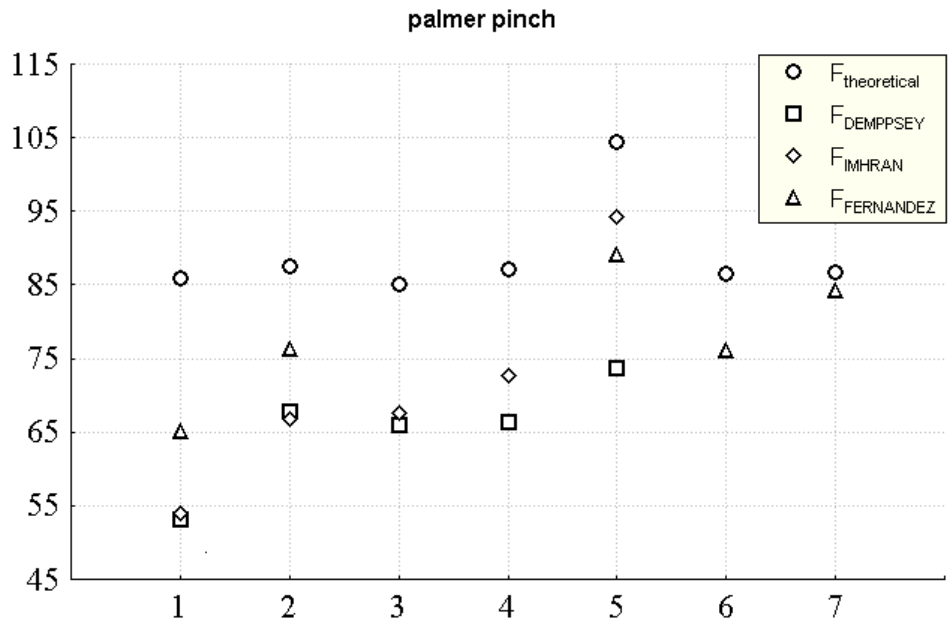

Fig. 6
Theoretical and experimental values of maximum force for palmer pinch (numbers mark upper limb location like in Table 3)

Values of maximum pinch forces calculated on the basis of theoretical studies are about 20% higher in relation to the experimental studies. Although the values of theoretical and experimental studies differ, the tendencies of changes according to upper limb location are similar. However even for the same experimental conditions different values of maximum force can be obtained according to the different population of subjects differentiated by subjective factors such as body mass, lifestyle, occupation, etc. Therefore there can occur some discrepancies between studies of different researchers as well as theoretical and experimental studies.

Taking into account that the values of the maximum forces of the studies [3] and [7] differ according to the population tested and that those studies were not taken into consideration in the process of developing a mathematical relationship, the tendencies in the changes of maximum force according to upper limb location

should be considered as crucial. In this respect, the results of the experimental studies and theoretical studies are in step.

Summary

The established formulas are the effect of the study which considered data available in world literature. The formulas make it possible to express the force of tip pinch, lateral pinch and palmer pinch in relation to upper limb location by using a predictive equation developed in the study by Roman-Liu [16]. Values of maximum forces of lateral and palmer pinch are on the very similar lever, therefore the is no necessity to differentiate between those two types of upper limb activities.

Comparing the results of the calculations based on the developed formulas with the experimental results leads to the conclusion that there exists a high agreement between the experimental and theoretical analyse of maximum pinch forces in relation to upper limb location.

The developed mathematical relationship could change if more studies were taken into consideration and then of course it would be closer to reality. However, even in this form, the developed relationship will be very useful in assessing maximum pinch forces. The combined results can be used for creating norms in sport and rehabilitation as well as occupational settings

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Accepted for publication 10.08.2002

Acknowledgement
This study was a part of the National Strategic Programme "Occupational Safety and Health Protection in the Working Environment", supported in 1998–2001 by the State Committee for Scientific Research in Poland