

Quantification of Functional Deficits Associated with Rectus Abdominis Muscle Flaps

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To evaluate the deficits in trunk flexion due to partial or complete unilateral rectus abdominis muscle flap transfer in reconstructive surgery, 27 patients (11 females, 16 males) with rectus abdominis muscle flap transfer dating back at least 3 years, clinically healthy at the time of testing, and 22 controls (10 females and 12 males), comparable in age and body mass index, were compared. For clinical assessment of power of the straight and oblique abdominal muscles, Janda's test of muscle function was used, and torque (in N·m) of isometric trunk flexion at 0, 5, 10, 20, and 30 degrees was determined with the TEF Modular Component, an auxiliary unit of the Cybex 6000. Results were analyzed for males and females separately.

Relative torque (N·m/kg) of operated male and female patients was significantly lower ($p < 0.05$) as compared with controls. Differences were more pronounced in males than in females. Clinically, there were no significant between-group differences in the power of the straight and oblique abdominal muscles.

In conclusion, trunk flexion deficits following rectus abdominis muscle flap transfer can be compensated for satisfactorily in most cases, supporting the use of this muscle in reconstructive surgery, if patients are selected carefully. (*Plast. Reconstr. Surg.* 96:1623, 1995.)

Muscle flaps have gained a firm place in reconstructive surgery. Acting on the assumption that every muscle is supported in its function by synergists so that functional deficits at the donor site were negligible, reconstructive surgeons obviously felt justified in raising whatever muscle for flap grafting. The literature abounds with reports on the use of the rectus abdominis muscle.¹⁻⁴ This muscle is used either as a pedicle or as a microvascular flap^{5,6}; its anatomy is well documented.⁷ Many surgeons almost enthusiastically used the flap with a unilateral or bilateral pedicle for breast reconstruction,^{8,9} while

the potential functional losses caused at the donor site were hardly given any attention. According to Kroll et al.,¹⁰ breast reconstruction in irradiated patients has fewer complications when a rectus abdominis muscle flap is used rather than a latissimus dorsi muscle flap. On the basis of a clinical study of 57 patients undergoing rectus abdominis muscle transfer, Lejour and Dome⁶ described functional deficits in 1991, and Mizgala et al.¹¹ recently reported on a similar test. Since neither study included an objective quantification in addition to clinical examinations, the present study was performed aiming at both aspects at the same time.

MUSCLE ANATOMY AND FUNCTION

The rectus abdominis muscle arises from the fifth to the seventh rib and xiphoid process. With its strong tendons, it inserts at the crest of the pubic bone and the symphysis pubis. It is traversed by three to four tendinous intersections (lineae transversae). The muscle is usually supplied by the inferior intercostal nerves but may sometimes receive its innervation from the superior lumbar nerves.

Kapandji¹² described the actions of the muscle as a function of the fixed point: If the symphysis pubis is fixed, the muscle acts as a powerful flexor of the trunk. If the thorax is fixed, it tilts the pelvis. These actions of the rectus abdominis muscle are supported by the two oblique abdominal muscles and by the iliopsoas muscle.

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PATIENTS AND METHODS

Patients (Table I)

Twenty-seven patients (11 female and 16 male) aged 20 to 75 years (mean age 42 years) were examined clinically by experienced physicians of a university department of physical medicine and rehabilitation. All of them had undergone flap grafting at least 3 years prior to the study. The muscle had been raised unilaterally to serve as an isolated muscle flap in 4 patients and as a myocutaneous flap in the remaining 23. In 10 patients, part of the fascia covering the oblique abdominal muscles also was removed. Twelve flaps were pedicled and 15 were microvascular free flaps. Eleven patients with major soft-tissue defects needed extended rectus abdominis muscle flaps; in 10 patients, the muscle had been used in its full length, and in 6, two-thirds of the muscle length was raised for flap grafting.

