

The cytoplasm and the ground substance are gels that display changes in viscosity in response to pressure. They are jelly-like when not in motion and flow easily when under steady pressure. They also show the property of viscoelasticity in that they flow when subjected to a steady pressure but bounce back when a force is applied at high velocity. Consequently, the hydrostatic pressure in the periodontal ligament generated by momentary forces such as masticatory forces is different from the pressure produced by steady forces such as forces exerted by fixed orthodontic appliances.

When a load of certain magnitude is applied rapidly and for a short period of time, there is less displacement of the tooth than if a steady force of the same magnitude had been applied. That is, the duration rather than the magnitude of the momentary force is of greater significance relative to the degree of displacement that will occur. These findings cannot be explained by the force-absorbing capabilities of the collagen fibres alone.

When pressure is increased in the periodontal ligament as a consequence of external forces, fluid that is trapped between the tooth and the alveolar bone moves toward the boundaries of the ligament space (i.e., the alveolar crest, the apex of the tooth, and through the cribriform plate). This so-called "squeeze-film" action of the periodontal ligament dissipates the energy that is generated by the external forces and cushions the load. When the load is removed, the fluid compartment of the periodontal ligament

is replenished by recirculating blood and interstitial fluid. Under light orthodontic forces, of less than 15 grams, the vasculature remains patent and an equilibrium can be reached, but under heavy orthodontic forces capillary forces cannot counteract the imposed load, and the squeeze film is exhausted.

Bien further hypothesised that, after the squeeze film is exhausted without replenishment, gas (oxygen) cavitation occurs past the constriction of the capillaries and small vessels where they are caught between the tightened periodontal fibres and between spicules of bone leading to bone resorption.

When a tooth is moved in its socket, the periodontal fibres are tightened, which causes a constriction and occlusion of the vessels that are running between the fibres. Ballooning of the vessels occurs and fluid is forced through the vessel walls at a high pressure. To a certain degree, this replenishes the extracellular fluid that is being squeezed out of the periodontal ligament space. These cirroid aneurisms also cushion the load that is applied to the tooth and referred to as the "spring effect".

According to Roberts, et al., (1981) the stress-induced bone remodeling responses due to orthodontic forces, are divided into 3 major categories:

1. Turnover, in response to accumulation of microfractures,

2. Reorientation of bone mass to optimally resist stress (Wolff's law), and
3. Net change in bone volume related to functional load.

Rygh (1984, 1986) reported his interpretations on the response and remodeling of the fibrous structures of the periodontium: collagen and oxytalan fibrils in the periodontal membrane and the gingiva as related to physiologic migration and situations during experimental tooth movement such as direct resorption, hyalinisation and tension with bone apposition.

#### 7.1. Physiologic migration

The cell population consists of fibroblasts, osteoblasts, and cementoblasts; the resorptive cell types are the osteoclasts and the cementoclasts. Alveolar bone resorption occurs on the side towards which the tooth is moving during physiologic tooth movement, while at the same time reconstruction of the ligamentous support between tooth and bone is taking place.

Active resorption is indicated by the presence of osteoclasts in scattered resorptive lacunae on the alveolar bone wall. Simultaneously, the active resorptive phase will end and start in new locations. Thus, the alveolar wall retracts by the occurrence of alternating areas of resorption and repair.

Very few osteoclasts are seen on the alveolar bone surface along the whole root aspect of animal teeth. Adjacent to these osteoclasts, blood vessels are frequently seen in the alveolar half of the periodontal ligament. Few blood vessels are seen in the other parts of the ligament. The collagen fibre system dominates the periodontal space.

The fibroblasts according to Ten Cate (1972) and Ten Cate and Deporter (1974), play an important role in fibre remodeling and relinking due to its dual function, and they suggest that in healthy tissue all collagen degradation is intracellular although originally considered extracellular. The resorption of collagen in a selective manner insures that most of the supporting apparatus of the tooth remains intact. The blood-borne macrophage cell which can degrade collagen has not been confirmed during physiologic tooth movement.

## 7.2. Experimental tooth movement.

Rygh (1984,1986) stated that whenever we apply a "continuously" acting forces on teeth, we produce areas of limited local compression (resorption) or tension (apposition) of the periodontal membrane instead of pressure evenly distributed along the entire side. He studied these local areas in an attempt to understand the reactions and mechanisms incident to stress application.

Rygh (1986) mentioned that the loss of marginal bone does occur with tooth movement. The most critical tooth movement

is in the buccal and lingual direction. When teeth are moved mesiodistally, the tooth is largely positioned between the buccal and lingual cortical plates of the alveolar process. In buccolingual tooth movement these cortical plates have to be resorbed on the alveolar aspect and need apposition on the outer periosteal aspect. This latter process is slow and often does not occur, and may result in gingival recession and bone dehiscence.

#### 7.2.1. Frontal Resorption (direct bone resorption).

A brief initial phase of rapid tooth movement occurs because of a certain compression in areas of pressure, and strain in areas of tension. Within hours or a few days, depending on the local concentration of force, tooth movement will stop. Such a period of overcompression (hyalinization) is likely to occur during nearly all initial force applications, and Reitan (1951), and Ten Cate (1976), categorize orthodontic tooth movement as occurring in three stages: initial phase, hyalinization (lag phase), and tooth movement phase (Fig. 7-1). Rygh (1986) does not dispute this but stated that the initial phase may also be one of frontal resorption and Rygh, et al., (1986) and Bowling, et al., (1988) were able to show that no, or only minor, episodes of hyalinization were observed in their studies.

responsible for the reconstructing changes. According to Hassell (1986) and Proffit (1986, p228) these undifferentiated cells may also exist within the periodontal ligament long after the ligament is fully formed and mature. It is possible that these cells are merely quiescent fibroblasts or quiescent cementoblasts, or quiescent osteoclasts anticipating the appropriate trigger factor to stimulate their re-entry into the cell cycle to execute their genetically determined functions.

According to Roberts, et al., (1981) the initial wave of active osteoclasts, which appears within hours, is derived from a combination of the following:

1. Activation of previously present, inactive osteoclasts,
2. Migration of osteoclasts from adjacent bone,
3. Formation of new osteoclasts by local macrophages of the periodontal ligament, and
4. Influx of monocytes from vascular spaces.

The important distinction is that active osteoclasts are recruited and not dependent on local osteoprogenitor cells within the periodontal ligament.

Rygh (1986) reported that during rapid orthodontic tooth movement, the fibrous supporting apparatus on the pressure side is restructured by an almost complete breakdown of the old fibres and fibre bundles and by ensuing formation of new fibrous elements.

The characteristic rich vascularisation ("aseptic inflammation-like process") present during maximised tooth movement associated with direct bone resorption, caused Rygh (1984) to propose that the degradation of fibres in remodeling is carried out by fibroblasts and by vascular cells such as blood-borne macrophage-like cells, as compared to remodeling during physiologic tooth migration.

If hyalinisation processes are largely avoided or very limited in space and duration, this inflammatory-like reaction pattern that occurs in frontal resorption should not be a major concern and the prognosis for treatment time and for avoiding root resorption is good.

#### 7.2.2. Hyalinization.

In 1951, Reitan found that in the initial phase of clinically induced tooth movement a period of overcompression seemed almost unavoidable, even if light continuous forces (50-100 g) were applied. Generally he favoured light force to move teeth because it minimized the amount and episodes of hyalinization in order that osteoclastic activity may begin at the periodontium-alveolar bone interface. Rygh (1986) specifically mentioned tooth movements in a buccolingual direction.

Hyalinization is local necrosis of the cellular elements within the periodontal ligament and leads to

"undermining resorption" of the alveolar bone and as Reitan (1960) stated these "...cell-free areas must be eliminated before direct bone resorption and tooth movement can take place...". Other studies by Rygh (1972,1973) and Buck and Church (1972), have supported these findings.

This implies that orthodontic tooth movement with continuous forces often is a damage/repair process. Since tooth movement not only stops during a period of hyalinisation of even a very limited part of the periodontal ligament but even leads to permanent damage, such as root resorption, was shown by Reitan (1974) and Rygh (1976).

In attempting to clarify the events occurring in the tooth-supporting structures as a result of the application of strong forces, Rygh (1974) reported the fine changes and the thrombosis and degeneration of blood vessels in the overcompressed zones together with invasion of blood vessels and macrophages in the adjacent periodontal ligament. Macrophages were implicated in the removal of hyalinised tissue and increased vascular permeability was shown by Storey (1973). It was suggested that orthodontic mechanical forces cause an inflammatory process in the periodontal tissues.

According to Rygh (1984), removal of the hyalinised zone occurs by:

1. resorption of the major obstacle, viz the adjacent alveolar bone against which the tooth is pressed, by the osteoclasts differentiating in the rear marrow spaces in the cortical bone on the outer surface, or in the peripheral intact periodontal membrane; and
2. invasion of cells and blood vessels from the undamaged periphery of the periodontal membrane.

He observed that the hyalinised structures disappear simultaneously with the invasion of cells and blood vessels, that these areas are populated by new cells, and that the removal of collagen is mediated by different forms of cellular activity. The invading cells possess the ability to penetrate the hyalinised zone by pushing cellular extensions into the area.

The sequence of events ending in complete removal of the compressed fibrous structures seems to begin with the breakdown of collagen fibrils near the first vascular cells which penetrate into the compressed tissue. Collagen breakdown occurs around these extensions, apparently due to enzymatic activity on the surface of cells. Penetration of capillaries into the hyalinised zones also seemed to be an important factor in the breakdown, removal and repair of collagen.

Many invading cells revealed the characteristics of macrophages and it was assumed that "macrophages

contribute to the removal of compressed tissue". Other invading cells which had a different appearance, suggested that fibroblasts take part in the removal of degraded collagen tissue (Rygh 1974), in view of the observations by Ten Cate (1972) that fibroblasts may also be capable of phagocytosis.

