Telemetry Recordings of Forces in the Harrington Distraction Rod: A Method for Increasing Safety in the Operative Treatment of Scoliosis Patients

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Numerous reports have demonstrated that for correction of severe scoliosis the Harrington procedure is the method of choice.[4, 7, 8, 11-20, 22, 24-26, 28, 30, 32, 35, 37, 38, 40, 42, 45] However, in many of the published reports, a number of complications have been listed, the most common complication being loss of correction due to fracture of the upper lamina, where the Harrington hook is seated, and/or dislocation of this hook from its purchase site. With regard to this problem, *i.e.*, how to avoid dislodgement of the rods, we now know from investigations of Harrington[19, 21] and Waugh[43] the limit for the axial forces of the posterior elements of the thoracic vertebrae. In the different age groups these vary according to Waugh from 30 kp† of axial force in the young spine (10–15 years) to about 50 kp in the adult. In the lumbar vertebrae the posterior elements can withstand about twice that force. Knowledge of the axial forces to which the purchase sites are subjected during and after surgical correction is necessary if one wishes to keep the postoperative loss of correction to a minimum.

With our previously described method[9, 31, 33] of intravital wireless telemetry of axial forces in Harrington distraction rods we have now been able to study these forces for a 2-week period following instrumentation in 11 patients in a number of commonly-used positions, maneuvers, and physical exercises. We have also been able to evaluate the mechanical effect of the Harrington compression system in 4 of these patients as well as some external means of maintaining the correction of the spine during the postoperative course.

MATERIAL

As seen from Table 1, the material consists of 11 girls with idiopathic scoliosis, aged 12 to 20 years. They were all operated upon twice with 2-week intervals, as has been the custom for 7 years in the Göteborg scoliosis unit.

In the second operation the force-gauging rods were removed and replaced by an ordinary rod. On this occasion a thorough facet fusion was performed with addition of autogenous iliac bone in the manner described by Harrington,[19, 20] Hall,[17, 18] and others.[14, 15, 26, 42] No complications attributable to the special rods and inserted silicone rubber coated equipment were noted, either clinically or histologically. The patients were kept supine for 5 to 6 weeks following the second procedure, after which time they were fitted with a Milwaukee brace, made after a mold cast 10 to 12 days follow-

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† Kilopond is a metric unit of force; it is defined as a force (in any direction) of 9.80665 newtons. This force is equivalent to the weight of a 1-kilogram mass under standard earth gravity; it represents the force with which this mass is attracted toward the center of the earth.

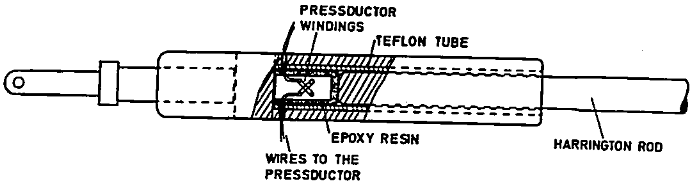


FIG. 1. Schematic drawing of the force-gauging pressductor in the modified Harrington distraction rod. The gauge is shown in actual size.

ing the first operation. The patients were then rapidly ambulated and sent home. Our patients wore the Milwaukee brace constantly for 6 months and then were gradually weaned for another 6 to 12 months.

Although it is not the purpose of this paper to describe in detail the background for this 2-stage approach, it may be mentioned that one reason is that we have found increased correctability after 2 weeks, in most patients about 10°. Another advantage is the biologically-proven enhancement of bone graft incorporation after this period of time.[39, 41] The 3-year follow-up results of the first consecutive 70 patients operated in this manner will be published separately,[34] but we only wish to state here that they have been gratifying, with less complications and loss of correction than in any other series presented.

METHODS

In our equipment we have used a so-called "pressductor," the principle of which is based on changes in mutual inductance between 2 coils.[9] The primary and secondary windings of a pressductor are so placed that the coupling between them is zero in the mechanically unloaded state. If an alternating current is applied to the primary winding and the pressductor subjected to compressive stress, a voltage approximately proportional to the force is obtained from the secondary winding. Figure 1 shows a schematic drawing of the force-gauging pressductor in the modified Harrington distraction rod. The upper part with the notches is made exchangeable so that the surgeon can choose a rod of proper length. In order to minimize losses by friction between the rod and the steel cylinder the inside is lined with a layer of Teflon. The pressductor is encapsulated in epoxy resin.

