**Chapter 8B -** *Atlas of Limb Prosthetics: Surgical, Prosthetic, and Rehabilitation Principles*

**Prosthetic Principles**

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**THE NEED FOR EARLY INTERVENTION**

Of all the new developments that have occurred in the past decade as regards upper-limb amputee management, nothing has made as singular an impact as recognition of the need for early prosthetic intervention. In this context, early intervention means the application of some form of upper-limb prosthesis within the first 30 days after amputation.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) Historically, the use of traditional methods that would delay prosthetic fitting for 3 to 6 months, i.e., until full healing had been achieved, had yielded a rejection rate of approximately 50%.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) However, the application of a prosthesis within the first 4 weeks of amputation has dramatically improved the long-range outcomes, with some centers reporting a success rate of prosthetic use and acceptance of 90% and higher.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) This improvement is believed to be due to the effective preservation of bimanual functional patterns resulting from early prosthetic training.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)

The use of an immediate or early postoperative prosthesis has been demonstrated to be an effective way to achieve the goals of early intervention. Although this procedure has been in widespread use for well over 20 years in lower-limb amputation, it has remained underutilized in upper-limb applications despite the fact that it does not jeopardize wound healing, as is sometimes the case in weight-bearing lower-limb situations.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)

**COMPREHENSIVE PROSTHETIC MANAGEMENT**

A total of five distinctly different types of prostheses make up the armamentarium necessary to provide optimum and comprehensive management for the upper-limb amputee. These five procedures include (1) immediate/early postoperative prostheses, (2) preparatory/ training mechanical prostheses, (3) definitive mechanical prostheses, (4) preparatory/training electronic prostheses, and (5) definitive electronic prostheses. Listed in [**Table 8B-1.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=11','FIGURE','600','600');) is the ideal fitting timetable for the utilization of these five prosthetic procedures.

A discussion of comprehensive prosthetic management would not be complete without some comment on the historical precedent to "save all length." Although the intrinsic advantages of disarticulation surgery through the wrist have been understood for decades, the introduction of new electronic componentry necessitates careful scrutiny on the part of the surgeon prior to choosing the level of amputation. The two major issues are limb length and residual pronation and supination. In those cases where amputation is carried out at the wrist, the use of a prosthesis will frequently result in an overall prosthetic length that is cosmetically unacceptable to the patient.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) This is particularly true in those instances where a quick-disconnect wrist is employed in order to provide easy interchangeability between an electronic hook terminal device and an electronic hand. In addition, the absence of residual pronation and supination mitigates against disarticulation surgery if it is anticipated that the amputee will derive greater benefit from an electronically controlled wrist rotation module. In the event that skin grafting is necessary in order to preserve the viability of a disarticulation surgical level, a higher-level amputation just proximal to the graft site may prove to be a better decision, especially if the amputee will alternate between wearing an electronic prosthesis and a mechanical body-powered prosthesis.

**IMMEDIATE AND EARLY POSTSURGICAL PROSTHESES**

The first prosthesis to be considered when attempting to provide early intervention is either the immediate or early postoperative prosthesis. An immediate postoperative prosthesis is applied in surgery at the time of final closure, while an early postoperative procedure is one that is performed anytime between surgery and suture removal. There appears to be no significant difference in the long-range outcomes between immediate and early postoperative application.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)However, it can be argued that an immediate application can provide additional psychological benefits to the patient and the patient's family.

Essentially, both immediate and early procedures are done by utilizing the same technique. This begins with the application of two separate layers of stockinette directly over the dressing ([**Fig 8B-1.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=1','FIGURE','600','600');)), followed by distal