#### 7.2.3. Post-Hyaline Phase (Tooth movement phase).

In frontal resorption of alveolar bone, the histology shows a widening of the periodontal membrane and osteoclasts occurring over a wide surface area of the alveolar bone surface.

The periodontal membrane behind the osteoclasts is richly vascularised, and a network of fine fibrils have replaced Sharpey's fibres. A high number of macrophage cells also are present. The essence is that again we see an inflammation-like process now associated with extensive tooth movement. This situation will last throughout the clinical treatment provided that the applied force is distributed over a wide enough root surface area, that the supporting bone is mainly cancellous, or that the tooth is moved into an extraction space and there is no systemic disease. However, if during reactivation the applied stress is concentrated over a small area or the tooth is moved into cortical bone, new hyalinization ensues, and the whole treatment may become a series of damage-repair situations. There is little doubt that tissue damage to

varying degree is involved in the reactions elicited by orthodontic stresses on the aspects of the tooth where the alveolar bone must recede.

According to Rygh, et al., (1986), it has even been suggested that tissue damage is a necessary prerequisite to the stimulation of bone resorption in orthodontic tooth movement since positive correlation among magnitude of force, tissue injury, and the degree of bone resorption could be established according to King, et al. (1982). However, a better understanding is still required of possible tissue damage in the areas of tension.

#### 7.2.4. Tension areas.

Reitan (1959) well documented the histologic process in areas of tension. Bone apposition as well as stretching and remodeling of the fibrous system occurs. To permit the tooth to move, a lengthening of Sharpey's fibres after the initial stretching must occur. However, the mechanism of collagen remodeling is not well understood in tension areas.

Edwards (1968) suggested several other alternative mechanisms:

1. The stretching of the wavy collagen fibres and reorientation of the direction morphology could permit a certain amount of tooth movement, and

2. The existence of a type of intermediate plexus might allow an elongation of fibre bundles by "slippage" of the fibres over one another, resulting in a subsequent reorientation of the fibres in new positions. Because many fibres cooperate in the lengthening of a collagen bundle, it has furthermore been hypothesised that groups of fibres could separate from a parent bundle and then combine with a neighbouring fibre bundle as suggested by Orban and co-workers (1958).

With the concept of an intermediate plexus no longer widely supported, the explanation of the rapid lengthening of fibres under tension should be sought elsewhere. In view of the extremely high cell turnover in the periodontal ligament, it may be sought in the balance between collagen breakdown and production. The observation that fibroblasts are involved in both synthesizing and degrading collagen in physiologic tooth migration by Ten Cate, et al., (1976), may explain the remodeling mechanism, although it has not been demonstrated how the lengthening of fibrils actually occurs.

Rygh (1976) showed a high activity of fibroblasts in orthodontic tension zones indicating a breakdown of fibrils. It corresponded with similar observations by Freeman and Ten Cate (1977), showing collagen turnover increases on the tension side of the ligament during orthodontic tooth movement.

Rygh (1984) questioned whether this is the only mechanism in fibre remodeling and lengthening, during experimental tooth movement, particularly where the periodontal ligament must respond very rapidly to external forces.

Having detected increased activation of the vascular system on the pressure side, Rygh (1984) investigated the tension side in rats and also found increased vascularity with and without hyalinisation. The vascular invasion occurs after some days. It may be hypothesised that where rapid remodeling in the periodontal ligament is urgent because of high local stress, vascular cells, either part of the blood vessels or blood borne, play a role. In other words, an inflammation-like reaction similar to wound healing occurs.

Rygh, et al., (1986) found that the reaction in the periodontal ligament may be supplemented by a proliferation of the blood vessels inside the alveolar bone resorbing from behind the alveolar bone plate, which is under tension. This should not be confused with the undermining resorption seen behind compressed hyalinized zones. The new observation of many macrophages near the blood vessels in the areas of tension may be important. They strongly indicate that there is injury to the periodontal ligament in areas of tension with an initial acute inflammatory response followed by multiplication of cells and formation of new

collagen to start the process of repair. This was similar to tissue responses reported by Ten Cate et al., (1977) in expansion of sutures.

Baumrind and Buck (1970) found a decrease of collagen synthesis in areas of tension as well as in compression zones during the first 3 days of force application. At the same time an increase of cell replication occurred in both areas. These findings parallel those of Crumley (1964), who reported decreased collagen formation in tension areas.

Rygh (1986) suggested that the damage-repair response in tension areas provided inflammatory cells such as macrophages which have "a regulatory influence on fibroblast function." The macrophages not only contribute to collagen breakdown by phagocytosis but produce substances that activate and inhibit fibroblast production and collagen.

However, it is still widely held that the degradation of collagen is for the most part extracellular, since as Rygh (1986) stated the major portion of collagenase produced derives from infiltrating macrophages.

Rygh (1986) further suggested that with this change of fibroblast function, a shift in cell population is conceivable, thus implying a clonal selection occurs. Certain specific prostaglandins appear to have an

effect on clonal selection. If different population of fibroblast synthesise different types of collagen, then clonal selection of fibroblast populations may have important effects on the periodontium. From his results Rygh was able to hypothesise that the more rapid the tooth movement response is, the more extensive is the activation of vascularization and the greater is the part of the remodeling process of the periodontal ligament played by the cells of the blood vessels which invade the regions of rapid change setting up an inflammation-like reaction similar to the hyalinized zones in both areas of compressed periodontal membrane and areas of tension of the periodontal ligament.

He believed that mechanisms of tissue remodeling other than those seen during physiologic migration of teeth are likely, and further studies are needed to establish whether tissue remodeling leads to a complete restoration of the original architecture or to scar tissue with varying degrees of architectural distortion.

Recently, long-term studies, by Michael, et al., (1985), on the recovery of the periodontal tissues of the rat incisors following force application have revealed disorientation and loss of attachment of collagen fibres, presence of scar-like tissue, and infiltration of inflammatory cells, and the implication of a possible lowered resistance to functional stress in the periodontium after orthodontic treatment are likely.

The literature is replete with discussions of factors important to increasing the stability of rotated teeth after orthodontic therapy because of their strong tendency to return back toward their original position. Clinical investigators such as Hawley (1925) and Hahn (1944), regarded the rotation of teeth as the most difficult of all orthodontic movements to maintain and advocated a long period of retention. As a consequence, there is a wide range of treatment procedures proposed by many authors over the years.

Angle (1907, p122) discussed the presence of a strong fibrous band, the "peridental membrane", that resist tooth movement by means of their numbers, arrangement and inelastic property. He stated that after depressing the tooth in its socket, the next most difficult movement to overcome in orthodontics is that of rotation. Normally the teeth move slightly, probably due to the bundles of fibres pursuing different directions in their course, so that none is on actual tension until the slack is taken up.

Angle (p130) believed that the thickness of the peridental membrane varied in different periods of life, being much greater in childhood and becoming gradually less with age. This is brought about largely by the deposition of bone and by the increase in the thickness of cementum. A less dense bone in youth, permits a greater "bending of the alveolar process" and more rapid remodeling of alveolar bone and

rearrangement of the periodontal fibres along the entire length of the root that resist movement.

He also stated that in all cases of tooth movement a large number of the fibres remain on tension long after its completion due principally to the "recurrent spring of the bone", their force tending to draw the tooth back to its original position. He believed early treatment and long term retention was significant in maintaining stability of rotations.

Only recently, Bridges, King, and Mohammed (1988) reported a similar observation, whilst studying the effect of age on tooth movement and mineral density in the alveolar tissues of the rat. Compared with the adult group, they recorded greater amounts of "instantaneous" movement in the young rat due to a more visco-elastic bone, the delay period was shorter, and the rate of late tooth movement was faster. They found the young rats had significantly lower mineral densities before orthodontic treatment.

Case (1920), stated "stretched and bent fibrous structures are brought to equilibrium in their changed positions by the physiologic processes of nature". To achieve these ends he recommended:

1. Overcorrection of rotated teeth.
2. Correction should take place slowly.
3. Correction during youth is more easily retained than in adult life.

4. Wearing of fixed or removable retainers often indefinitely.

Many other authors have described the contributions of such factors as occlusion, musculature, and fibres of the periodontium to the relative stability of orthodontically rotated teeth.

In 1922, Bull recommended the procedure of "immediate torsion" for the correction of a rotated tooth in the incisor region. He believed that the chances for relapse are greatly reduced if the malaligned tooth is rotated forcibly with surgical forceps. One recommendation was that it be carried out on incisor teeth with a well-open apex which reduced the risk of pulp death and that in a fully developed root of tooth slow rotation of the tooth should be carried out to correct it.

Hallett (1956) reported on a preliminary study of 23 cases with immediate torsion and was supporting this procedure which is intended to destroy completely all fibrous attachment to the tooth and allow new attachment after rotation, thus minimizing relapse yet causing no ill effects. Unfortunately, this method does not appear to lessen relapse significantly and Haryett (1962) proved that the teeth relapsed in addition to pulp pathology and apical root resorption.

In 1932, Skogsborg attempted to lessen the frequency of relapse and devised a radical surgical technique called a

"septotomy". He believed that unfavourable "unknown" forces developed within the bone itself and not in the periodontal membrane or the supragingival fibres and that the relapse occurred very quickly after the removal of the retainers. His surgical technique involved vertically slicing through either the buccal or lingual cortical plate (interdentally) and into spongy bone of the alveolus to "neutralize" the elasticity of cancellous bone tissue. He emphasised that the interdental papilla and septum must be left intact and he reported an improvement of cases treated with this technique.

Kole (1959) promoted surgical intervention on the alveolar ridge to facilitate orthodontic treatment and prevent a relapse. He termed this procedure "corticotomy" and recommended it for either a single tooth or a group of teeth, that may require alignment. The principle of corticotomy was that the cortical plates of the alveolar process was removed both buccally and lingually in its entire height, and the spongiosa was left intact to serve as a nutritive pedicle to the bone denuded of its mucoperiosteum and preventing any possible devitalization.