The telemetry system consists of 2 parts, one outside the body and one inside the body (Fig. 2). *There is no wired connection whatever between these 2 parts, and the part inside the body contains no batteries.* Electrical power is transmitted into the body from the outside, and information on the Harrington rod forces is transmitted out of the body, as indicated before, without wires. This is very important, because wires brought through the skin often act as media for infections. Reliability of the system is enhanced by the fact that there are no batteries inside the body; the unit inside the body could, moreover, not be autoclaved if it included batteries. The output from the pressductor is amplified and converted to a voltage proportional to the applied force, which pulse-width modulates a radio-frequency transmitter (500 kHz). The units are first embedded in a solid block of epoxy resin (Araldite D) and then coated by a 2 mm thick layer of Medical Silastic. Figure 3 A shows the Harrington rod with the power-transfer coil and transmitter, and Figure 3 B shows a roentgenogram taken immediately following an insertion of the system.

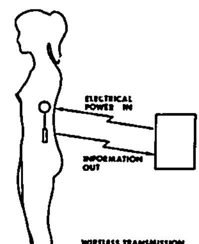
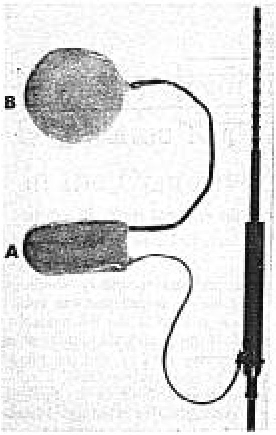
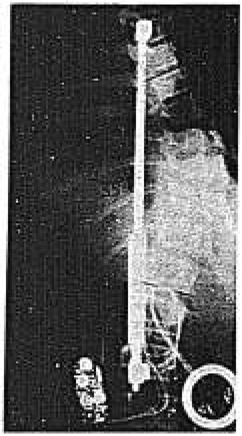


FIG. 2. The principle of the intravital wireless telemetry system, without internal batteries, for measurement of forces within the body.





Figs. 3 A–B. A (left). The modified Harrington rod with silicone rubber - encapsulated transmitter (A) and power - transfer coil (B). B (right). Roentgenogram showing the modified Harrington rod and the telemetry units. Patient M.S.

Electrical energy for the implanted transducer and the transmitter is provided by coupling electrical energy into the interior of the body by electromagnetic induction from the external primary winding to the secondary winding, which is placed between the subcutis and the lumbo-sacral fascia. The voltage induced in the internal coil is rectified to meet the demands of the transmitter. This electrical coupling through the skin is completely harmless to the patient.

In the receiver the signal is amplified and converted to a DC-voltage proportional to the applied force and measured by a standard dc-voltmeter or an ink-recorder. The complete system is shown in Figure 4. The transducer is calibrated at 38 C with the aid of a dynamometer. After the telemetry units are removed at the second operation the transducer is recalibrated and corrections made for the minute difference that may have occurred.

Because of the precise temperature regulation inherent in the body no precautions against drift due to changes in temperature were taken. The accuracy of the calibration unit is plus or minus 0.5 per cent of the indicated value, and as only minor errors are introduced in the telemetry system and as the equipment is recalibrated after removal, the total error of the measured forces is estimated

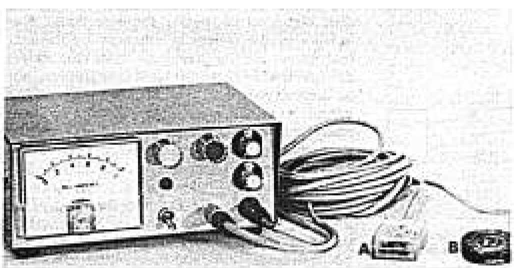


Fig. 4. The external receiver and power-transfer unit. The antenna probe is marked A and the external power-transfer coil is marked B.

TABLE 1. Material: All Eleven Patients were Females with Idiopathic Scoliosis

				Degrees (Cobb[5])			
Patient	*Age Years*	*Type of Curve*	*Rod Position*	*Standing*	*Supine*	*After 1st Operation*	*After 2nd Operation*
K.E.	16	Thoracic-lumbar	T5–L4	65°	55°	30°	23°
B.A.	16	Double primary	T7–L4	T 65° L 75°	60° 70°	55° 33°*	45° 30°
M.S.	12	Thoracic	T5–L3	90°	75°	35°	30°
L.K.	15	Lumbar	T8–L5	55°	35°	18°	10°
A.J.	18	Thoracic	T4–L2	70°	60°	35°	30°
E.J.	12	Thoracic	T5–L2	55°	40°	32°	28°
M.E.	15	Double primary	T5–L5	T 50° L 60°	40° 45°	25° 24°	25° 24°**
Y.N.	20	Thoracic	T5–L2	55°	45°	25°	19°
R.B.	13	Thoracic	T4–L3	80°	73°	40°	30°
A.A.	19	Thoracic	T5–L3	120°	105°	80°	65°
E.M.J.	13	Thoracic	T4–L2	70°	60°	30°	24°

* Rod only over lumbar curve 1st operation. Laminar fracture sixth day postop. 2nd operation repositioning of rod T4–L4.

