# Preliminary Design Analysis of Linkage Feeders[1]

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In 1962 the Committee on Prosthetics Research and Development authorized a survey of current orthotics research and development in a number of selected centers as an initial step in a proposed orthotics evaluation program. A prime purpose of the survey was the identification of orthotic devices and procedures as suitable subject matter for the evaluation program.

One of the devices selected as meeting the requirements for inclusion in the evaluation process was the linkage feeder designed at the University of Michigan. However, it was apparent that this device, plus a number of others, was essentially a variant of the ball-bearing feeder designed and developed two decades ago by the (ieorgia Warm Spring Foundation. Hence, a review of existing feeder designs was undertaken as a prelude to any formal evaluation program.

The systems involved were those currently in use at the Georgia Warm Springs Foundation, Rancho Los Amigos Hospital, the University of Michigan, the Texas Rehabilitation Center, and the Texas Institute for Rehabilitation and Research. Two prefabricated units that were available commercially were also reviewed, but these units resemble the Rancho Los Amigos Hospital feeder so closely that separate consideration is not warranted.

Ideally, a feeder supports the weight of the arm and permits the patient with severely weakened or paralyzed upper extremities to position the hand with a minimum of muscular effort. The extent of a patient's performance with a feeder and his method of performance are, of course, contingent on the nature and extent of his disability.

The feeders considered in this article have numerous structural features and operational principles in common. An aluminum forearm trough and two stainless-steel swivel arms that rotate on ball or needle bearings support the weight of the upper extremity and provide useful motion when activated by a slight residual motor power in the head, neck, trunk, or arms. The joint cylinders may be rotated to bring the feeder assembly into an inclined plane which provides gravity assistance to the horizontal motions of the extremity. The trough pivot may be positioned to give a bias to both vertical motions of the forearm, namely, raising the hand to the head or lowering it to the table top.

A number of accessory components may be attached to a feeder to adapt the equipment to individual requirements without modifying the basic design. Among these are metal clips, straps, and foam-rubber liners to prevent slip-

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page of the forearm; horizontal and vertical stops to restrict feeder motions to a controllable range; elastic-band and supinator assists to aid motion; and double T-bars to support the hand and provide attachments for self-help devices.

The basic principles of the various feeders being the same, a matter of interest is the significance of the points on which they differ. In Appendix A the distinctive features of each of these systems are identified and illustrated in detail. The Georgia Warm Springs Foundation model is presented as the basic design, with its apparent advantages and disadvantages. The other four designs are then compared with the Georgia Warm Springs Foundation item.

## SUMMARY AND CONCLUSIONS

Linkage feeders were received from the Georgia Warm Springs Foundation, the University of Michigan, Texas Rehabilitation Center, the Texas Institute for Rehabilitation and Research, and Rancho Los Amigos Hospital. With the Georgia Warm Springs Foundation balanced forearm orthesis as the frame of reference, the design and operational features of each feeder were subjected to critical examination. In summarizing the findings of the examination, two points must be emphasized:

1. All feeders are in current and apparently successful use at the centers from which they were obtained
2. The feeders were not applied to *bona fide* patients, but were analyzed in relation to use by a normal adult.

Thus the validity of the advantages and disadvantages cited in this report might require further verification.

It is of value, however, to identify the *apparent* strengths and weaknesses of each feeder in relation to the Georgia Warm Springs Foundation balanced forearm orthesis. This feeder was the first of its kind, and its basic design served as a model for the subsequent feeders. The question that this review attempts to answer is: In what respects do the features of the other feeders appear to be superior or inferior to those of the Georgia Warm Springs Foundation Feeder?

## UNIVERSITY OF MICHIGAN

The multiple adjustment features of the University of Michigan feeder appear to make it the most versatile of those reviewed. Moreover, this adjustment capability is maintained throughout the life of the feeder, in contrast to the reduced adjustability of the "permanent" feeder which is the end product in some of the other designs.