Burk, et al., (1977) followed the recommendation of Kole and recommended the use of small segment and unitooth ostectomies for adult patients to improve both the form and function and give a more stable and predictable result. This procedure was carried out in two stages so that there was no likelihood of bone necrosis or severe pain.

Recently, Goldson and Van Reck (1987) have renamed corticotomy first described by Kole, "interalveolar segmental osteotomy". This refers to a surgical procedure in which one tooth or a group of teeth with the adjacent bone is repositioned in one step and reserving the term corticotomy for a technique in which cuts are made in the buccal cortical plate of bone, so that the segment to be moved orthodontically is held only by cancellous trabecula and palatal cortical bone.

Both these procedures have been suggested for stabilisation of rotated teeth. They tend to stress that there are problems connected with these teeth and that these problems are related chiefly to the retention period.

In the classic study by Reitan (1959) on tissue rearrangement, valuable histological observations of the supporting structures were reported following orthodontic rotations and retention of teeth in dogs.

Reitan indicated that there are various factors involved in the movement of rotation, the anatomical and mechanical factors. The anatomical factor is primarily related to the position of the tooth, its form and size. He mentions that most roots, seen in cross section, have an oval form. Other important anatomical factors to be considered are the arrangement of the periodontal fibres, with the major group of bundles running from the root surface to the inner alveolar surface, and the free gingival fibres with attachments to the gingival soft tissues and periosteum, and

transseptally to the adjacent teeth.

The mechanical factor primarily influences the degree of rotation. He found that the mechanics of the appliance will determine which portion of the root will be moved the most.

Reitan (1959) applied only light forces of 30 grams and the degree of rotation varied between 50 and 70 degrees. He examined three regions, marginal, middle and apical, and found that during the movement of rotation:

1. The older teeth required more time to correct than younger teeth.
2. Displacement of the fibrous structures at some distance from the teeth occurred, because the free gingival fibres were continuous with it.
3. Compressed cell-free fibre bundles were found in some pressure areas and direct resorption in the others. Undermining resorption ("indirect resorption") was more frequent in the labial pressure areas.
4. Root resorption occurred with extensive undermining resorption.
5. On the tension side, new bundle bone and osteoid tissue were found arranged in "tongue-like" spicules along stretched fibres. Hence apposition of bone is stimulated by the traction exerted by fibre bundles.

On observing the fibrous tissue during retention, Reitan found that:

1. No rearrangement of fibrous structures in the marginal region after retention periods of 15 and 28 days. Although some cases showed slight rearrangement on the mesial side of the root, the fibre bundles attached to the labial and lingual side of the root were still under tension. After retention of 232 days the free fibre bundles still remained stretched, especially those attached to the labial and lingual surfaces.
2. In the middle region of the root the periodontal fibres were still arranged obliquely and under tension after a retention period of 15 days. The fibre bundles were fairly well rearranged between 28 and 83 days and complete rearrangement only after periods between 147 and 232 days.
3. In the apical region, the fibres were rearranged similarly to those observed in the middle region after 83 days.

The bone changes during retention indicated new (tongue-like) formation along stretched fibre bundles after a period of 15 days. After 232 days minor reorganisation of bone tissue was still occurring.

Reitan concluded that the persistence of stretching and displacement of free fibre bundles in the marginal region indicate that complete rearrangement of the supporting

structures requires a longer period of retention than 232 days. He also believed that the contraction of the elastic fibres within the supra-alveolar structures and the fibrous system displaced at some distance from the tooth, can contribute to the rotational relapse of the tooth (Fig. 8-1).

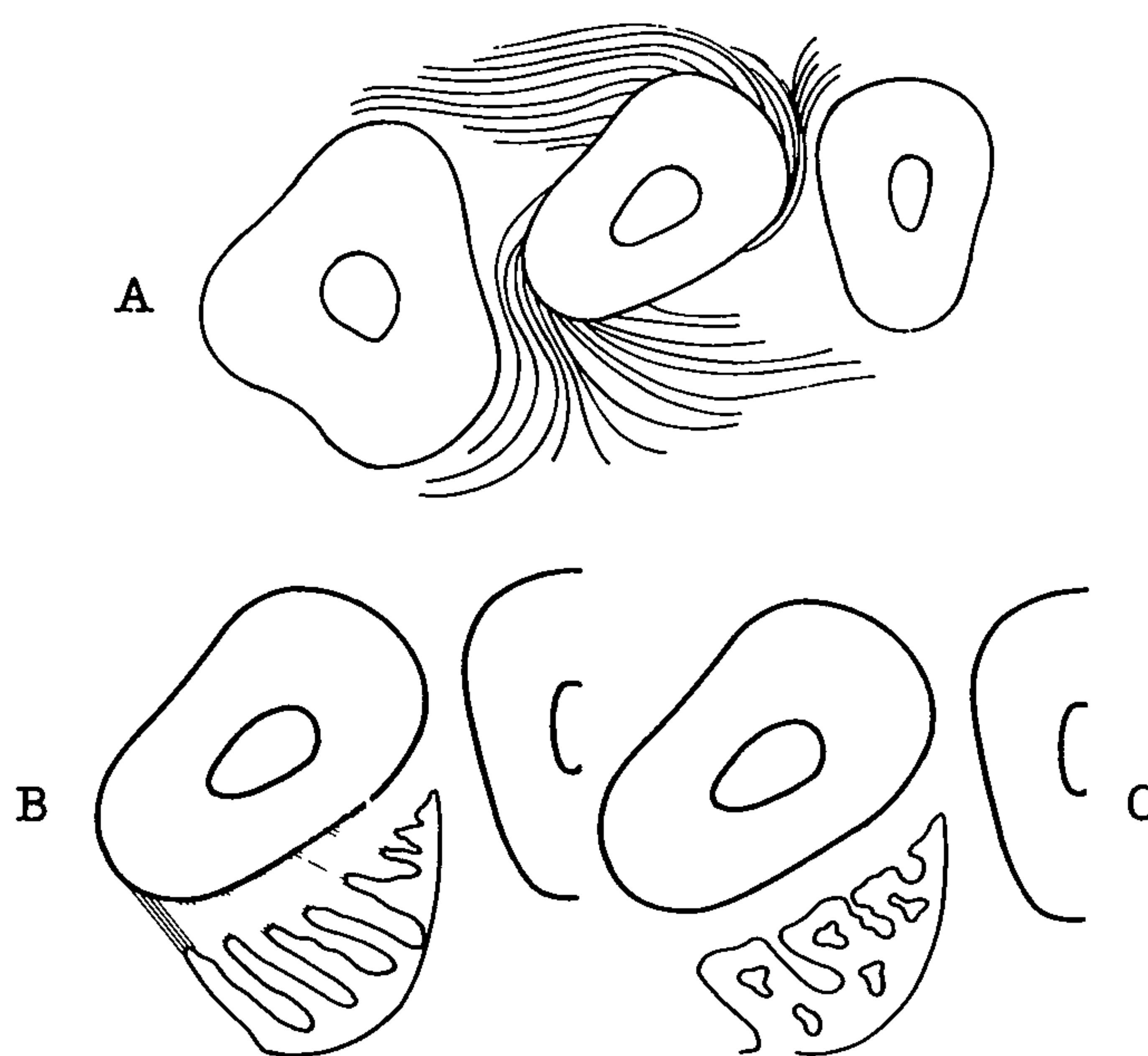


Fig. 8-1. A: Arrangement of free gingival fibres after rotation.

B: Arrangement of new bone layers formed on the tension side along stretched fibre bundles following rotation.

C: Same area after a retention period of 3 to 4 months. The bone and the principal fibres are rearranged much sooner than the displaced supraalveolar structures. (Reitan 1985, p160)

In 1960, Reitan mentioned that some cases displayed greater tendency to relapse, due to the quality of their fibrous structures as related to the age factor. He suggested that early treatment, preferably before the apical portion of the root is developed, overrotation, and supra-alveolar fibre transsection may, to a large extent, prevent rotational relapse tendency. However, the early treatment of malocclusion conflicts with Dr. Begg's (p84) recommendations for treatment timing, since most roots of the mandibular incisors are completed at the permanent dentition stage.

Graber (1966) agreed with Reitan and indicated that the manner in which the space is obtained, either by expansion or tooth removal, to correct rotations, affects the stability of the treatment although the tendency to relapse is always there.

In response to Reitan's work, many surgical approaches with experimental animals and human subjects to control or lessen rotational relapse in orthodontic treatment have been reported in the literature.

Wiser (1966) experimented on dogs, resecting the greatest possible number of supra-alveolar fibres (transseptal and dentogingival fibres) to the depth of the alveolar crest of orthodontically rotated teeth, and demonstrated a reduction of relapse. In a small sample of four teeth with rotations ranging from 29% to 60% and retained for a period of 6 to 10 weeks, the degree of regression in every instance, was four times greater on the non-surgical control teeth as compared

to those treated surgically, regardless of the severity of the rotation, duration of appliance therapy, or postretention interval.

Histologically, Wiser (1966) found localised degenerative changes present in the surgical group, due to the loss of gingival vascularity and replacement with osseous tissue. The nonsurgical control group, where rapid reorganisation of the cervical fibres occurred was free of degenerative changes. The regression tendencies in the control group of rotated teeth with mean of 43.8% compared with a mean regression of 11.2% in the surgically treated group.

Edwards (1968), used a tattooing technique to demonstrate that the attached gingiva and the mucosa followed in the direction of orthodontic rotation. After 5 months of retention, the transseptal fibres closest to the alveolar crest as well as the bundles of the periodontium appeared completely adapted. Only the supracrestal transseptal fibres and the gingival connective tissue fibres were still disorientated in direction.

Boese (1969) and Brain (1969) both supported Reitan's hypothesis that the supra-alveolar portion of the periodontal fibres is largely responsible for rotational relapse following orthodontic treatment.