Indications included major soft-tissue defects secondary to third-degree compound fractures, soft-tissue necroses, chronic osteomyelitis, large-surface third-degree burns causing functional impairment, defects left after removing malignant masses of the chest, and a large hemangioma of the skull.

Grafted sites included the skull (1 patient), the forearm (2 patients), the hand (4 patients), the hip (2 patients), the thigh (2 patients), the knee joint (5 patients), the lower leg (9 patients), the ankle (2 patients), and the feet (3 patients).

Clinical follow-up examinations of the donor site showed sagging of the upper abdominal wall in one patient within an area of 10 × 10 cm containing no more than the rectus sheaf. Raising a superiorly pedicled rectus muscle for reconstructing the chest wall had caused a diffuse lower abdominal bulge in another (female) patient. To cope with the activities of daily living, these two patients had to wear an abdominal brace. In a questionnaire, all other patients reported not to feel impaired in their activities by

the absence of the rectus muscle at the donor site. But particularly the younger patients felt that the long scars left after raising extended flaps were cosmetically disfiguring.

Methods

Unilateral muscle testing, which would be desirable after unilateral flap raising, is ruled out by the underlying anatomy. Since most of our patients underwent acute flap grafting following trauma, preoperative data such as would be needed for a prospective study were not available.

To assess abdominal muscle function, we used the clinical muscle function test described by Janda¹³ in 1986. In addition, we measured the torque of isometric trunk flexion at 0, 5, 10, 20, and 30 degrees with the Cybex 6000 TEF Modular Component.

Both tests mainly concentrate on the superior portion of the rectus abdominis muscle. However, since muscle continuity is lost during surgery, since the nerves enter the muscle from proximal, and since the agonist activity of the iliopsoas muscle cannot be obviated, isolated testing of the superior portion appears to be acceptable.

Janda's Muscle Function Test. This test was performed with the subject in the supine position with knee and hip joints flexed and the soles fixed to the support. Special emphasis was placed on slowly lifting the trunk from the support and briefly holding it in an oblique right and oblique left position (ipsilateral internal and contralateral external oblique muscles) as well as in straightforward position without trunk rotation (rectus abdominis muscle). Lifting the trunk from the supine position with knees and hips flexed largely eliminates the synergistic activity of the iliopsoas muscle.¹³⁻¹⁵ Table II shows the criteria for scoring muscle power in Janda's test.

TABLE II
Janda's Muscle Power Score

Points	Description
5	Lift trunk including lumbar spine with hands touching ears and elbows spread laterally
4	Lift trunk including lumbar spine with arms stretched forward
3	Lift lower scapular angle with arms stretched forward
2	Flex cervical spine while pressing lumbar spine against support
1	Muscle tension palpable only during maximal expiration or coughing
0	No muscle contraction palpable

TABLE I
Descriptive Patient Data (\pm SD Where Applicable)

	Females	Males
<i>n</i>	11	16
Age (years)	45.8 \pm 6.5	39.0 \pm 14.0
Height (cm)	162 \pm 5.9	175 \pm 7.2
Body weight (kg)	69.1 \pm 13.2	73.7 \pm 8.6
Body mass index (kg/m ²)	26.1 \pm 4.9	24.1 \pm 2.8

Trunk Flexion Test with the Cybex 6000 TEF Modular Component. The Cybex 6000 is widely used for determining the torque of isometric or isokinetic muscle contractions. *Torque* is defined as the power times the power arm of the lever. Since the machine measures torque in the axis of rotation, it is always directly proportionate to the power.

The TEF Modular Component is an auxiliary unit that permits isolated trunk flexion measurements. Torque was measured at 0, 5, 10, 20, and 30 degrees of forward flexion of the trunk during isometric contraction of the muscle for 4 seconds. In each position, three readings were obtained. Between measurements, a rest of 30 seconds was allowed. The peak torque in absolute terms and relative to the body weight, as well as the average of three readings, was used for statistical analysis.