The significant additional adjustment involves the rocker-arm assembly and allows the trough, and consequently the forearm, to be raised or lowered with respect to the trough pivot. The fore-and-aft adjustment found in other feeders is also available. Thus the forearm may be balanced against gravity in two dimensions, permitting maximum control of the forces acting about the trough pivot in horizontal, vertical, and intermediate positions of the forearm. The use of ball bearings in the distal link and trough pivot, as well as in the first and second joints, minimizes frictional forces in the system. The screw-adjustment system permits precise adjustment without the use of tools. The lateral location of the rocker-arm assembly, combined with the use of a triceps strap, permits a closer relationship between table top and trough, while the lateral space required for feeder operation is reduced by the use of a relatively short proximal link.

The prime limitations of the University of Michigan feeder are:

1. It is bulky and has a nonaesthelic appearance.
2. The nondetachable proximal link imposes the necessity for removing the entire feeder from the wheelchair when it is to be collapsed, transported, or stored.
3. The triceps strap may bind, reducing or eliminating elbow support.

## TEXAS REHABILITATION CENTER

The outstanding characteristic of the Texas Rehabilitation Center feeder is its simplicity. The adjustability of link lengths should also be useful for applications to children during the growth years.

The absence of ball bearings in the proximal joint makes this feeder more difficult to maneuver in horizontal motions. The short swivel arms and stationary elbow dial restrict extension of the arm and thereby limit function to a reduced zone of motion. Contact of the elbow dial with the distal link obstructs lateral trough motion, while the rocker-arm assembly restricts the upward tilt of the trough. Because the trough is offset from the distal link

vertically, placement with relation to a table top is more distant than with the Georgia Warm Springs Foundation, University of Michigan, or the Rancho Los Amigos Hospital system, each of which has horizontally offset troughs. In order to change tilts at the first and second joints, the device must be returned to the orthotics shop.

### TEXAS INSTITUTE FOR REHABILITATION AND RESEARCH

The Texas Institute for Rehabilitation and Research model is notably streamlined in appearance. Frictional resistance is minimized in horizontal feeder motions by the use of needle bearings at the end of the distal link.

As with the Texas Rehabilitation Center feeder, an orthotist must make any tilt adjustments. This lack of ready adjustment might tend to hinder a patient's performance if his wheelchair were on uneven terrain. It might also delay accommodation to improvement or regression of his disability. The trough's vertical offset from the distal link and relatively long vertical rod limit the closeness of trough placement to the table top. Moreover, to bring the trough as close as possible to the table top, clearance of the distal link is minimized (1/2 to 1 in.) and the link may strike objects on the table.

### RANCHO LOS AMIGOS HOSPITAL

In the Rancho Los Amigos Hospital feeder a unique tilt adjustment is provided at the distal end of the proximal link. Adjustment of the second joint, therefore, is easier and more precise. The rocker-arm assemblies permit greater ranges of motion at the trough pivot than those of the Georgia Warm Springs Foundation model. The outside rocker-arm assembly, which has a ball-bearing unit at the trough pivot similar to that of the University of Michigan feeder, minimizes friction in vertical motions and permits two-dimensional adjustment of the pivot relative to the forearm. A ball-bearing unit may also be added to the joint at the end of the distal link to minimize friction in horizontal feeder motions.

Each of the feeders, when compared with the Georgia Warm Springs Foundation system, appears to have both positive and negative features. On the basis of the available data, resolution of the various pros and cons as to which feeder is the best is not feasible. Certainly the thought that the most advantageous characteristics of the five feeders might be combined in one superior system has appeal.

However, selection of the optimal feeder for a particular patient depends primarily on the purpose for which the device is prescribed. Purposes may range from support of the arms in a comfortable position for the most severely disabled to increased functional independence and participation in vocational activities for others. Thus a single feeder, even one incorporating the best elements of the various designs, may not serve the needs of all patients.