In 1969, Boese studied the stability of orthodontically rotated teeth following gingivectomy to remove all displaced supra-alveolar fibres (including the attached gingiva)

completely around the tooth and one tooth anterior and posterior to it, in monkeys at 4 and 8 weeks post retention period. After 8 weeks the amount of relapse expressed as a percentage of the original rotation, was 58% in the control group, compared to 9% in the gingivectomized group.

He also found that a different amount of time was required for the completion of relapse in the control and gingivectomized groups. After an 8 to 9 week retention period, relapse continued to occur in the control group throughout the 8 weeks postretention. In the gingivectomized group, relapse was complete within 2 to 4 weeks following removal of retention, without any further change during the remaining experimental period. He further stated, that the stability of rotated teeth is increased ten-fold by gingivectomy combined with a minimum of 8 week retention period to allow the principal fibres to complete their adjustment.

In conclusion, Boese (1969) offered two possible suggestions as to the causes of orthodontic rotational relapse:

1. The concept of two distinct phases of tooth rotational relapse where the main factor is the insufficient period of axial stabilization immediately following correction even if circumferential supracrestal fiberotomy (CSF) is employed. During the first 4 weeks following orthodontic movement a significant proportion of the relapse is caused by the stretched principal

fibres which are not affected by CSF. However, this terminates by 8 weeks postretention due to remodeling of the alveolar bone providing new attachments for these fibres. After 8 weeks the relapse is caused by supra-alveolar fibres since the cemental attachments of the transseptal fibres remain unchanged, as cementum remodels much slower than alveolar bone.

2. The increase in oxytalan fibres in the supra-alveolar tissues due to orthodontic tooth rotation.

On this evidence he believed that the "clinical procedures of overrotation and prolonged retention would be ineffective for preventing rotational relapse".

In 1980, Boese further indicated other significant factors involved in relapse. Failure to completely correct the rotation prior to CSF, and not producing a normal contact point relationship was mentioned as well as occlusal prematurities that result in prominent lingual-marginal ridges on maxillary central and lateral incisors.

He recommended, that to produce long-term stability of previously rotated teeth, a combination of CSF, slight overcorrection at least 6 months prior to CSF, precise and conservative reproximation early in treatment and within 6 months of band removal and thereafter serial reproximation during the posttreatment period.

During the same time, Brain (1969), performed a less radical

surgical procedure on the free gingival fibres of orthodontically rotated teeth in dog, and incised only on the buccal and lingual sides, including one tooth on either side. He retained his teeth for a longer period than Boese, between 148 to 150 days. After retention, he analysed the degree and rate of regression at 2, 4, 6, 8, 12, and 24 hours 2, 3, 4, 5, 6, and 7 days and 2, 3, 4, 5, and 6 weeks.

In his findings, Brain found that the extent of regression in the control group ranged from 5 to 21 degrees with a mean regression of 26.7%. The regression measured on the surgical side ranged from 0 to 1 degree, with a mean regression of 1.1%. The interpretation of these findings reflect the high degree of stability of the surgical side.

The findings also revealed that 48% of the regressions of the control incisors, expressed as a percentage of the original rotations, occur within the first 4 hours and that 86.7% occur within the first 18 hours postretention. After 6 days, no further regression was measurable. These findings were consistent with those of Reitan's (1960), when he reported that the regression of a rotated tooth was almost 43% in the first 5 hours, and the teeth approximated their original position in every instance within 8 days when no mechanical retention was applied.

Brain (1969) concluded that:

1. A repair period of 192 days allows for reorganisation and rearrangement of the fibres of

the periodontal membrane proper.

2. That the surgical transsection of free gingival fibres following orthodontic tooth rotation in connection with an optimal period of retention, is a valuable adjunct to the clinical orthodontic retention procedure.

In an effort to determine the influence of the various components of the periodontal ligament on relapse of orthodontically rotated teeth, Schultz (1969) rotated the second incisors of 6 young dogs, retained them, then reduced the crowns of the control teeth to the level of the gingiva to remove the influences of occlusion and muscular balance. The experimental teeth were further reduced to the level of the alveolar bone to remove the influence of the gingival and transseptal periodontal fibres, and concluded from his results that these fibres were responsible for at least 50% of the relapse.

In 1970, Edwards reported on 16 human rotated teeth in which he had tattooed the gingiva around the teeth with 4 dots positioned in a vertical straight line. The teeth were rotated orthodontically which caused a skewing of the gingival dots in the direction of rotation. The rotation of the teeth varied from 20 to 90 degrees and rotational movement was completed as rapidly as the patients pain thresholds permitted. The teeth were retained for 8 weeks and then removed, the relapse was recorded. These same teeth were then rerotated to correct alignment along with the other 8 teeth, retained for 8 weeks and subjected to a

periodontal surgical procedure.

This surgical technique consisted of a gingival sulcular incision to a depth approximately 3 mm., below the alveolar bone crest so as to cut all fibrous attachments surrounding the tooth but not damage the periodontium. Although no measurements were taken photographs were made, and within 20 to 40 hours he noted that all tattoo marks, with one exception, returned to a vertical alignment. Further photographs were also taken after a 3-month period postsurgical.

From this study Edwards emphasised the following:

- "1. Alveolar bone and the periodontal ligament surrounding teeth reorganises rapidly (in 50 to 80 days of retention) to a stable relationship with a rotated tooth.
2. Relapse tendencies of rotated teeth are apparently inherent in the fibrous network of the periodontium above the marginal alveolar crest.
3. Prolonged retention of rotated teeth is ineffectual in producing a reorganisation of the supracrestal fibres which are stretched and deviated during rotation.
4. Overrotation has not been shown a valid method of lessening relapse; nor is it predictable that an

overrotated tooth will relapse the desired amount into good alignment."

This concept of rapid rotational movement suggested by Edwards conflicts with Reitan's (1959) views that the degree of relapse is pronounced in a tooth which is rotated rapidly with a typical light continuous force as in the case of the Begg technique.

Subsequently, Strahan and Mills (1970) reported a measured study involving 4 orthodontic patients on the amount of relapse in tooth rotation after sectioning of the gingival fibres. After the teeth had been retained for 8 to 18 weeks, they found a mean rotational relapse of 10 degrees.

Pinson and Strahan (1973) extended the study of Strahan and Mills (1970) to involve a larger number of patients and compare them with a group of patients in which there was no surgical intervention. They adopted the term "pericision" to describe the procedure whereby the free gingival and transseptal fibres are surgically divided. Measurements were taken of the amount of tooth rotation and the amount of relapse that occurred at least one year postretention. In most cases subjected to pericision the relapse was small.

The mean relapse for this group was 8.5 degrees which represented 25.5% of the original rotation. Of the group not subjected to pericision, 16 degrees was the mean relapse which represented 56.5% of the original rotation.

On the basis of the length of retention, the group subjected to pericision was subdivided into 3 equal groups and it was shown that there was a greater reduction in the rotational relapse in those cases where retention had been continued beyond 16 weeks. However, no further reduction in the amount of relapse was evident where retention was extended for more than 28 weeks.

In their conclusion, Pinson and Strahan (1973) stated that even when accompanied by pericision, the alignment of rotated teeth will be still followed by a measurable amount of relapse, which is usually clinically insignificant. It related this relapse to other factors such as occlusal relationships and axial inclination of the teeth after orthodontic movement. An optimum length of retention associated with pericision is between 16 and 28 weeks.

Parker (1972), in a clinical study of transeptal fibres, states that "rotational relapse is a normal, predictable, physiological response to abnormal forces....The paralleling of tooth roots, discriminate transsection of free gingival fibers and adequate retention time are very important and useful adjuncts to stability in treated orthodontic cases". Lim (1973) showed that rotational relapse varied from tooth to tooth, ranging from 0 to 16 degrees after 4 weeks posttreatment. Relapse generally did not result in the tooth going back to its original position, with some teeth moving further away from their original positions as well.

In 1975, Walsh published his findings when investigating

pericision as an aid to reducing rotational relapse following varying periods of retention, and reported similar conclusions to those of Pinson and Strahan's (1973). The pericision he performed was similar to that of Edwards' (1970) supracrestal fibre surgery. In studying the effects he stated that relapse cannot be eliminated completely and accepted that some relapse would occur if overcorrection was instituted to produce an ideal alignment at the end of a long period of retention and following the principal concepts of Reitan. He suggested that following rotation and prolonged retention, the tooth relapses to a position of stability between the forces of the stretched supracrestal fibres on the one hand, being resisted by the reattached middle and apical fibres on the other.

Walsh, carried out pericision immediately once the appliances were removed, and it was decided not to retain some teeth at all following pericision; to use fixed retainers on some cases while removable retainers were used on others; and to use varying periods of retention. Because of the difficulty in accurately assessing degrees of rotation of mandibular incisor teeth these were not included in his survey. From the results he reported that the mean period of retention was 9.8 weeks (nil to 20 weeks) and of rotation was 43.4 degrees (7 to 162 degrees).

The sample was divided into three groups;

1. Group A, which had no retention displaced a mean rotation of 41 degrees and a mean relapse of 75%.

2. Group B, which had a retention period between 2 and 12 weeks showed a mean rotation of 45 degrees and a mean relapse of 27%. The general trend of results seemed to improve with increased retention especially when it was continued for more than 4 weeks.
3. Group C, which had a retention period of 13 to 20 weeks displayed a mean rotation of 47° and a mean relapse of 9%.

These results, although the sample size was small, strongly indicated that rotations should be retained with fixed appliance after pericision for at least 12 weeks. Walsh suggested that the 2 to 3 hours whilst the retainer was off the teeth, accounts for a relatively high relapse of 33%, although it was uncertain whether further retention produced better results with regard to Reitan's (1959) observations.

Crum and Andreasen (1974), using a model radiograph technique, studied the effects of gingival fibre surgery on the retention of rotated anterior teeth, and showed considerable reduction in the percentage of rotational relapse. The surgical procedure required a circumferential incision extending 360 degrees around the tooth to a depth of approximately 1 to 2 mm., below the alveolar crest on the periodontal ligament side of the alveolar crest. Total severing of all fibrous attachments surrounding the tooth was accomplished without severing any portion of the interdental papilla and no soft tissue was removed.