** Laminar fracture during maximal distraction at 2nd operation. Subsequent repositioning.

to be less than plus or minus 5 per cent. Before implantation the telemetry equipment was tested in various ways to ensure that no foreign material that could lead to a harmful tissue reaction was able to penetrate the encapsulation material. The whole implant was also bathed in normal saline for 30 days and no visible alteration or change in electrical characteristics could be detected. The telemetry unit is able to withstand repeated sterilizations in the autoclave with temperatures up to 140 C with no changes in calibration. The unit described has been proven safe and with a small degree of error (± 5%), especially compared to the method described by Hirsch and Waugh[23] and Waugh,[43] who used rods with wire-connected strain gauges. With that method only 1 out of 3 patients was measured successfully and for only 1 day.

A. Axial Force Measured During Surgical Correction

During the instrumental correction of the 11 patients, the distraction was carried out, after proper seating of the hooks, over a period of 5 to 10 minutes, with the maximum axial force

TABLE 2. Measurements During and Immediately Following Surgery

Patient	*Maximum During Distraction kp*	*After 60 Min kp*	*Lift and Turn kp*
K.E.	42	31	43*
B.A.	25	18	32*
M.S.	21	12	16
L.K.	20	14	23*
A.J.	27	14	14
E.J.	22	8	12
M.E.	43	28	31
Y.N.	29	16	21
R.B.	25	11	—
A.A.	39	15	17
E.M.J.	37	24	20

* In 3 of our first 4 patients we noticed forces exceeding those reached during surgery.

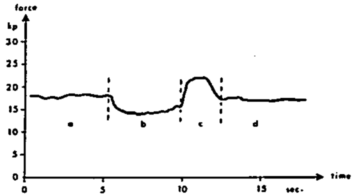


FIG. 5. Recordings of forces during lifting and turning from the scoliosis operating frame to the supine position in bed. Patient Y.N. (a) on operating frame, (b) being lifted, (c) turned, (d) supine in bed.

reaching 35 to 40 kp. This was measured by using a special force-gauging Harrington rod distractor.[29] In spite of the fact that we applied this approximate amount of force in all cases, the pure axial force measured in the rod itself was in all instances somewhat lower. This is due to friction between the hook and the rod.

As seen from Table 2 and Figure 9 the axial force decreases rapidly. In some cases a decrease of 70 per cent from that maximally used during operation was noted.

In 4 of our patients we also evaluated the effect on the axial force in the distraction rod by application of the Harrington compression system[19] on the concavity of the curve. As seen from Table 3, in only one of these patients did the addition of the compression system result in a decrease of the axial force. This was in the youngest of the 4 patients, with the most flexible curve, in whom the compression system was used. We were fortunate to have

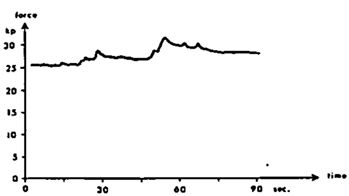


FIG. 6. Forces caused by leg movements during recovery from anesthesia. Patient M.E.

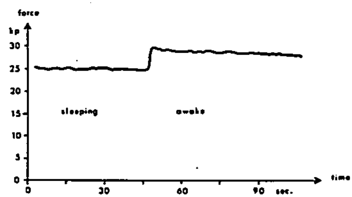


FIG. 7. Difference in force between the sleeping and awake states 3 hours following surgery. Patient M.E.

Dr. Harrington himself with us to perform this part of the operation in 2 of the patients (patients A.J. and E.J.). In 2 of these 4 patients (Y.N. and R.B.) the compression was removed following the measurements, while in the remaining 2 patients it was left until the next intervention.