The position of subjects was as follows: The frontal plane through the axis of rotation was defined by a line connecting the lateral malleolus, the greater trochanter, and the acromion. Patients were fixed in this position by a lumbar supporting plate placed between the superoanterior iliac spines and the trochanter major. The horizontal plane through the superoanterior iliac spines also was placed in the axis of rotation. This position ensured an average hip flexion of 26 degrees, an average knee flexion of 35 degrees, and an average dorsiflexion of the ankle joints of 10 degrees, respectively.

Subgroups

Since Maughan et al.¹⁶ found males and females to show highly significant differences in the peak flexion force generated at the knee joint, we decided to investigate male and female patients separately. In addition to a control group with an age and sex distribution similar to that of the patient group, a second control group was introduced to evaluate "physiologic" reference values. Hence a homogeneous group was built consisting of young healthy adults of either sex and normal body mass index (Table III). Groups are specified as follows:

- Group 1: normal subjects (12 females and 11 males) aged 20 to 30 years
- Group 2: normal subjects (10 females and 12 males) aged 27 to 75 years
- Group 3: patients (11 females and 16 males) aged 27 to 75 years

Statistical Analysis

Data were analyzed by means of the SPSS/PC+ software package. Cybex readings of groups 2 and 3 were compared with the Mann-Whitney U test. To identify sex-specific differences, respective subgroup analyses were done. But since these would not have been sufficiently conclusive for the clinical muscle power test data on account of the small number of subjects in the subgroups, no statistical tests were performed on the pertinent data.

RESULTS

Janda's Clinical Muscle Function Test

Table IV shows that almost all subjects in group 1 (21 of 23) scored 5 for muscle power. In group 2, including the elderly normal subjects, 2 subjects reached a score of 3, 4 a score of 4, and 16 a score of 5. This agrees well with the usual pattern in the general population. Of the patients in group 3, 2 females did not score better than 2; 2 males and 3 females scored 3. The majority of the males managed to score 5 (9 patients) or 4 (5 patients). Of the females, by contrast, only 2 reached a score of 5 and 3 reached a score of 4.

Cybex Trunk Flexion Readings (Table V)

Group 1. In both sexes, peak and average torque readings were found to rise slowly with progressive trunk flexion. This was also true for torque readings related to body weight.

Absolute torque readings showed a sex-specific difference of 115 percentage points at 0 degrees of trunk flexion and 90 percentage points at 30 degrees of trunk flexion for female readings considered 100 percent. Controlled for body weight differences ranged between 75

TABLE III
Age and Body Mass Index (Mean \pm SD)

	Group 1		Group 2		Group 3	
	Female	Male	Female	Male	Female	Male
<i>n</i>	12	11	10	12	11	16
Age	25.0 \pm 2.1	24.7 \pm 2.0	39.4 \pm 15.7	37.0 \pm 12.0	45.8 \pm 16.5	39.0 \pm 14.0
Body mass index (kg/m ²)	20.4 \pm 1.3	22.9 \pm 2.9	24.3 \pm 4.9	23.1 \pm 2.5	26.2 \pm 4.9	24.1 \pm 2.8

TABLE IV
Distribution of Janda's Muscle Power Scores in Trial Groups

Score	Group 1		Group 2		Group 3	
	Female (n = 12)	Male (n = 11)	Female (n = 10)	Male (n = 12)	Female (n = 11)	Male (n = 16)
5	10	11	7	9	2	9
4	2	0	2	2	3	5
3	0	0	1	1	3	2
2	0	0	0	0	2	0