The positions of the teeth were recorded before treatment, at the time of rotational correction, at one week postretention, 4 weeks postretention, and 8 weeks postretention. In the experimental teeth the range of rotational relapse was from -23.1% to 75%, with a mean of 10.8%, whereas in the control teeth it ranged from -10% to a 166.6% with a mean of 48.4%. A negative value represents postretention tooth rotation away from the pretreatment tooth position or in the same direction as treatment rotation.

The clinical significance of these findings was to demonstrate that incising circumferential gingival fibres, together with an adequate period of retention, significantly reduces postretention tooth rotation and improves the stability of tooth position. They also suggested the importance in maintaining physiologic contact points between the teeth and in maintaining a healthy periodontium.

When performing the circumferential gingival fibre cut, Crum and Andreasen recommend the following:

- "1. Ideal alignment must be accomplished prior to performing the circumferential gingival fiber cut. All rotations should be corrected prior to the surgical procedure. This is to allow the supracrestal fibers to heal and re-establish themselves in a position free from tension or distortion with the tooth in the desired position.
2. The circumferential gingival fiber cut procedure should be performed when oral hygiene is well

controlled and gingival inflammation and hypertrophy are eliminated.

3. An adequate period of retention must be combined with the surgical procedure to allow adjustment of the principal fibers of the periodontal ligament and to allow remodeling of the alveolar bone."

They believed that postretention rotational relapse is not only caused by the distorted supracrestal gingival fibres exerting tensile forces, but other factors such as mandibular growth, labial and lingual musculature, tooth morphology and incisor function, may be involved.

They concluded that "circumferential gingival fiber cut is a procedure which significantly reduces the return in rotation caused by the distorted supracrestal fibers."

In 1975, Swanson, et al., examined a large sample of 116 orthodontically treated malocclusions not less than 10 years out of retention to determine the incidence and stability of rotated teeth in humans. They concluded that:

1. The amount of rotational relapse differs in certain teeth and is apparently unrelated to age at the end of treatment, sex, Angle class, extraction or non-extraction, arch length changes or growth of the jaws during the treatment or postretention periods.
2. That the severity of the rotational relapse is a

direct function of the severity of the initial rotation.

Each tooth considered in the sample was categorized before treatment and postretention according to the amount of angular change that would be required to rotate it into a proper contact relationship with the adjacent teeth. The rotational categories used were mild (0 to 10 degrees), moderate (>10 but <20 degrees), and severe (>20 degrees). The majority of pretreatment rotations fell into the mild categories. At the end of the 10 year postretention period the majority of teeth, 97.6%, were mildly rotated regardless of the severity of the rotational correction required during orthodontic treatment. This is to be expected since the bulk of the sample fell into the mild rotation treatment category.

Contradicting this are the few initially mildly rotated teeth, that relapsed into a moderate or severely rotated postretention category. They suspected that the mesial forces within the arch rather than the pull of periodontal fibres was the cause of such a relapse pattern . Possibly these forces, if active in an arch where rotations were not fully corrected (or left overcorrected) during treatment, could have caused a further turning of the tooth away from an ideal contact relationship with adjacent teeth.

Kaplan (1976) reviewed the findings of Swanson, et al., (1975) and reported that a 48% postretention incidence was evident. Of the mild pretreatment rotations, 10% ended up

in the moderate or severe groups. Of the moderate pretreatment rotations, 22% ended up in the moderate or severe categories. Of the severe pretreatment rotations, 33% relapsed into the moderate or severe groups.

With the growing evidence that the presence of intact transseptal fibres was the major cause in rotational relapse as shown by Thompson (1959), Edwards (1968,1970), Boese (1969), and Parker (1972), Kaplan (1976) undertook a national survey of 1000 orthodontists to determine the extent of circumferential supracrestal fiberotomy (pericision) as an adjunct to retention procedures. Kaplan concluded that "while the surgical technique is not widely prescribed... the technique is reasonably problem-free and that its use will probably will be increasing in the future". He cautions that there are as yet no follow-up studies of the efficacy of this treatment procedure.

Kaplan (1977) suggested to modify the fiberotomy technique advocated by Edwards (1970) so that the incision is made only to the alveolar crest and not to penetrate 2 to 3 mm apically to the alveolar crest. This ensues the division of the supracrestal fibres.

A study in 1976 by Prakash and Iyer, to assess the effect of circumferential gingival fibre surgery in the control of rotational relapse with the Begg technique, proposed its use in combination with prolonged retention and overrotation to obtain more stable results. The surgical procedure similar to Edwards was performed, only when the rotated teeth were

aligned with slight overcorrection and retained for 4 weeks by the archwire.

Tooth rotations were measured to the nearest 1 degree from radiographs of study models taken at the beginning of treatment, after the 4 weeks postretention period and after the 8 weeks postretention period. From their findings, the mean degree of postretention relapse on the control side was 9.41 degrees and for the experimental teeth was 0.33 degrees. The mean percentage of postretention relapse of the original treatment rotation in the control was 71.01% and that of the the experimental teeth was 2.83%.

According to Prakash and Iyer (1976), the clinical significance was to show that circumferential gingival fibre surgery is effective in reducing posttreatment relapse in Begg technique. They suggested that since overrotation, used as a method to minimise relapse, is not predictable in the amount of desired relapse that occurs, then surgical intervention either in the first stage or after the retention stage routinely combined with overcorrection and prolonged retention helps in stability of the derotation achieved with the Begg technique.

Schacter and Bernick (1976), in an experimental study on nonhuman primates, demonstrated a completely separate band of fibres which ran from the labial gingiva to the lingual gingiva in the interdental area. Although not attached to any teeth, it could contribute to rotational relapse when placed under tension. They stated that "the return of these

fibers to a relaxed state would then appear to influence the other alveolodental fibers in the same vicinity contributing to rotational relapse". According to them, any surgical procedure involving the transection of the alveologingival fibres this labial-lingual band would be free of tension.

Ahrens et al., (1981) tested a simple surgical method as promoted by Vanarsdall and examined the effect of transecting supra-alveolar fibres in orthodontically rotated teeth. It was hoped that if a simple technique were developed and refined, the procedure would be more universally practiced.

Twelve cases were chosen for this study in which a tooth and its antimere were rotated in excess of 10 degrees prior to orthodontic treatment. Gingival fiberotomy was performed on one of the rotated teeth the other served as a control. The incision was made at a 45 degree angle to the long axis of the tooth, on the buccal and lingual aspects of each tooth. The initial incision was made vertically through the papilla to the crestal bone and continued to the bleeding points.

The data for this study was obtained from the initial, pregingival surgery, debanding, and 30 day postbanding (with no retention) study casts. The amount of relapse occurring in the controls ranged from 0 to 18 degrees, with a mean of 5.57 degrees. The amount of relapse occurring on the fiberotomy teeth ranged from 0 to 4 degrees, with a mean value of 0.42 degree. Ten teeth in the treatment group had no relapse, compared to only 2 in the control group.

The results of this study demonstrated a significant decrease in relapse within the fiberotomy group as compared to the control group during the 30 day period, although it was recognised that relapse may continue for one year or more. They concluded that the procedure could be a valuable adjunct to overcome a greater portion of rotational relapse problems.

Recently, Bellardie (1985) investigated the long term effects of pericision on the relapse of rotational upper incisors. Using 84 patients with a total of 95 pericised incisors in the experimental group and 81 non-pericised incisors in the control group, standardised photographs were taken and landmarks on the photographs were digitised to calculate angular and arch width measurements. The groups were compared for rotational relapse during retention, at 16 months and 5.5 years postretention. Both groups were observed to have the larger proportion of relapse during retention, significant amounts occurring up to the 16 months stage but very little subsequently.

He found that the larger the degree of rotation the larger the degree of relapse with or without pericision. Whilst the control group relapsed about 2 degrees more than the experimental group at all stages the pericised laterals rotated 10 to 20 degrees and centrals rotated 20 to 30 degrees relapsed 4 degrees less than the controls. Where the intercanine width was increased by 2mm or more in treatment it subsequently relapsed and in these cases there was no difference between the groups in the amount of rotational

relapse. The results of 4 teeth rotated before root completion suggest that combined with pericision early treatment may be more stable. Pericision and removable retainers contributed little to greatly reducing rotational relapse in the long-term, thus dispelling some of the early optimism. Little, et al., (1988) also noted the fact that although some improvement can be achieved by pericision, their study showed that rotations can recur, and conversely that rotations may not recur even though pericision was not performed.

However, current orthodontic literature still recommends surgical intervention to reduce the relapse influence of distorted supracrestal gingival fibres on corrected rotated teeth. Some form of removable retention appliance should be placed immediately upon removal of the fixed appliance, and if a fibre section has been preformed, retention should be continued for 6 months, whereas if no fibre sectioning was carried out then retention should be continued at night for an indefinite period (Proffit 1986, p496). The retention of the rotated teeth allows for the fibres which run into the alveolar bone to reform in a more desirable position, since they are not dealt with in fibre sectioning. Mills (1987) has recommended to leave bands or bonds on the appropriate teeth and to retain by means of a sectional fixed retainer. Little, et al., (1988) recommends that the only way to "ensure" continued satisfactory alignment posttreatment of the mandibular incisors is by the use of fixed or removable retention for life.

Finally, Schacter and Bernick's (1976) conclusion, that their "study does not answer the problem of why certain rotations recur even after surgical transsection of the (supracrestal) fibers" must be pertinent to all the fiberotomy studies mentioned. They did agree with the suggestions of Furstman and Bernick (1972), that early correction of rotations is advisable since the supracrestal fibres are not fully formed until the teeth are in clinical occlusion. Resorting to cutting the periodontal ligament to aid in maintaining rotations cannot be recommended as not only does the severed ligament reconstitute in 5 days, but that a surgical method can only sever transseptal, free gingival, and alveolar crest fibres and not affect the stretched thick bundles of obliquely oriented fibres within the periodontal ligament.