B. Forces Recorded Immediately Following Surgery

Measurements were also performed in most of the patients when they were moved from the scoliosis operating frame[36] to the supine position in bed and during the period of recovery from anesthesia. It is obvious from Table 2 and Figure 5 that great care must be exercised during lifting and turning. In 3 of our first 4 patients we noticed forces that exceeded those reached during surgery. We then changed our technic to employ at least 4 persons to lift the patient and to turn the

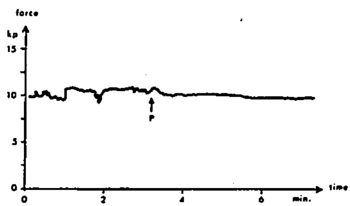


FIG. 8. Effect of intravenous administration of 25 mg Pethidine (P) 8 hours postoperatively. Patient Y.N.

TABLE 3. Effect of Harrington Compression System

Patient	Type of Curve	Degrees Standing	Degrees Supine	Axial Force in Distraction Rod: Distraction Rod Alone kp	Axial Force in Distraction Rod: Compression System Added kp
A.J.	Thoracic	70°	60°	27	33
E.J.	Thoracic	55°	40°	22	18°
Y.N.	Thoracic	55°	45°	30	34
R.B.	Thoracic	80°	73°	18	23

° In only 1 patient did the addition of the compression system result in a decrease of the axial force.

patient very slowly to the supine position in the bed. It is also seen from Table 2 that thereafter we were able to protect the purchase sites from undue stress.

A smooth recovery from anesthesia is important. One of our patients had a very stormy recovery with several forceful spells of coughing and vomiting during the first postoperative hours. Several times the forces recorded exceeded 50 kp. With the patient still in the recovery stage it is also important to keep the patient calm. Notable increases were seen while some of the patients moved their legs (Fig. 6). We also recorded the difference of the forces while the patients were sleeping and while they were awake, 2 to 3 hours following recovery; as seen from Figure 7 the difference in some patients was striking, – 5 kp. A similar difference was noted after the administration of a morphine-like analgetic (*e.g.*, Pethidin) (Fig. 8). It is obvious that this results in definite relaxation of the patient. When administered intravenously this relaxation occurs already after a few minutes' time.

TABLE 4. Axial Force in the Supine; The Right and the Left Positions

Patient	Convexity of Curve	Number of Days Postoperative	Axial Force in kp: Supine	Axial Force in kp: Right Side	Axial Force in kp: Left Side
K.E.	Right	7	22	25	22
B.A.	Left	5	16	16	18
M.S.	Right	4	10	12	10
L.K.	Left	8	9	10	13
A.J.	Right	1	18	23	19*
E.J.	Right	4	7	8	9*
M.E.	Double	1	24	29	29
Y.N.	Right	1	14	16	14
R.B.	Right	6	1.5	4	2
A.A.	Right	4	3	6	5
E.M.J.	Right	5	12	14	13

* Compression system added.

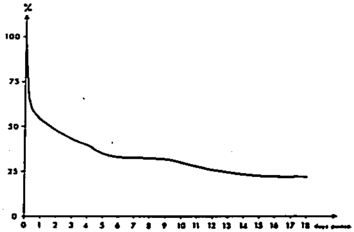


FIG. 9. Axial force decline in the Harrington distraction rod. Average of 11 patients. The maximum force used during operation was chosen as 100 per cent.

C. Decline of Axial Force From the First to the Fourteenth Day After Surgery

In Figure 9 the time-dependent force in the supine position is shown as it declines during the first 2 weeks following surgery. The curve shows the average percentage decrease of all 11 patients, using the maximally recorded force during operation as the 100 per cent value. Two things are obvious: the rather rapid force decline within the first 3 days, and the relatively stable value reached after about 12 days. This general pattern was noticed in all 11 patients.

D. Forces Measured in Different Positions

In all 11 patients, measurements were performed in a large number of different positions and movements besides the flat supine position, which was recorded several times daily. The results reported here were all recorded while the patients were lying freely in bed without external supports. Additional movements were studied with the Milwaukee brace and with a plaster cast; these results are reported in paragraph G.

Log Rolling to Either Side. In Table 4 is seen that in all subjects an increase of up to 5 kp compared to the force in the supine position was noted. When the patients lay on the concave side of the curvature the force was generally 2 to 5 kp less than when they lay on the convex side of the curve. As seen from Table 4 there are 2 exceptions to this rule: (1) patient E.J., who still had her Harrington compression system in and in whom this difference was slightly reversed. She was the only patient who showed any mechanical benefit from the introduction of the compression system. (2) patient M.E., who had a double curve and in whom no difference was noticed between lying on the 2 sides. In her case 1 single rod crossed the 2 major curves.