Nevertheless, the similarities and differences of the five feeders identified in this review, and particularly the significance of the differences, are worthy of further study. If patients' needs in relation to the functions offered by the various components could be precisely defined, an individual's requirements might best be met by using selected components from one or more of the available feeders.

## APPENDIX A

## A DETAILED COMPARISON OF FIVE FEEDERS

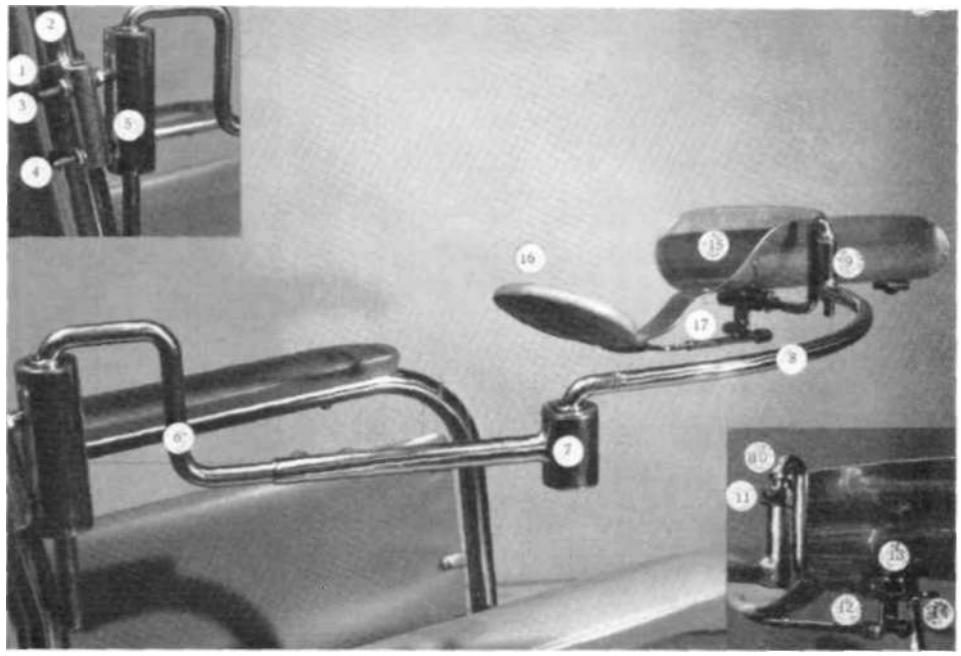


FIG. 1. The Georgia Warm Springs Foundation (GWSF) balanced forearm orthesis.

| Wheelchair Assembly | Proximal and Distal Links | Rocker-Arm Assembly | Trough |
|---|---|---|---|

### DESCRIPTION

A round clamp *1* attaches to the chair upright *2*. Two screws *3 and 4* extend from the clamp to provide attachment for, and anteroposterior angular adjustment of, a ball-bearing tube 5.

The detachable swivel arm *6* terminates distally in a ball-bearing tube *7*. Length of proximal link is adjustable during fitting, nonadjustable in the finished unit. The proximal link is either a drop-type *6* or straight (not shown). Accessory collars (not shown) may be used to raise the proximal link. The distal link *8*, curved approximately 90 deg., terminates in a vertical tube or post *9*, the height of which may be increased by height extenders (not shown).

A drop *10* or straight (not shown) offset rod inserted in the tube permits rotation of the trough. Accessory collars *11* increase rod height. The distal end of the rod fits into two sleeves *12* which rotate on the rod. The sleeves are brazed to a 1-in. flat bar with threaded holes for attachment to the underside of the trough *13*. An L-shaped bar *14* soldered to the rod between the sleeves holds the movable sleeve unit on the rod.