padding that can be made of either lamb's wool, sterile fluffs, or a reticulated urethane foam pad. Over this is applied a thin cast/socket fabricated of plaster or fiberglass casting tape ([**Fig 8B-2.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=2','FIGURE','600','600');)), which will come up to the level of the epicondyles but leave the elbow free. A thermoplastic frame with a lightweight terminal device on the end is then taped in place by using a good-quality linen adhesive tape ([**Fig 8B-3.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=3','FIGURE','600','600');)). This is followed by a similar application of tape in order to affix the flexible elbow hinges, which are connected to the triceps pad. A standard Bowden cable assembly is applied, and either a shoulder saddle harness or, more typically, a figure-of-8 harness is employed for suspension and terminal device control. Once all the components have been taped to the cast/socket, a final covering of either Coban or Elastoplast can be applied in order to reinforce the fixation of the components ([**Fig 8B-4.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=4','FIGURE','600','600');)). It is important to note that no synthetic casting tape or plaster is used to attach the components to the inner socket. This ensures easy removal of the components when it becomes necessary to change the cast/socket. The two stockinette socks, applied at the beginning, allow easy removal and application of the postoperative prosthesis, which facilitates wound inspection and management.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) However, the patient and the nursing staff should be advised that removal should only be done for very short periods of time so that edema control can be maintained. Occupational therapy with this prosthesis can generally be started as soon as the patient is alert enough to follow directions.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)The benefits of using immediate or early postoperative prostheses are as follows: (1) decreased edema, (2) decreased postoperative pain and phantom pain, (3) increased prosthetic use, (4) improved proprioceptive/prosthetic transfer, and (5) improved patient psychological adaptation to amputation.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)

**PREPARATORY/TRAINING MECHANICAL PROSTHESES**

The second type of prosthesis utilized in the comprehensive management of upper-limb amputees is the preparatory/training mechanical prosthesis. Ideally, this prosthesis is applied at the time the sutures have been removed, generally 10 to 14 days after surgery. The major differences between the preparatory/training prosthesis and the postoperative prosthesis are that (1) the preparatory socket is made over a plaster model of the patient's residual limb, (2) the prosthesis is fabricated from materials that are more durable than those in a postoperative prosthesis, and (3) the design of a preparatory prosthesis allows for the easy interchange-ability of various components during the evaluation process ([**Fig 8B-5.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=5','FIGURE','600','600');)). It should be understood that to be successful, a preparatory/training prosthesis should be designed and fitted with the same care as a definitive system, even including the use of test sockets when necessary. The primary purpose of the preparatory/ training prosthesis is threefold and consists of preparation, evaluation, and training objectives. In terms of preparation, the preparatory prosthesis provides (1) continued edema control, (2) a reduction of the pain and anxiety that the patient experiences, and (3) help to condition tissues to accept the forces exerted by a prosthetic socket. As an evaluation tool the preparatory prosthesis (1) helps the clinic team and the patient determine which components may prove to be of the greatest benefit, (2) assists the rehabilitation team in assessing the patient's level of motivation and compliance, and (3) aids the patient in identifying the functional value and limitations of a mechanical body-powered prosthesis. With regard to training, the preparatory prosthesis helps the patient preserve two-handed function and allows the amputee to practice using a mechanical prosthesis for the normal activities of daily living (ADL).

**DEFINITIVE MECHANICAL PROSTHESES**

Once the patient has worn a postoperative prosthesis for 1 to 2 weeks, followed by a preparatory mechanical prosthesis for an additional 2 to 4 weeks, the formulation of definitive prosthetic prescription specifications is a relatively academic matter. If the two previous prostheses were used in the way intended, i.e., to provide a diligent evaluation of the socket design and the harnessing system and also to determine which wrist and elbow components prove most functional, then the elements of an appropriate prescription become self-evident. However, there are several things that should be considered when developing definitive specifications. Among these factors are socket configuration, elbow joints, wrist components, and harness designs.

**Socket Designs**

For the mechanical prosthesis, the choice of sockets lies either with a harness-suspended or self-suspended design. As a general rule, the longer the residual limb, the lower the proximal trim line of the socket can be. When the patient has a significant amount of natural pronation and supination available after surgery, the proximal trim line of the socket should be cut low enough to preserve at least 50% of the active pronation and supination. Although there are several self-suspended sockets that are now available for wrist disarticulation and long below-elbow (transradial) levels, most of these designs cannot provide maximum benefit to the patient as long as some form of suspension/control harness is necessary. The most popular type of self-suspended socket for midlength amputation is the Northwestern University-style socket,[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) while the Munster-style socket is the frequent choice for short transradial levels.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)

**Elbow Joints**

The most common type of elbow joint to be employed for use with a wrist disarticulation or transradial amputation is the flexible elbow hinge, which can be made out of either triple-thickness Dacron webbing ([**Fig 8B-6.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=6','FIGURE','600','600');)) or flexible metal cable. When socket rotation around the residual limb becomes a problem secondary to a very short bone length, the use of single-axis elbow joints is the most effective measure to provide stability. In those rare instances where the patient has very limited elbow flexion, the use of step-up hinges may prove beneficial, particularly in the case of the bilateral amputee.