Attempts at *rolling the patient over completely* without any external support were in most instances stopped because of too high a force increase. Only in 2 patients with relatively high thoracic curves was the prone position found to cause a relatively small increase, around 2 to 3 kp. As a rule we never allow patients to lie prone. The patients were all instructed after the first week to *turn themselves carefully from side to side.* The recorded increases in load compared with the supine values were about 2 to 7 kp and always followed the same pattern as when they were log-rolled to either side, *i.e.*, a lower load was always recorded when the patient was rolling herself over to the concavity of the curve. It also became obvious in many of our patients that their own active movements, like *lifting of the head* from the pillow, and *lifting of the buttocks from the bed* while changing position in bed, caused considerable increases, in the first instance around 5 kp, in the second instance about 10 kp. If, on the other hand, someone else lifted the buttocks or raised the head considerably less increase or even a decrease in force was noticed.

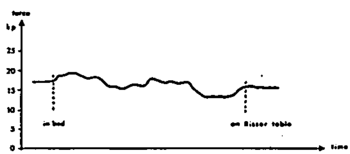


FIG. 10. Forces registered when lifting the patient from bed to Risser table. Patient M.E.

E. Making of Plaster Mold for the Milwaukee Brace

As mentioned earlier we use the Milwaukee brace extensively as a postoperative holding device. In most of the patients the mold is cast between the 2 operations on the eleventh or twelfth postoperative day, using an ordinary Risser table.[38] Recordings were made in 4 patients while moving them from the bed to this table and while applying the plaster mold. With all the precautions taken, *i.e.*, with a

TABLE 5. Effect of Various Exercises

Patient Convexity of Curve	Exercises Performed Days Post-operative	Load Supine, Relaxed kp	Bicycling in Bed Leg Pushing	Bicycling in Bed kp	Vital Capacity Determination kp	Coughing kp	Positive Pressure Breathing
K.E. Right	10	21	Right Left	18 23	24	23	—
M.S. Right	8	10	Right Left	9 12	13	16	—
L.K. Left	12	8	Right Left	13 7	11	9	—
A.J. Right	7	6	Right Left	5 6	8	11	—
E.J. Right	12	4	Right Left	3 6	5	6	5
M.E. Double	4	24	—		26	27	24
Y.N. Right	11	2	Right Left	3 3	3	2	4
A.A. Right	14	1	Right Left	3 3	3	—	—

sufficient number of people lifting and holding the patient on the Risser table, no undue load was recorded, the highest increase being 4 kp (Fig. 10).

F. Forces Measured During Different Types of Exercises

Prolonged recumbency without voluntary movements leads to numerous negative effects such as disuse osteoporosis and muscle wasting. Therefore most orthopedic surgeons institute various types of physical exercises at different times in the postoperative period. Our own rule has been to start bicycling in bed after 10 days to 2 weeks and weight lifting exercises about 2 to 3 weeks following the second operation.

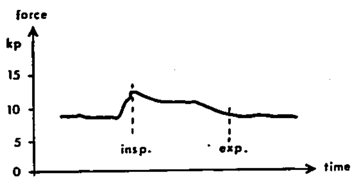


Fig. 11. Forces registered during determination of vital capacity. Patient A.A.

The most commonly used type of physiotherapy for the operated scoliosis patient is breathing exercises, including coughing, vital capacity determination and positive oxygen pressure exercises. The recorded maximal values of axial load during the performance of leg exercises and various types of breathing exercises is seen from Table 5. With the ex-

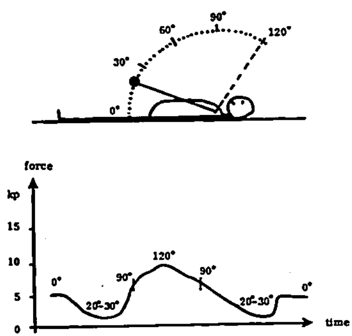


Fig. 12. Weight-lifting exercise, see text. Patient E.M.J.

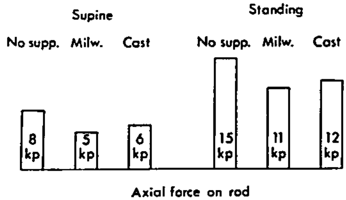


FIG. 13. Effect of the Milwaukee brace and the Risser cast.

ception of the deep-breathing exercises the majority were started after 1 week. As seen from Table 5 none of the above-mentioned types of breathing exercises caused any considerable increase of load (Fig. 11). Bicycling in bed resulted in rather small increases of 1 to 5 kp and always more when the limb opposite the convexity of the curve was extended. In some patients a decrease was seen when the other limb was extended against resistance. Arm exercises were performed by having the patients lift a dumbbell of 2 kg in each hand from the neutral position in a flexion movement over the head to 120° with straight arms. As seen from Figure 12, a large force-increase was recorded at 110–120°. At about 20° the force was less than with the arms resting along the sides. On the other hand similar lifting exercises in the 90° flexion plane caused no noticeable increase.