The forearm cradle *15* has prepunched holes interiorly for anteroposterior adjustment on the sleeve bar. The elbow dial is stationary (not shown) or hinged *16* to the stem of the cradle and connected to the rocker-arm assembly by a linkage rod *17*.

### ADVANTAGES

The proximal joint may be independently tilted anteroposteriorly and rotated mediolaterally to

The feeder may be removed from the chair upright without disturbing the base assembly. Mini-

The offset rod provides additional trough-link clearance. Additional height adjustment is use-

The hinged dial permits full elbow extension.

| Wheelchair Assembly | Proximal and Distal Links | Rocker-Arm Assembly | Trough |
|---|---|---|---|
| provide a gravity assist or to compensate for an inclined chair upright or for slopes. There is minimal joint friction. | mal friction is present between proximal and distal links. Drop-type proximal link is useful in obtaining proper feeder height for short patients (without clamp adjustment). The straight proximal link may be used with collars to provide elevation of the feeder for taller patients. The curved distal link reduces interference between elbow and distal link. Height extenders are useful for gaining additional trough height and increasing elbow-distal link clearance. | ful in accommodating tall patients. | |
| | DISADVANTAGES | | |
| | Benders must be used on the proximal link to provide anteroposterior tilts at the second joint. | The L-shaped bar imposes a "down" stop on trough motion. | The stationary dial restricts elbow extension. |

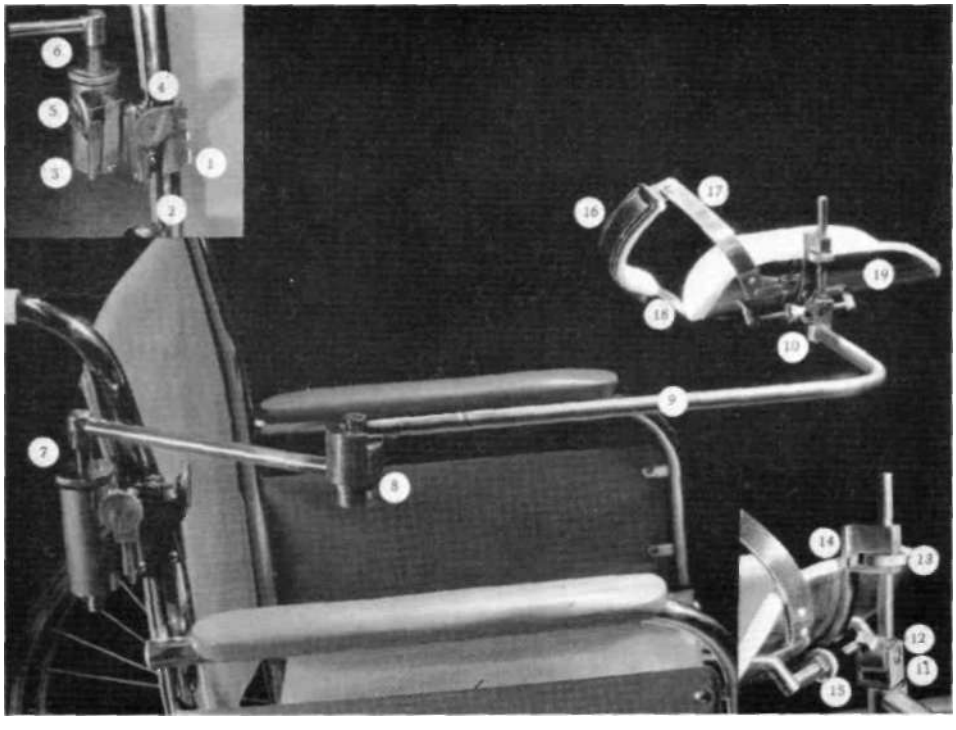


Fig. 2. The University of Michigan (U of M) feeder.