**Wrist Components**

The three most commonly used wrist units are the standard friction wrist, the quick-disconnect/locking wrist, and the flexion wrist unit. If the patient is to use more than one terminal device or is routinely performing activities that require the elimination of any unwanted wrist rotation during functional performance, the quick-disconnect/locking wrist has proved to be the most useful for adult unilateral amputees. In those cases where normal functional performance of the contralateral upper extremity has been compromised, a flexion wrist unit may add an additional measure of function to the prosthetic side and of course would be an appropriate choice for a bilateral amputee.

**Harness Designs**

There are three basic harness designs, including the figure-of-9, the figure-of-8, and the shoulder saddle harness with a chest strap. The figure-of-9 harness is used primarily with a self-suspended socket that requires a harness only to provide terminal device operation. The most popular harness is the figure-of-8 design that can be fitted with either a sewn crosspoint or a ring to provide adjustable posterior fixation for all the straps. The shoulder saddle harness is beneficial to those amputees who will be doing an unusual amount of heavy lifting. It also provides relief from some of the axilla pressure exerted by a figure-of-9 or figure-of-8 harness. However, the shoulder saddle harness will frequently be rejected by a patient who prefers to wear an open V neck shirt or blouse that exposes the chest strap.

**Advantages and Limitations**

When evaluating the benefits and disadvantages of the mechanical prosthesis, several factors emerge. Among the advantages are the freedom to operate in a carefree manner within most physical environments and the ability to achieve a high level of accuracy and speed during functional performance.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) The primary disadvantages of the mechanical prosthesis are the discomfort caused by the shoulder harness and the cosmetic appearance of the hook terminal device, which generates various degrees of negative attention.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)

**PREPARATORY/TRAINING ELECTRONIC PROSTHESES**

In the last decade, electronic technology has made significant strides in the field of prosthetics. This has led to increasing complexity and a much broader array of options to be considered when prescribing prostheses for the upper-limb amputee. However, a practical method to simplify the decision-making process has slowly evolved throughout the past several years. This involves the use of a temporatory electronic prosthesis that will allow the clinician and the patient the opportunity to respectively evaluate and experience many different design and component options before coming to a final conclusion.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) As such, the preparatory/ training electronic prosthesis should be considered a separate and distinct procedure in the total evaluation process of the upper-limb amputee's needs.

Components and Technique

Although a preparatory electronic prosthesis should be fitted with the same care as any definitive prosthesis, the fabrication process and the components used provide a very cost-effective way of analyzing the patient's needs. What follows will be a brief description of the actual process involved in fitting and fabricating a preparatory/training electronic prosthesis.

As previously stated, it is very important that the same careful effort be taken in designing and fitting this temporatory prosthesis as would be for a permanent electronic prosthesis. This ensures that the experience of the patient, while wearing the prosthesis, will compare very closely with a similar experience in a more costly definitive electronic limb. The same techniques are used for taking the negative plaster mold of the residual limb and subsequent modification as with a definitive fitting. A transparent test socket is then made over the modified plaster model, and this is used to both evaluate the suspension and stability of the socket design as well as establish electrode sites. The test socket is then filled with plaster to create the final positive master model over which the preparatory electronic socket will be fabricated. Once the socket has been fabricated, it is then possible to attach a simple fitting frame ([**Fig 8B-7.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=7','FIGURE','600','600');)) to provide a means by which the electronic components can be installed in the prosthesis. This entire complex is then covered with some form of temporatory material, either rigid or semiflex-ible, that provides protection to the wiring and various electronic components during the time that the patient will wear the prosthesis ([**Fig 8B-8.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=8','FIGURE','600','600');)). Finally, a standard protective outer glove is applied over the prosthesis to cover the inner shell of the electronic hand. It is very important that the patient receive preprosthetic signal training prior to the start of the prosthetic fitting and fabrication. Following the fitting, the patient should continue with occupational therapy that stresses the specific activities that relate to that patient's daily routine, both on and off the job. Although most electronic prostheses use myoelectric signals as the primary control format to command the prosthesis, there are three other electronic control modes that may also be utilized in a preparatory or a definitive electronic prosthesis. These include electronic servo controls, electronic switch controls, and electronic touch controls.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) It is not uncommon for a prosthesis to have a combination of one or more electronic controls in addition to one or more mechanical controls. Under such a scheme, the design of the prosthesis is designated as a hybrid system.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)Although multiple combinations are seen primarily in amputation levels above the elbow and higher, a hybrid combination may very definitely be indicated for a patient with marginal elbow function, which may require a step-up mechanical hinge in conjunction with either a switch-controlled or myoelectrically controlled terminal device and/or wrist rotator.