G. Forces Measured in the Milwaukee Brace

Seven of our patients were fitted with a Milwaukee brace 12 to 14 days following surgery and recordings were made while they were recumbent, standing, walking, and in 2 patients also while sitting. In 3 patients a holding cast was also applied on the Risser frame the day following the test with the Milwaukee brace and the same measurements were repeated. The results are demonstrated in Table 6 while the averages in the supine and in the standing positions, comparing the 2 conditions of external means of holding the patient—the Milwaukee brace and the body cast with no external support—are shown in Figure 13.

The best way to mobilize a patient with Milwaukee brace from lying in bed to standing was also studied. Three methods were examined: (1) Gradual tilting on a tilt table. (2) Mobilization from lying on the side. The patient turns herself over on the side, moves her legs over the edge of the bed, raises herself by means of the arms to the sitting position and then carefully stands up on the floor. Both positions of lying on the right and on the

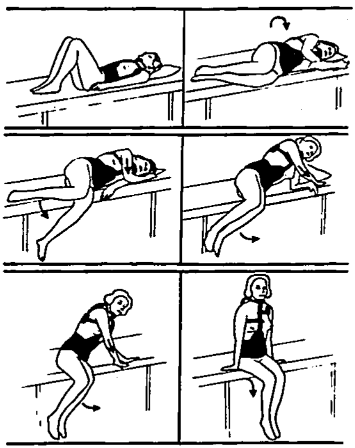


FIG. 14. Mobilization from the position lying on the side.

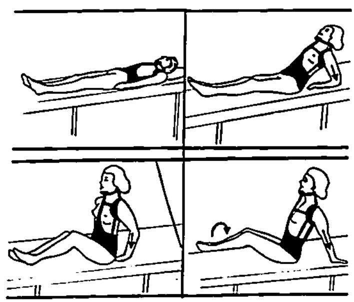


FIG. 15. Mobilization from the position lying supine.

left side were studied as starting positions (Figs. 14 and 16). (3) From the supine position the patient is raised, with some aid, to an angle of 90° by hip flexion followed by twisting of the whole body over the edge of the bed and then down on the floor (Figs. 15 and 17).

In both patients tested the pattern was similar, *i.e.*, the manner of mobilization to standing that caused the least load-increase was that in which the patient turned towards the side of the concavity of the curve and then proceeded as seen in Figure 14. On the other hand it must be pointed out that should our patients need to be mobilized very early, the most gentle way is on a tilt table (Fig. 18).

Finally, in 5 of the patients while standing in the Milwaukee brace the specific effects of the different parts of the brace were tested. Separate evaluation was carried out of the occiput and chin pads, the side straps and the pelvic cage. The results from 3 of the patients have been reported previously,[31, 33] and were confirmed in the 2 additional patients in which this was studied now. Again, the effects of increasing tension in the upper side strap or arm ring against the lower side strap was definite, and uniformly noted in all subjects. The approximate distracting forces on the spine in these patients resulting from the different parts of the Milwaukee brace are displayed in Figure 19.

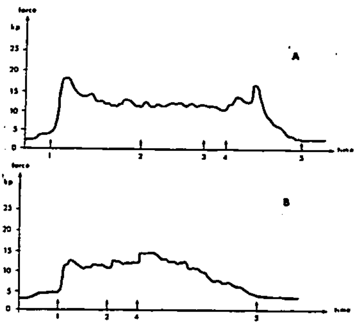


FIG. 16. Forces recorded during rising from bed to the convex side (A) and to the concave side (B): (1) start rising, (2) sitting with legs hanging, (3) standing on floor, (4) start lying down, (5) supine. Patient Y.N.

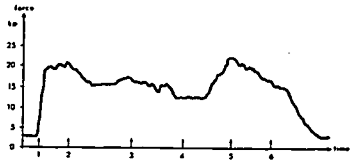


FIG. 17. Forces recorded during rising from the supine position as shown in Figure 15: (1) start rising, (2) sitting in bed with 90° hip flexion, (3) turning of legs over edge of bed, (4) sitting with legs hanging, (5) return to sitting in bed with 90° flexion in hip, (6) start lying down. Patient Y.N.