| Wheelchair Assembly | Proximal and Distal Links | Rocker-Arm Assembly | Trough |
|---|---|---|---|
| **DESCRIPTION** | | | |
| A round clamp *1* similar to the GWSF item attaches to the chair upright *2.* An adjustment assembly connects the clamp with a ball-bearing cylinder *3* and allows positioning anteroposteriorly by screw *4* and mediolaterally by screw 5. Feeder height may be regulated by an adjusting nut *6* incorporated into the ball-bearing tube. | The vertical portion 7 of a straight swivel arm is threaded to accommodate the height-adjusting nut. The proximal link, which terminates distally in a ball-bearing tube *8,* is relatively shorter than the GWSF item. The distal link is angled distally 90 deg. and has a ball-bearing tube *10* attached. The distal link is proportionally longer than the GWSF item. | A short vertical rod fits into the ball-bearing tube to permit horizontal rotation of the trough. Affixed to the superior end of the rod is a U-shaped housing *11* which supports a ball-bearing unit *12.* Extending from this unit is a threaded shaft which is mounted by a grooved block and adjusting screw *13.* Affixed to the block is a curved supporting arm *14* which extends under the trough and attaches to another grooved block and screw assembly on the inferior lateral aspect of the trough *15.* | A triceps strap *16* has hinged attachments to two outriggers *17* and *18* which are riveted to the inferior and lateral aspects of the forearm cradle *19.* |
| **ADVANTAGES** | | | |
| Greater precision in mediolateral, anteroposterior, and height adjustments than the GWSF feeder. No tools are required for adjustments. Minimal joint friction. | Short proximal link decreases space required (laterally) for feeder excursion. Minimal friction present at second ball-bearing joint. Angled distal link provides trough-link clearance. Minimal friction present between distal link and rocker-arm assembly. | Minimal friction present in vertical motions of the trough. Screw-type adjustments permit finer control of elbow-hand balance. Balance of the feeder may be adjusted in two planes, vertical as well as anteroposterior. No tools are required for adjustments. | Triceps strap permits full elbow extension. Posterior protrusion of elbow is less with triceps strap than with elbow dial. |
| **DISADVANTAGES** | | | |
| Bulky, conspicuous. Weight of unit must be supported when attaching clamp to wheelchair. | Benders must be used on the proximal link to provide anteroposterior tilts at the second joint. Linkage is not readily detachable from the wheelchair assembly. | Conspicuous, crude appearance. | Triceps strap may be displaced from support position with repetitive motion. |

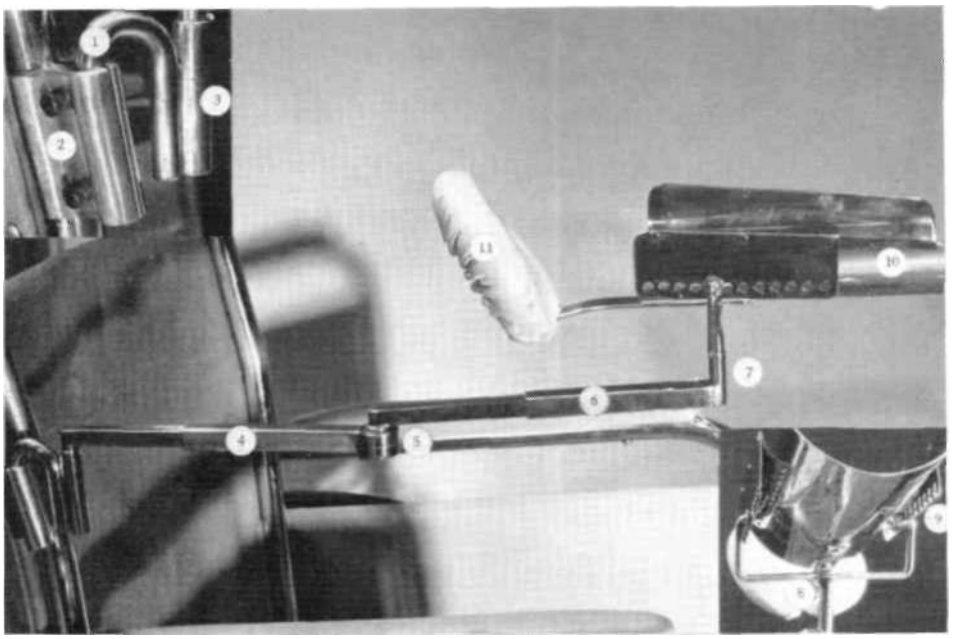

Fig. 3. The Texas Rehabilitation Center (TRC) feeder.