TABLE V
Trunk Flexion Test with the Cybex 6000 TEF Modular Component*

	Group 1		Group 2		Group 3	
	Female	Male	Female	Male	Female	Male
pT 0 (N·m)	94.9 ± 15.1	205.6 ± 26.7	91.0 ± 25.3	194.7 ± 46.8	81.6 ± 21.9	152.1 ± 44.7
pT 0/BW (N·m/kg)	156.0 ± 30.6	272.0 ± 36.5	141.0 ± 32.8	257.5 ± 57.0	112.0 ± 33.6	205.1 ± 56.9
avT 0 (N·m)	78.2 ± 14.7	168.0 ± 24.2	74.7 ± 25.9	164.3 ± 44.9	65.9 ± 19.4	126.2 ± 37.6
pT 5 (N·m)	98.6 ± 15.7	208.2 ± 26.5	94.9 ± 25.2	200.6 ± 48.8	79.3 ± 19.3	152.5 ± 43.1
pT 5/BW (N·m/kg)	161.8 ± 28.8	275.3 ± 34.0	147.0 ± 30.7	264.5 ± 55.8	109.7 ± 31.3	205.5 ± 51.4
avT 5 (N·m)	83.9 ± 14.0	178.7 ± 29.2	81.8 ± 25.3	273.7 ± 50.5	64.7 ± 16.5	127.9 ± 37.0
pT 10 (N·m)	101.3 ± 18.3	207.5 ± 33.8	97.4 ± 27.5	203.0 ± 49.0	76.3 ± 15.1	155.9 ± 46.0
pT 10/BW (N·m/kg)	166.1 ± 32.3	273.7 ± 40.9	150.8 ± 34.6	266.8 ± 53.2	104.8 ± 22.8	210.0 ± 54.6
avT 10 (N·m)	88.3 ± 15.8	178.8 ± 33.8	86.8 ± 26.1	178.6 ± 47.9	64.1 ± 16.6	129.9 ± 37.8
pT 20 (N·m)	106.1 ± 19.1	211.2 ± 35.0	103.2 ± 29.6	204.5 ± 41.3	81.7 ± 14.9	161.4 ± 46.7
pT 20/BW (N·m/kg)	174.5 ± 33.3	278.2 ± 40.7	160.8 ± 41.1	269.2 ± 41.9	112.0 ± 22.7	217.2 ± 53.9
avT 20 (N·m)	92.3 ± 18.8	180.6 ± 33.2	89.6 ± 28.7	182.6 ± 40.7	69.4 ± 18.1	137.2 ± 38.3
pT 30 (N·m)	110.5 ± 20.9	209.5 ± 38.1	106.7 ± 30.9	215.2 ± 42.3	89.0 ± 14.6	164.9 ± 47.6
pT 30/BW (N·m/kg)	182.5 ± 34.8	276.1 ± 44.3	167.8 ± 45.4	283.0 ± 40.4	122.2 ± 23.7	221.3 ± 51.3
avT 30 (N·m)	98.4 ± 20.9	181.6 ± 39.0	96.4 ± 28.8	193.0 ± 41.2	77.2 ± 13.8	137.7 ± 40.6

* pT = peak torque (N·m), pT/BW = peak torque related to body weight (N·m/kg), avT = average torque over 4 seconds (N·m); 0, 5, 10, 20, 30 = degrees of trunk flexion.

and 50 percentage points. The sex-specific difference was significant ($p < 0.05$).

Group 2. As in group 1, all torque readings increased with progressive trunk flexion, and the readings showed sex-specific differences. Mean values of men were between 200 and 215 percent of the corresponding mean values of women for peak torque, between 200 and 220 percent for average torque, and between 167 and 182 percent for torque relative to body weight (corresponding absolute figures are given in Table V).

Group 3. In females of group 3, the torque dropped with increasing trunk flexion from 0 to 10 degrees, while in males, it remained constant. Torque readings rose, however, in both sexes with trunk flexions beyond 10 degrees. Male versus female differences were 85 to 103 percentage points for torque relative to body weight.

Group 2 versus Group 3. Group comparisons showed statistically significant differences between the male subgroups for all readings ($p < 0.03$). In female subgroups, differences reached

the level of significance only when torque readings were related to body weight ($p < 0.05$).