DISCUSSION

The results obtained by intravital wireless telemetry of the axial forces in the Harrington distraction rod have demonstrated a number of points that are of importance during the operation as well as in the postoperative care of these patients. Based on the observations obtained by Waugh and Harrington from autopsy experiments, the maximum tolerable force is only about 35 kp for a thoracic purchase site, considerably higher for the lumbar vertebrae. Waugh's[43] and Harrington's[19, 21] conclusions have been

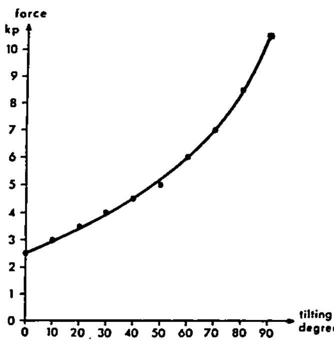


FIG. 18. Forces recorded during rising on tilt table. Patient Y.N.

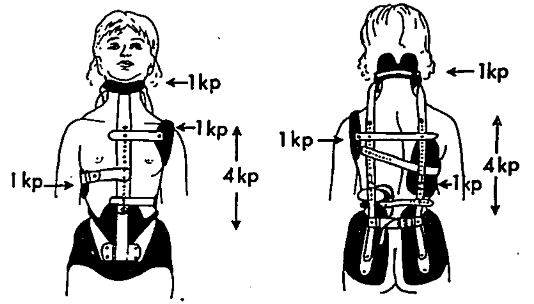


FIG. 19. Approximate distracting forces on the scoliotic spine resulting from different parts of the Milwaukee brace.

verified by numerous clinical reports,[11, 13, 16–18, 22, 24, 35, 40, 45] where a rather high incidence of fracture of the thoracic purchase site has occurred. If we desire to assume the *principle of safety first* in scoliosis surgery the results reported above can serve as a guide.

We recommend that the following precautions be taken: (1) Seating of the hook should be deep under the lamina as recommended by Harrington.[19, 21] (2) During operation care should be taken not to exceed an axial force of 30 to 40 kp in any patient, dependent on age (Fig. 20 A). In some patients, *i.e.*, particularly paralytic cases with osteoporosis and in cases of neurofibromatosis, less load should be applied. The use of cement as recommended by Waugh[44] is indicated in particular cases with extremely weak bone. Use a force indicating distractor.[29] (3) Great care must be taken when turning the patient from the table to the bed (Fig. 20 B). Four persons should be employed in this maneuver. (4) Always alert the anesthetist to secure a very smooth recovery (Fig. 20 C). In our department we use neuroleptic analgesia with phentanyl and a muscle relaxant (tubocurarine). Before extubation all patients are given intra-

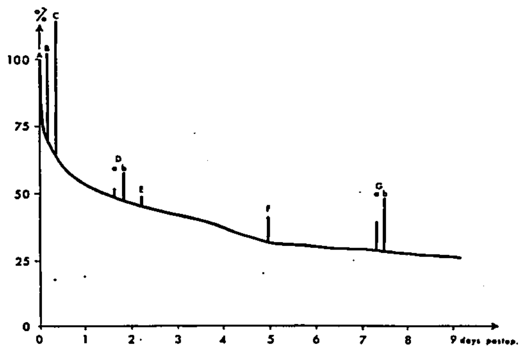


FIG. 20. Schematic drawing of the most important results from which the "principle of safety first" was deduced. (A) Maximum force used during operation 30–40 kp. (B) Lifting and turning from operation table to bed. (C) Recovery from anesthesia. (D) Turning to the concave side (a) and to the convex side (b). (E) Coughing and deep breathing. (F) Bicycling in bed. (G) Turning by own force to the concave side (a) and to the convex side (b).

TABLE 6. Comparison of Axial Forces; Without External Support, With Milwaukee Brace and With Risser Cast

	Supine			*Standing*			*Walking*		
Patient	*No Support kp*	*Milwaukee kp*	*Cast kp*	*No Support kp*	*Milwaukee kp*	*Cast kp*	*No Support kp*	*Milwaukee kp*	*Cast kp*
K.E.	14	12	12	21	16	20	23	18	21
M.S.	9	6	8	16	10	11	17	12	12
L.K.	8	4		14	10		17	12	
A.J.	6	4		16	11		17	13	
E.J.	4	2	2	9	6	7	10	8	8
Y.N.	3	2.5		9.5	8.5		13	11.5	
R.B.	1	1		9	6		11	7	