| Wheelchair Assembly | Proximal and Distal Links | Rocker-Arm Assembly | Trough |
|---|---|---|---|
| DESCRIPTION | | | |
| One arm of a U-shaped rod *1* inserts into the round clamp *2.* The other end is brazed to a vertical tube *3* so that bending of the U-rod tilts the tube anteroposterior!)'. Rotating the rod within the clamp tilts the joint mediolaterally. | A detachable straight swivel arm *4* is adjustable in length from 4-3/4 to 8 in. and terminates in a ball-bearing tube 5. The distal link *6* is a straight swivel arm, adjustable in length from 4-3/8 to 8 in., and terminates in a vertical tube *7.* | A rod, Y-shaped distally *8,* swivels within the tube and articulates with pre-drilled holes in the trough fenders *9* to form the trough pivot. | The trough *10* has anteroposterior adjustment on pre-drilled holes. Forearm cradle as stationary dial *11.* |
| ADVANTAGES | | | |
| Simple and inconspicuous. The effect of increased friction from absence of ball bearings in the proximal joint is uncertain. Some friction at this point may be advantageous, for example, to lend stability at the shoulder so that motion imparted to the feeder will occur at the elbow first. It may, however, be disadvantageous if the impedence cannot be readily overcome, particularly in the zone of hand motions about the head, | Feeder can be removed from chair without disturbing the base assembly. Ball bearings reduce joint friction. Short proximal link reduces lateral space required for feeder excursion. | Pivot joints are easily adjusted on the trough without tools. The location of the trough pivot, being higher with respect to the trough than that of the GWSF feeder, more closely approximates the center of gravity of the forearm. | |

DISADVANTAGES

| Wheelchair Assembly | Proximal and Distal Links | Rocker-Arm Assembly | Trough |
|---|---|---|---|
| Benders must be used to obtain anteroposterior tilt adjustments. | Short linkage lengths limit reach and permit joint toggle. As with the GWSF unit, benders must be used on the proximal link to obtain tilts at the second joint without affecting the plane of motion of the first joint. When the forearm is inclined vertically, the distal link interferes with horizontal excursion of the dial. | Y-shaped rod imposes "up" stop on trough. | As with the GWSF stationary dial assembly, elbow extension is limited. |