It was suggested that further studies are required in a time sequence during rotation correction and retention to determine which fibres play an exact role in the rotational relapse phenomenon.

The purpose of this study was to investigate the rotational relapse tendencies of all four mandibular incisors, posttreatment, in patients who underwent Begg orthodontic mechanotherapy.

This study tests the hypothesis that:

1. Rotational relapse of the unretained mandibular incisors is greater soon after bands-off at 6 weeks, than later at 6 months posttreatment.
2. Rotational relapse differences occur between the individual mandibular incisors.
3. Rotational relapse differences occur between extraction and nonextraction treatment therapies.
4. Rotational relapse tends usually in one direction, presumably toward the pretreatment position.

In this study rotational relapse refers to a rotational change that occurs posttreatment, and not relapse as defined in the Introduction (pp 1) because the pretreatment models were not considered.

A detailed description of the sample study, method chosen, data recording, data analysis and digitising is given.

### 10.1 Sample Description

The sample used in this investigation consists of 71 adolescent patients who underwent orthodontic treatment and for whom study models were taken at the following stages T, R<sub>2</sub> , and R<sub>3</sub> :

T: At the completion of active treatment with fixed appliances ("bands-off").

R<sub>2</sub> : Average 6 weeks after bands-off.

R<sub>3</sub> : Average 6 months after bands-off.

The selection of these cases, was at random and as available without bias towards any Angle's class malocclusion, and based on the following criteria:

1. Each patient underwent fixed Begg mechanotherapy and was completed according to the technique prescribed to the graduate students within the Department of Orthodontics, University of Sydney, Australia.
2. No mandibular retainer was used after bands-off.
3. A permanent dentition, either erupted or unerupted, existed prior to treatment.
4. Bilateral extraction was carried out in those cases designated as extraction cases, before treatment.

5. Reproximation was not carried out on any of the sample cases.

The active treatment was carried out during periods of growth. There was no attempt made, to select cases on the basis of treatment results. The sample consisted of 42 cases, currently treated by students in the Graduate Orthodontics Program. The remaining 29 cases were acquired from registered orthodontists trained in Begg mechanotherapy at the University of Sydney, and are members of the Begg Light Wire Study Group.

Of the total sample, 26 cases were treated without the extraction of permanent teeth, and 45 cases with bilateral extraction of one mandibular premolar teeth. The individual incisors were treated separately in the analysis and were referred to as:

A-1, for the Lower Left Lateral Incisor.

A-2, for the Lower Left Central Incisor.

A-3, for the Lower Right Central Incisor.

A-4, for the Lower Right Lateral Incisor.

(refer to Fig 10-1 on page 147)

Relapse movements of the incisors in both direction away from the corrected position were represented by the positive and negative values of the differences between the stages. The values, however, do not indicate the exact direction of movement, if either toward the initial pretreatment position or in the opposite direction, since pretreatment positions of incisors were not analysed in this study.

In most cases a Begg "wraparound" removable retainer was used as a retention appliance in the maxillary arch only.

Because this was a retrospective study of treated cases, there was no control in the placement of overrotation bayonet bends in the archwires in the early Stages of the Begg therapy, but it will be assumed to have been carried out according to Begg's theory and technique.

The mean age of sample at commencement of treatment is:  
14years 9months, minimum 11years 5months - maximum 18years.  
The mean active treatment time is:  
23.0 months, minimum 13 months - maximum 47 months.

## 10.2 Method Selected

Although several studies have been carried out on rotational relapse as mentioned in its Chapter, many investigators have found inherent difficulty in accurately measuring the pretreatment and posttreatment angular changes of the teeth, thus necessitating measuring a combination of rotational and labiolingual relationships of the teeth, as reported by Ahrens, et al., (1981) and Edwards (1988) and as determined when using Little's Irregularity Index (1975).

However, the method for angular measurements of rotated teeth used in this study, was similar to that described by Ahrens, et al., (1981) and Lim (1973), since the mandibular arch, unlike the maxillary arch, offers no stable reproducible landmarks on the dental casts, according to

Wickwire, et al., (1974) and Ahrens, et al., (1981).

Although it is possible to project reference points from a maxillary cast to a mandibular cast to establish more stable, reproducible reference points, as used by Lebrecht (1962), Biggerstaff (1969) and Hechter (1978), this study unlike others, did not assess the amount of rotational change achieved during treatment, and the initial pretreatment casts were not analysed. It was considered reasonable to accept a reference line directly on the mandibular cast tracing without projections from the maxillary cast to measure the angular changes at various times posttreatment, as they were no longer altered by treatment therapy.

Pinson and Strahan (1973) did point out the difficulty with the reference landmarks of the median palatal raphe, it was not used in their study as a sole point of superimposition as it was not found to be consistently identifiable on routine study models. Superimpositions were made on the basis of the best fit of the dental arch tracings as performed by Biggerstaff (1969), taking into consideration the tooth movements that had been carried out, to determine the amount of rotation and relapse for each tooth. Walsh (1975) in his investigation stated that "because of the difficulty in accurately assessing degrees of rotation of mandibular teeth these were not included in the survey."

Hechter (1978) agreed with Pinson and Strahan, that the mandible does not provide an easily definable baseline for

measurement, and mentioned that most investigations of the dental arch had been restricted to the maxillary arch. He concluded that although the transfer method was adequate, any transfer method is subject to the same criticisms and inaccuracies because the models need to be positioned so that the teeth are in occlusion, and a more reliable method has yet to be developed.

It is readily apparent that the comparison was based upon stability of the molar position as a (pretreatment and) posttreatment landmark. In nonextraction treatment this kind of stability may occur; however, in extraction procedures movement of the molar segments is likely, according to Wickwire, et al., (1974). Because of this built-in error component, they did not place credulousness on the derived degrees of rotations but viewed the results in terms of clinically-acceptable, orthodontically corrected lower incisors and the number of teeth concerned.

Although Lim (1973) calculated the relapse angular measurements to the nearest degree, there was no mention, as was the case with many other studies (Brain 1969, Pinson and Strahan 1973, Walsh 1975, Boese 1969), of the error involved in the method of measuring angles.

### 10.3 Photocopy Tracings

Singh and Savara (1964) reported the use of Xerox duplicating machines as an easy to use and accurate method for making prints of dental casts. It is an alternative

method for making tooth and dental arch measurements, to conventional photography, and was well received by Biggerstaff (1969).

The simplicity of the procedure, its low costs, reproducibility and the possibility of enlarged tracing of four to five dental casts at one time makes it economical and timesaving.

Walsh (1975) and Pinson and Strahan (1973) also used a copy-scanner to make enlarged tracings of the dental arches, by projecting an image of each study model.

#### 10.4 Digitising

Bondevik, et al., (1981), Broch, et al., (1981), stated that digitising provided great advantages over conventional methods of analysis both linear and angular. They further supported digitising to analyse radiographic headplates and dental models due to their simplicity in use and their efficiency, as well as the reduction of introduced errors such as those in tracing, measuring and recording and transfer of statistical data into a computer for calculation. Both agreed that the only source of errors was in landmark identification and supported Midtgard, et al., (1974) study on reproducibility of landmarks and errors of measurements. Although digitisers were first introduced for the analysis of maps, Houston (1970) and Huddart, et al., (1971) used digitisers in the analysis of study casts.

Richardson (1966, 1981) further indicated in a comparison between direct digitization and tracing with hand instruments using a ruler and protractor, that better reproducibility accuracy of the majority of landmarks was achieved with digitizing.

Houston (1982) compared digitization of tracings with direct digitization in determining linear and angular measurements and found errors in delayed direct redigitization to be slightly greater than those in digitizing repeat tracings. He suggested that the tracing of indistinct anatomical structures aids in its identification, but the digitizing cursor design can obscure structures which help landmark identification.

Cohen (1984) evaluated the use of the digitizer on tracings, modified "dot" tracings and direct digitizing and found that the errors in measurements of angles were comparable irrespective of the method chosen, but errors in landmark location were smallest when the observation was more direct. Sandler (1988) stated that construction of points is a more reproducible method than estimation when digitizing. As well, the ease and speed at which the measurements were obtained via digitization contributed also to the selection criteria. Sandler (1988) did report that the use of hand measurements from tracings was most tedious and more time consuming than digitization.

### 10.5 Preparation of Material

On the basis of the above findings and in discussion with Godfrey (1987), it was my intention to clearly define the landmarks on the models to appear on the photocopy tracings with dots, either pencil or pens, keeping the diameter minimal, to reduce error. (Fig. 10-1)

All study models were marked using dots on the mesial and distal incisal edge of the lower four mandibular incisors. Further dots were made at a discreet landmark in the molar region, usually the mesiolingual cusps of the lower first permanent molar. They provided a reference line, to measure angles. The same landmarks were duplicated throughout the set of models for each case at each time interval.

Refer to Appendix (p 202) --- " MEASURED ANGLES  
USED IN STUDY."