DISCUSSION

The rectus abdominis muscle has been used widely for reconstructing soft-tissue defects of the abdomen, groin,² and lower extremities.^{17,18} As a unilaterally or even bilaterally pedicled flap ensuring the blood supply of the skin and subcutaneous tissues from the lower abdomen, it also has been recommended for reconstructing the breast.⁹ In recent years, the comparatively high complication rate of unilaterally pedicled TRAM flaps and the abdominal-wall morbidity associated with bipedicled flaps have increasingly prompted surgeons to give preference to microsurgical flap transfer.¹⁰

The rectus abdominis muscle is functionally supported by a number of synergists. Since long-term results are not yet available, however, candidates for flap grafting should be selected carefully on the basis of stringent criteria with due consideration to their age, occupation, and physical activities. Of paramount importance is

meticulous closure of the donor site.¹⁹ As our follow-up examinations of the donor site showed, problems with activities of daily living were reported only by patients with less than meticulous abdominal-wall closure. The strikingly few reports of subjective complaints, which do not entirely match the objective data, are probably due to the patients' satisfaction with the positive outcome of their primary disease, which prompted the grafting procedure in the first place.

Janda's clinical muscle function test showed between-group differences for females that were not as conclusively demonstrable for males. Mizgala et al.¹¹ performed similar tests, where test 2 compares to muscle power score 5, test 3 full situp to muscle power score 4, and the partial situp in this position to muscle power score 3. Their female patients seem to have had higher absolute values on average. There might be different reasons: (1) Since we tested males and females, we had to build subgroups, resulting in smaller patient numbers. (2) We included different indications for the operation, while in the Mizgala et al. study all patients had undergone breast reconstruction. (3) Differences in the average physical condition between Americans and Austrians are not known but cannot be ruled out.

In group 3, torque as a function of the degree of trunk flexion differed from that in groups 1 and 2. Up to 10 degrees of trunk flexion there was not a steady increase; on the contrary, in females there was even a drop. Factors explaining increasing torque levels with increasing trunk flexion in groups 1 and 2 include (1) noncorrection of the measured data for the gravity pull, (2) increasing agonist activity of the iliopsoas and oblique abdominal muscles, and (3) a potential effect of training.

The test outcome in the females of group 3 can be seen to differ from that in the males. Presumably this group suffered only minor losses in muscle power initially, which was compensated for by the synergists beyond 20 degrees of trunk flexion. However, since groups 2 and 3 differed in all parameters, the losses apparently cannot be fully compensated if maximal muscle power is needed. In the females, differences only became apparent when the measured data were related to body weight. In our view, this is explained by the overall lower power level in females clearly seen in the subjects of group 1. While minor torque deficits apparently can be compensated for by synergist

activity, the compensatory potential for major deficits appears to be limited. This may become important in extreme situations, e.g., lifting unexpectedly heavy objects in biomechanically unfavorable posture.

Although our patients did not complain of any major impairments in the activities of daily living, great importance is attached to a variety of therapeutic exercises specifically directed to the abdominal muscles to prevent²⁰ or treat²¹ chronic lumbar pain. This suggests that chronic back pain due to muscle imbalance is thought to be a likely consequence of bilateral TRAM flap procedures in the long run. The protocol of our study ruled out an evaluation of perseverance. Maybe isokinetic studies with particular emphasis on perseverance would offer valuable further insights.

CONCLUSION

In summary, the data of the clinical tests and of torque measurements suggest that:

1. Janda's clinical muscle function test only gives useful information up to a certain muscle power level.
2. Clinical testing offers some orientation in females, because the muscle power of females is clearly lower than that of males, on average.
3. Minor torque deficits can be compensated for by synergists, but the compensatory potential is limited.

In light of this, perseverance testing would be desirable, because long-term stresses over years may well cause chronic back pain due to persistent muscle imbalance. Consequently, long-term studies are as indispensable as the validation of our trial protocol in another material.

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