**Limb Banking and Lend-Leasing**

In recent years, the formation of limb banks and corresponding lend-lease programs have made a favorable impact on the cost and complexities of providing sophisticated electronic limbs.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)The concept of a limb bank involves the collection, over a period of time, of a variety of different kinds of electronic components, including electronic hands, electrodes and electronic switching mechanisms, batteries, and battery chargers, all of which can be loaned to the patient on a trial basis for a modest leasing charge. The advantage of this arrangement is that for a fraction of the purchase cost of new electronic hardware it is possible to provide the necessary electronics in a preparatory/training prosthesis on a very cost-effective basis. A limb bank can generally have one of three origins for its initial development. The most common type of limb bank is a private limb bank, generally organized and funded by an individual prosthetic laboratory. The second type is a commercial limb bank sponsored by a manufacturer of electronic limb components. The third type is an institutional limb bank, which is generally organized and supported by either a hospital or a charitable organization.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)

**Rationale For Use**

As the fourth type of prosthesis used in the comprehensive management of the upper-limb amputee, the preparatory/training electronic prosthesis also adheres to the three general goals of preparation, evaluation, and training. By way of preparation, the preparatory electronic prosthesis provides for (1) the establishment of ideal definitive myoelectric signal sites, (2) the opportunity to improve marginal myoelectric signals, and (3) the conditioning of the tissues contained within a self-suspended socket. In terms of evaluation, the four specific objectives to be addressed are (1) validation of the socket design and selected electronic components, (2) an assessment of the patients motivation and commitment to derive maximum benefit from an electronic prosthesis, (3) providing the patient with the opportunity to determine the actual functional value of the electronic prosthesis when compared with other options, and (4) the development of clinical evidence to substantiate a cost-vs.-benefit comparison between various alternatives. The training objectives of a temporary electronic prosthesis include refinement of the patient's overall prosthetic control and the opportunity to practice ADL with an appropriate electronic limb.

**DEFINITIVE ELECTRONIC PROSTHESES**

After proceeding through the previous four types of prostheses, which not only exposes the patient to the majority of prosthetic technology but also provides the opportunity to personally evaluate both simple and sophisticated systems, the amputee and the clinic team are positioned at a unique vantage point from which to determine the prosthetic specifications for the long-term benefit of the patient. Since there has been a significant amount of controversy over the past two decades regarding the respective advantages of mechanical and externally powered prostheses, it has been found that by providing the amputee an opportunity to personally experience the actual benefits and limitations of each of these systems, the final choice can be made with some assurance that no major oversights have occurred. In today's world where health care costs seem to run toward the infinite and health care resources and funding most certainly have a finite nature, it is essential that effective methods for evaluating high technology be utilized whenever possible. Since one of the prime sources of upper-limb loss occurs secondary to work-related injuries, the ability of amputees to return to work or their preinjury activities has proved to be a useful guide in measuring successful outcomes. When the techniques described here are used, it has been documented that amputees treated by means of the aggressive methods presented have returned to work in five out of six cases reported.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)

**Self-Suspended Socket Designs**

An important decision to be made regarding the definitive electronic prosthesis is choice of the socket design. Under ideal circumstances, the patient should have had the opportunity to try more than one type of socket suspension at the time that the test sockets were being evaluated. This is particularly true of those patients who are wrist disarticulation or long transradial amputees. Socket designs for the transradial level fall into three basic categories: (1) supracondylar brims that capture the humeral epicondyles and the posterior olecranon, (2) sleeve suspensions that use either atmospheric pressure or skin traction to maintain suspension, and (3) suprastyloid suspensions for wrist disarticulation amputees with prominent styloids.