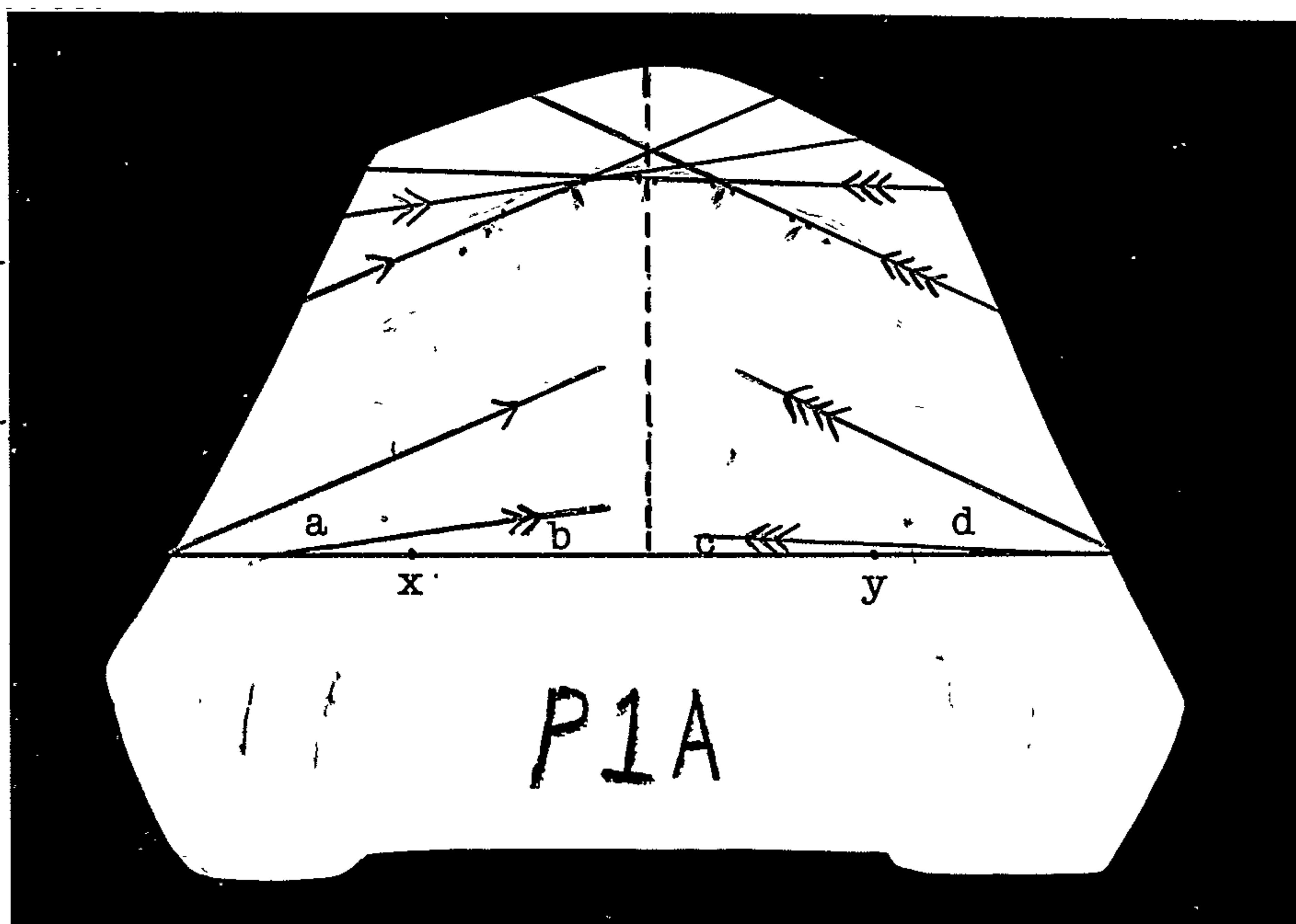


Fig. 10-1. View of mandibular cast with the "dot" markings of the dental landmarks prior to photocopying.

The models were placed horizontally, on a Toshiba photocopier, choosing a plane of maximum contact through the incisal edges of the mandibular incisors and the reference points. Constancy of location of the model in relation to the photocopying apparatus is obtained by means of a sheet of dark cardboard which accurately fits the glass surface on which the model is placed when being copied. A small square window is cut in the paper cardboard just large enough to accommodate 4 models. The model is then placed faced downwards in this window and centred. A black cover was placed over the models and photocopying surface to produce the best image possible. This insured minimum distortion and greater definition.

As many as four study models were used to project an image at one time and enlarged tracings of the dental arches were made at 154% of the original size.

Although the tracings often lacked enough definition and contrast of the outline of the teeth, due to incisal planes not all contacting the photocopying surface, and lack of a definite edge between two or more sides of a tooth, it was easy to identify the dot markings.

Enlarged photocopy tracings were made of the casts at bands-off, six weeks posttreatment and six months posttreatment.

#### 10.6 Data Recording

For the purpose of recording data, all records were

processed by computer. The enlarged photocopied tracings of casts with their 16 identified landmarks were digitised using a Hipad Digitising Pad by Houston Instruments, linked to an IBM computer (Fig 10-2).

Digitizing measurements were performed after securing the photocopies to the illuminated surface of the Hipad. The landmarks were digitized in sequence and the angular measurements for each tracing were automatically calculated and stored in the memory. Statistical analyses were then carried out on these data.

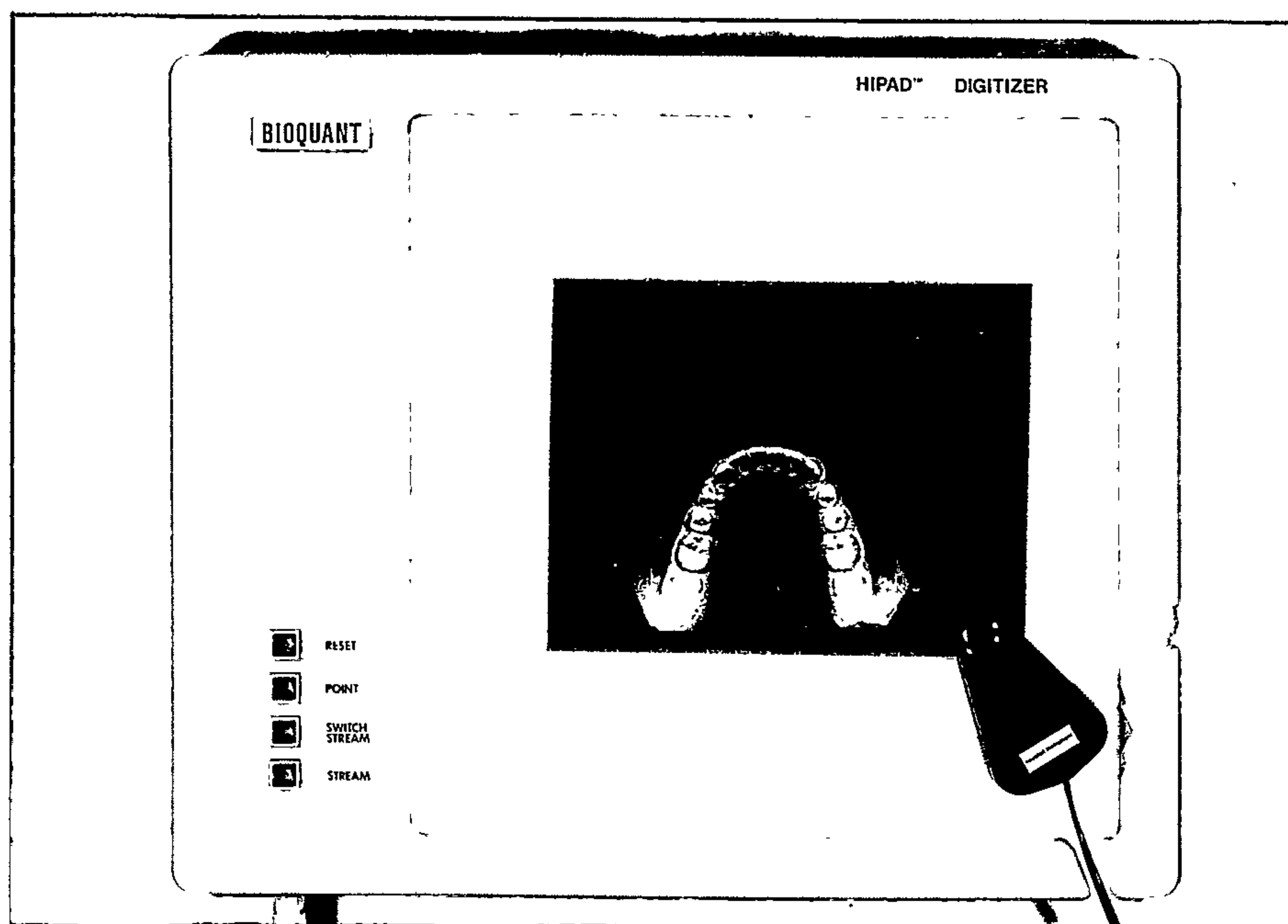


Fig. 10-2. View of setup for digitising the enlarged tracing on the Hipad Digitiser.

All the photocopies of the cases were digitised for computer analysis of the changes in rotations of the lower incisors according to the description of digitising mentioned previously.

### 11.1 Aims of Multivariate ANOVA.

There are two main aims in any analysis of variance (ANOVA):

1. The partitioning of the total sum of squares into components attributable to the various components of the design, and
2. The construction of relevant  $F$  tests so that hypotheses concerning various factors in the design may be examined.

It is arguable that the first aim was the more important, enabling one as it does to produce estimates and confidence intervals for both the parameters and components of variance in the model and also, when simple ANOVA tables only have been constructed, to test rather more informative a priori hypotheses.

Multivariate analysis of variance is a natural extension of this technique to a partition of the total sum of squares and products matrix. As a byproduct, one obtains the usual  $F$  statistics for each component of the data but overall tests are available to examine the variation of the response vector as a whole, taking into account the interactions between its various components.

## 11.2 Reliability Test

All measurements were digitised as a test of measurement reproducibility, using the Paired Students t-test, to indicate good reliability. 24 paired incisor angular measurements of 6 randomly selected mandibular casts were used. They were measured once on 2 different occasions at three days apart to assess reproducibility of landmark identification avoiding memorisation as outlined by Houston (1982) and Sandler (1988) and the means of the first and second measures were statistically analysed. The measurements are presented in Table 1, and the results showed no significant difference.