venous diazepam. (5) The use of the compression rod system when operating on curves exceeding 50° is questionable. Its mechanical advantage has not been properly demonstrated for most of these curves. These results confirm the clinical findings reported by Hall,[18] who, in a consecutive series of 100 patients, observed that only in curves of 50° or below was a better correction obtained with the addition of the compression system. In more severe curves no improvement was noted compared to the use of the distraction rod alone. Also it takes at least half an hour or more in additional operating time and also prevents thorough fusion on the concave side. In young patients with curves of around 50°, that in addition show only slight rotation, the compression rod might be of some benefit, but on the other hand the distraction rod alone gives sufficient correction. (6) Do not start coughing exercises or turning until 24 hours have elapsed and keep the patients supine and relaxed for the first 24 hours (Fig. 20 E). (7) There is no need for external support like a plaster cast or a Milwaukee brace immediately postoperatively when the patient is kept supine in bed. (8) Breathing exercises in the supine position are allowed as soon as the patient awakes. (9) Coughing exercises, intermittent positive pressure exercises and very deep breathing exercises can be started on the third or fourth postoperative day (Fig 20 E). (10) On the second day the patient can safely be log-rolled by 2 or 3 nurses to the side of the *concavity* of the curve, on the fourth day toward the convexity, *i.e.*, to both sides (Fig. 20 D (a) and 20 D (b)). (11) Arm and leg exercises should be restricted to the supine position and consist of movements like bicycling in bed and lifting of 2-kg weights up to 90° of flexion in the humeroscapular joint. Care must be taken not to flex the arms further. These movements can start 5 days postoperatively (Fig. 20 F). In patients with mainly lumbar curves the leg exercises should be deferred a few days. (12) On the sixth day the patient is taught carefully how to log-roll herself to either side (Fig. 20 G (a) and 20 G (b)). (13) The Milwaukee brace can be safely used as a postoperative holding device when the patient is allowed out of bed. Before that time the patients are allowed to lie supine or with the above-mentioned types of movements, without external support. The Milwaukee brace must be

TABLE 7. Complications Noted in 125 Consecutive Patients Operated Upon 242 Times and in Whom the *Principle of Safety First* Given in This Paper was Followed*

Neurologic loss		0
Wound infection		0
Clinical thrombosis		0
Fracture of rod		0
Fracture of purchase site, early (< 1 month) (2 detected at second operation, 2 detected soon after second operation and reinserted)		4
Fracture of purchase site, late (> 1 month)		0
Urethral stone		2
Congenital hydronephrosis requiring laparatomy		1
Positive urine culture	acute	18
	chronic	0
Loss of correction from discharge to > 6 months, average		2°

* Period of follow-up: 6 months or more (average ≈ 2 years).

equipped with at least 2 lateral holding devices, pads or arm rings. (14) In the Milwaukee brace the patient should be instructed to mobilize herself from the supine position by rolling over to the side of the concavity and then rise to the sitting position by pushing up with her arms. (15) It is safe to mobilize a patient with a thoracic curve with hook purchase site down to L2 or L3 after 3 weeks. In patients with rods extending down to L4 and L5 the mobilization should be deferred 5 weeks postoperatively, due to the increased mobility of the lumbar part. The length of time the patient should be kept in the Milwaukee brace is still being debated. We have used 6 months full-time and then gradual weaning for another 6 to 12 months, depending on type of curve and age of the patient. Further long-time observations with the telemetry-rod will give us information on this particular question. It should be added that our observations on the Milwaukee brace from a mechanical point of view should be valid and thus of value also in the conservative nonoperative treatment of scoliosis.[1-3, 27] They also confirm some of the measurements reported by Cochrane and Waugh[6] and Galante *et al.*[10] who used external force gauges on the brace.

Using the information obtained by the reported measurements, *i.e.*, by applying the guide lines presented above, we have been able during the last 5 years to reduce our number of postoperative complications and to minimize the loss of correction. This is shown in Table 7. Some of the precautions listed above were instituted successively over the years as more results became available. For example, the postoperative period of recumbency of 3 weeks only for the patients with thoracic curves was started about 2½ years ago and thus applies for only about 50 per cent of the listed patients. The material presented in Table 7 also contains a few patients, who for various reasons were operated only once. All the patients listed were followed for a minimum of 6 months, average about 2 years.

SUMMARY

Using a new method of intravital wireless telemetry of the axial forces in the Harrington distraction rod, mechanical forces maintaining the correction can be monitored during and within 2 weeks after the operation. Measurements are presented to illustrate the *principle of safety first* in scoliosis surgery with Harrington rods, a principle proven effective in reducing complications during and after operation and subsequent loss of correction.

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