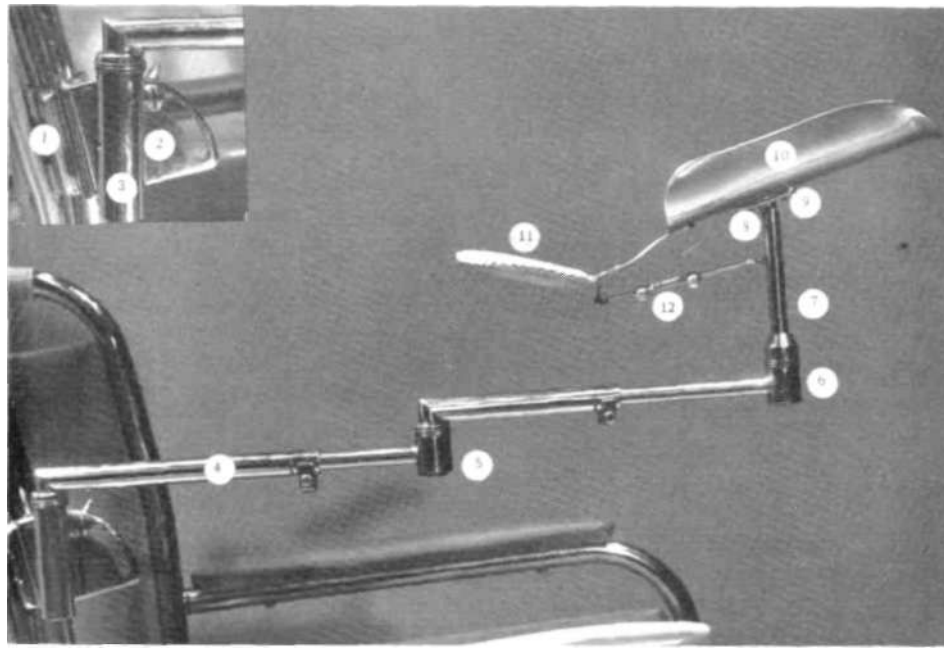

Fig. 4. The Texas Institute for Rehabilitation and Research (TIRR) feeder.

DESCRIPTION

| Wheelchair Assembly | Proximal and Distal Links | Rocker-Arm Assembly | Trough |
|---|---|---|---|
| A round clamp *1* is attached to the chair upright. An offset plate *2* affixed to the clamp provides the mounting for the needle-bearing tube *3,* which is adjustable anteroposteriorly in the trial feeder, nonadjustable in the permanent model (not shown). The tube is tilted mediolaterally by rotation of the round clamp. | The proximal and distal links are straight and terminate in needle-bearing tubes 5 and *6.* The proximal link is detachable and the length of the links is adjustable in the trial model, nonadjustable in the permanent model. | A relatively long vertical rod *7* terminates superiorly in a clevis hinge *8.* A rectangular bar *9* bearing two threaded holes for trough attachment is brazed to the movable portion of the hinge. | The forearm cradle *10* and hinged elbow dial *11* are similar to the GWSF unit's trough. The linkage rod *12,* which is adjustable for fitting purposes, is nonadjustable in the permanent feeder (not shown). |

ADVANTAGES

Smaller tube with needle bearings reduces bulk of unit and provides an unobtrusive appearance. Minimal joint friction.

Feeder may be removed from the chair without disturbing the base assembly. Minimal joint friction.

Permits full elbow extension.

DISADVANTAGES

In the permanent feeder, mediolateral adjustments cannot be made without affecting anteroposterior tilt which has been established.

As in the GWSF unit, benders must be used to effect tilts at the second joint without altering the base assembly.

The length of the vertical rod is not sufficient to prevent interference of the distal link with the lateral excursion of the elbow dial when the trough is in the "up" position. This means of offsetting the trough from the distal link positions the terminal end of the link approximately 1/2 in. above the table top. The path of feeder motion is obstructed by objects on the table.