Among the supracondylar designs there are four basic types. These are (1) the Miinster socket for short transradial amputations,[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) (2) the Northwestern supracondylar socket for midlength transradial amputations[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)([**Fig 8B-9.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=9','FIGURE','600','600');)), (3) the modified supracondylar brim with an olecranon cutout for long transradial amputations,[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)and (4) the floating-brim suspension for long transradial and wrist disarticulation amputations[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) ([**Fig 8B-10.**](javascript:popup('popup.asp?frmItemId=AD77E0FE-9550-4F81-8905-418DCE68FD0A&frmType=image&frmId=10','FIGURE','600','600');)). The sleeve suspension techniques include (1) latex rubber sleeves, which provide atmospheric pressure suspension; (2) neoprene sleeves, which provide a combination of atmospheric pressure and skin traction; and (3) elastic sleeves, which provide skin traction/suspension. The third category of suspension designs, i.e., those involving suprastyloid purchase, includes (1) silicone bladder suspension, (2) window/door suspension with elasticized closure, and (3) soft removable inserts that grip the styloids.

**Funding, Maintenance, and Downtime**

Among the concerns that come up when considering the viability of fitting electronic prostheses are the questions of funding, maintenance, and downtime. The issue of funding has long been one of the major obstacles in providing advanced technology to amputees. However, in the past decade it has been found that the majority of amputees have sufficient health care insurance to cover the cost of these procedures.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) In addition, it has been recognized that many of the upper-limb losses occur in job-related situations and are covered by very adequate postinjury funding through the various workmen's compensation programs around the country. As a result, it would be reasonable to say at this point in time that funding in the majority of cases no longer presents obstacles of any significant magnitude.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) A secondary concern involves the maintenance and corresponding downtime that may be associated with the continuous operation of a sophisticated electronic system. In recent years, the use of electronic prostheses has increased, and it has been possible to evaluate and compare maintenance schedules among mechanical and electronic prostheses. For the most part, electronic prostheses appear to require maintenance at approximately the same level of frequency as mechanical prostheses.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) However, the issue of downtime for maintenance can still be a major stumbling block unless the follow-up services are being provided by a specialty center that has developed a service delivery system that efficiently deals with the unique problems of repairing electronic prostheses. Access to an electronic limb bank has proved to be the best solution to problems of downtime: a replacement component can be immediately installed in those cases when immediate repair of the prosthesis is not possible. The solution that appears to be forthcoming is the development of regional specialty centers that can effectively deal with the complexities of providing uninterrupted service for electronic prostheses.

**Benefits and Disadvantages**

When evaluating the advantages and limitations of electronic prostheses, a mirrorlike image of the contrast between a mechanical and an electronic prosthesis appears. For most adult amputees, the advantages of an electronic prosthesis are in direct correlation to the disadvantages of a mechanical prosthesis. For these amputees, the absence of a control/suspension harness through the use of a self-suspended socket has proved to be the biggest benefit and has provided them with a maximum degree of comfort.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) Other amputees find the ability to function with a prosthesis that has a close resemblance to a normal human hand to be of the highest level of importance.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)

On the converse side, these same adult amputees who wear electronic prostheses have also come to realize that although the electronic terminal device generally provides a much stronger grip force, it may still prove to be somewhat slower in operation than a mechanical hook.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)Second, they generally find that the lack of freedom to use their electronic prosthesis in hostile environments where dirt, water, dust, grease, and solvents are in frequent contact with the prosthesis has proved to be a major drawback.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);) However, this has been partially remedied by the availability of electronic hook terminal devices such as the Otto Bock Greifer and the Steeper electronic hook. As a result, many adult amputees have found that the best solution is to have the freedom to choose between both a mechanical and an electronic prosthesis at their discretion, depending on the situations in which they find themselves.[http://www.oandplibrary.org/assets/images/icon_reference.gif](javascript:void(0);)

**CONCLUSIONS**

Each of the five prostheses described previously has proved to have a very specific role in assisting the rehabilitation team in providing comprehensive care for upper-limb amputees. Each system can provide a unique perspective on the potential solution and eventual outcome for each individual amputee. Although circumstances may not permit or necessitate the use of all five basic procedures in every case, the use of two or three of these techniques is almost always possible and indicated. In following the above model, the patient, the patient's family, clinicians, care givers, and third-party payers can all rest assured that the highest quality and most cost-effective methods have been utilized to help these amputees reach their maximum rehabilitation potential.

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