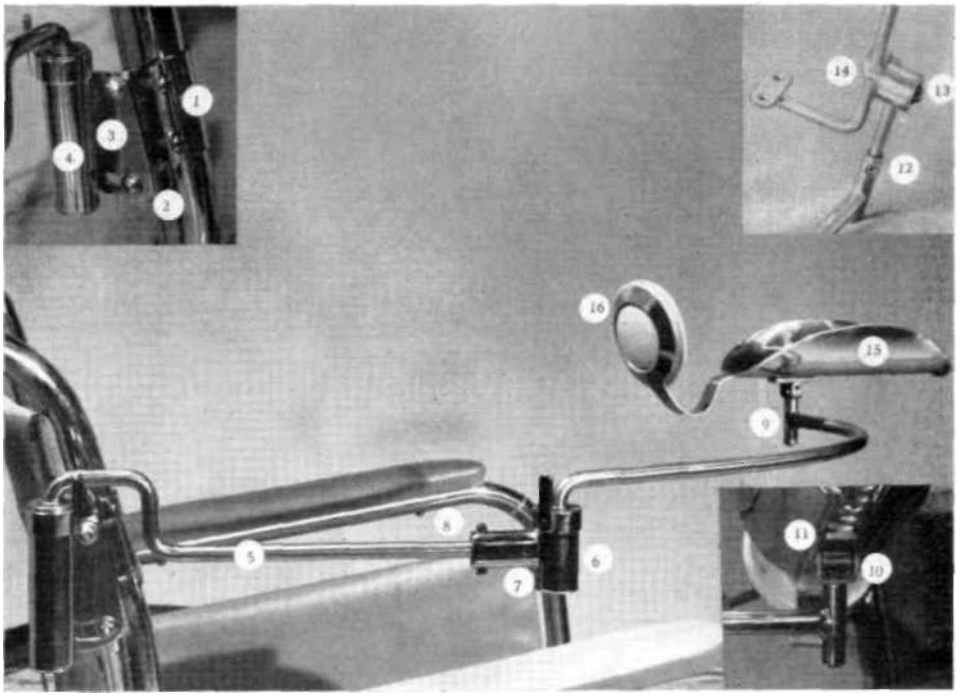


Fig. 5. The Rancho Los Amigos Hospital (RLAH) feeder.

| Wheelchair Assembly | Proximal and Distal Links | Rocker-Arm Assembly | Trough |
|---|---|---|---|
| **DESCRIPTION** | | | |
| As in the GVVSF unit, a round clamp *1* attaches to the chair upright. An L-shaped bracket *2* extends from the clamp to provide attachment for and anteroposterior angulation of an adjusting plate *3*. A ball-bearing tube *4* is soldered to the posterior lateral aspect of the plate. | The detachable drop swivel proximal link 5 is similar to the GWSF item and terminates distally in an adjustable ball-bearing tube *6*. A small hinge unit *7* permits anteroposterior tilting of the tube. The selected tilt position is maintained by set screws *8*. The distal link, similar to the GWSF item, is curved 90 deg. and terminates in a vertical tube P. An alternate unit (not shown) for patients with limited motion in the horizontal plane replaces the vertical tube with a ball-bearing unit. Post height extenders, like those of the GWSF system, may be fitted into the vertical tube to elevate the trough. | The standard assembly consists of a vertical rod which swivels within the tube and is surmounted by a U-shaped hinge unit *10*. Fixed to the movable portion of the hinge is a 1-in. rectangular bar *11*. Threaded holes in the bar can be aligned with drill holes in the underside of the trough for attachment and anteroposterior adjustment. The outside rocker-arm assembly incorporates a height-adjusting collar *12* on a longer vertical rod and a ball-bearing trough pivot *13*. A clamp anchored to the hinge axis medially, attaches to an offset rod *14* to permit vertical adjustment of the trough with respect to the hinge. | The trough *15* and dial *16* are similar to but not identical with the GWSF forearm cradle and stationary dial. |
| **ADVANTAGES** | | | |
| As with the GWSF unit, the proximal joint may be tilted mediolaterally by rotating the wheelchair clamp and anteroposteriorly by separate adjustment. The plate simplifies anteroposterior adjustment. | The tilt adjustment for the second joint permits greater ease and precision in providing assistance to horizontal motions of the forearm. As with the GWSF distal link, the curved offset permits adequate horizontal rotation of the rocker-arm assembly when the trough is in the "up" position. Ball bearings used at the end of the distal link reduce friction between the distal link and the rocker-arm assembly. Additional feeder height may be desirable for tall patients or for specific activities (for example, combing the hair). | The outside rocker-arm assembly reduces friction in vertical motions and permits greater control of elbow-hand balance by means of placing the trough pivot closer to the center of gravity of the forearm. | |
| **DISADVANTAGES** | | | |
| | | | Stationary dial restricts elbow extension. |