Table 1. Paired Students t-Test of Reliability.  
(Degrees)

| Incisor | First measure | Second measure | Difference (d) |
|---------|---------------|----------------|----------------|
| 1       | 0.579         | 0.578          | 0.001          |
| 2       | 4.607         | 7.766          | -3.159         |
| 3       | 18.871        | 17.279         | 1.592          |
| 4       | 17.112        | 20.974         | -3.862         |
| 5       | 36.158        | 37.545         | -1.387         |
| 6       | 34.799        | 29.722         | 5.077          |
| 7       | 7.628         | 21.850         | -14.222        |
| 8       | 6.877         | 7.947          | -1.070         |
| 9       | 16.429        | 16.547         | -0.118         |
| 10      | 10.918        | 11.821         | -0.903         |
| 11      | 27.780        | 28.064         | -0.284         |
| 12      | 5.266         | 5.553          | -0.287         |
| 13      | 8.508         | 7.549          | 0.959          |
| 14      | 3.119         | 5.254          | -2.135         |
| 15      | 37.408        | 34.826         | 2.582          |
| 16      | 33.073        | 32.564         | 0.509          |
| 17      | 22.897        | 25.153         | -2.256         |
| 18      | 24.975        | 22.075         | 2.900          |
| 19      | 29.123        | 24.557         | 4.566          |
| 20      | 12.504        | 15.330         | -2.826         |
| 21      | 29.878        | 33.195         | -3.317         |
| 22      | 19.958        | 18.566         | -1.392         |
| 23      | 36.634        | 38.306         | -1.672         |
| 24      | 11.440        | 12.514         | -1.074         |

$$d = -0.79141666$$

$$S_d^2 = 13.74460669$$

$$S_d = \sqrt{\frac{S_d^2}{n}} = 0.756764127$$

$$t \text{ calculated} = \frac{\bar{d}}{S_d} = \frac{0.79141666}{0.756764127} = 1.046$$

Now compare  $t$  calculated value with  $t$  critical

If  $t$  value  $>$   $t$  critical then reject  $H_0$

If  $t$  value  $<$   $t$  critical then accept  $H_0$

From  $t$  Tables,  $t$  critical = 2.807 at 1% level of significance

Therefore, since  $1.046 < 2.807$ , then accept the Null Hypothesis, as there is no significant difference between the first and second measure at the 1% level.

### 11.3 Statistical Analysis Used

For each separate mandibular incisor group a Two Factorial ANOVA of the Experimental Units were performed:

Factor 1 (F1) - Two Treatment Modes:

Extraction (E)

Nonextraction (N)

Factor 2 (F2) - Three Separate Stage Intervals:

Bands-off (T)

6 weeks posttreatment (R<sub>2</sub>)

6 months Posttreatment (R<sub>3</sub>)

Variate: Change in Rotational Angle.

Therefore, a 2 by 3 factorial MULTIVARIATE analysis of variance was performed, 2 levels of treatment and 3 levels of time interval.

*F* - table

For  $df = 1$ ,      5% = 3.84      1% = 6.63

For  $df = 2$ ,      5% = 3.0      1% = 4.61

A study of the relapse changes will be carried out at the 5% level of significance.

Mean change and standard deviations were calculated for each variable at each treatment stage interval; bands-off to six weeks ( $T-R_2$ ), bands-off to six months ( $T-R_3$ ), and six weeks to six months ( $R_2-R_3$ ).

There were two main sources of random variation in the data, the differences in the amount of rotational correction of each individual incisor and the overall error in measurement.

Data from the experimental units (mandibular study casts) for this study, were initially statistically analysed using the Complete Random Design (CRD). In this study, the relapse or changes in incisor position from the corrected position was analysed for mean, standard deviation and variance ratio. The "corrected position" refers to the end of treatment stage or bands-off stage in the following text.

Overall, there were no consistent significant changes between the two treatment groups (F1) or between the three stage intervals (F2), within any of the four mandibular incisors.

A trend was appearing in some incisor groups of changes between treatment modes at different stage intervals.

Examining our results, revealed that the  $SS_e \%$  (sum of the squares of error percentage) was very large, and contributed to almost all of the total variation (Table 2). The total number of observations within the sample (n) was 213.

Table 2. Sum of Squares Percentage of Error ( $SS_e \%$ )

| A-1   | A-2   | A-3   | A-4   |
|-------|-------|-------|-------|
| 97.96 | 98.20 | 98.73 | 99.20 |

When the initial CRD was used in examining the rotational relapse of the nonextraction group at different stage intervals in posttreatment, the ANOVA revealed that there was no significant change at the 5% level for all of the

four incisors (Table 3). Likewise, for the extraction group the ANOVA revealed no significant change at the 5% level for all four incisors (Table 4).

Table 3. Nonextraction group

|   | A-1  | A-2  | A-3  | A-4  |
|---|------|------|------|------|
| F | 0.81 | 1.52 | 0.59 | 0.37 |
| p | 0.45 | 0.23 | 0.56 | 0.69 |

Table 4. Extraction group

|   | A-1  | A-2  | A-3  | A-4  |
|---|------|------|------|------|
| F | 1.26 | 0.14 | 0.56 | 0.19 |
| p | 0.29 | 0.87 | 0.57 | 0.83 |

If we consider the A-1 incisor of the extraction group, there is a significant change between stage intervals at the 10% level of significance, indicating that some trend may exist as to the amount of change occurring at these stages.

On examining the mean, standard deviation, and range of the nonextraction group (Table 5), we can detect some trends as to the direction of movement of each incisor and the stage at which the change is greater.

For all four incisors, the range of rotational change at each stage interval, indicates movement in both directions away from the corrected position, indicated by the positive and negative values to the means. This represents either direction towards the pretreatment condition or away from the pretreatment condition. However, the exact direction

cannot be determined as the pretreatment casts were not investigated in this study.

Table 5. Nonextraction Group

|                                     | A-1    | A-2   | A-3    | A-4    |
|-------------------------------------|--------|-------|--------|--------|
| Mean T-R <sub>2</sub>               | 1.85   | -0.52 | 0.93   | 0.84   |
| Mean T-R <sub>3</sub>               | 2.65   | 1.19  | 0.39   | 0.37   |
| Mean R <sub>2</sub> -R <sub>3</sub> | 0.80   | 1.71  | -0.54  | -0.48  |
| s                                   | 5.26   | 4.83  | 4.90   | 5.59   |
| Minimum                             | -11.18 | -9.67 | -12.94 | -16.28 |
| Maximum                             | 15.18  | 11.18 | 14.46  | 14.87  |

Furthermore, the overall amount of change represented by the minimum and maximum values (Table 5) of the incisors at different stages appears evenly distributed in both directions of movement. The standard deviation does not appear to vary greatly, and compares well with the studies of Ahrens, et al, (1981).

Overall, the means do indicate a trend of relapse towards one direction by the greater incidence of positive values at all stages and for all four incisors. However, there is indication that the direction of movement can alternate between stage intervals.

Regardless of this alternation, the mean relapse of all four incisors between the stage interval T-R<sub>3</sub> was always in one direction away from the corrected position.

A trend is also seen when the greater amount of relapse

occurs, as the incisors A-1, A-3, and A-4 show the mean relapse in the period  $T-R_2 > R_2-R_3$ . However, the response by A-2 is opposite.

When we consider the extraction group and examine the mean, standard deviation and range (Table 6) the trend is very similar. The range of mean relapse for all four incisors appears to favour one direction away from the corrected condition which reaches greater values of change, but nonetheless the relapse does alternate between both directions. The mean relapse at all stages of the extraction group also indicate larger values for the lateral incisors, A-1 and A-4, and similar with the findings of Little, et al., (1981, 1988) that incisor rotations after extraction treatment, especially lateral incisors, do not always mimic the pretreatment condition.

Table 6. Extraction Group

|                | A-1    | A-2    | A-3    | A-4    |
|----------------|--------|--------|--------|--------|
| Mean $T-R_2$   | 1.48   | 0.42   | 0.43   | 0.56   |
| Mean $T-R_3$   | 3.11   | 0.84   | -0.15  | 1.25   |
| Mean $R_2-R_3$ | 1.63   | 0.43   | -0.57  | 0.69   |
| s              | 5.38   | 4.42   | 4.48   | 5.60   |
| Minimum        | -11.06 | -11.67 | -13.19 | -14.61 |
| Maximum        | 23.33  | 13.40  | 12.33  | 18.85  |

The means indicate that relapse is generally in the one direction from the bands-off position, with three of the four incisor groups. All four incisor groups indicate that the mean change in the period  $R_2-R_3 > T-R_2$ .

When both extraction and nonextraction groups were pooled together for each incisor, and analysed, no significant changes between stages were detected at the 5% level. There was only a slight indication of relapse, changes at  $T-R_2$  being greater than  $R_2-R_3$ . It was shown that the residual error for all four incisor groups contributed to more than 97.9% of the total SS%. The CV% was also high, ranging from 271.9% to 13,848.3%, indicating that there is too much contribution from variations of the experimental units and that this analysis design is not appropriate, in outlining isolated cases of very large or small relapse changes. Ahrens, et al., (1981) also mentioned the presence of one case in his sample which increased the range and standard deviation by 100%.

Accepting that the sample represents a range of mandibular incisors with minor to severe rotations and each tooth undergoes different amounts of relapse changes in the posttreatment period, then the CRD analysis performed previously tends to average out the small and large changes. An examination of the mean relapse of individual cases shows that generally the changes at all three intervals were below 10 degrees of absolute value.

Swanson (1973) called this group of rotational angle (0 - 10 degrees) the "mild" category, and excluded them from his study, although he believed they accounted for most of the relapse for all teeth in both arches. Ahrens, et al., (1981) also omitted teeth with less than 10 degrees rotation from their sample.

An analysis of a more homogeneous sample of each lower incisor, was considered by applying the multivariate General Linear Model regression analysis (GLM).

This technique enables us to find the best linear relationship between one variable and another by omitting the outliers or uncommonly high relapse values, from statistical analysis. The contributions from the residual error to the total variance was markedly reduced and the standard deviations of the incisor groups reduced significantly.

The final sample characteristics considered for analysis was as follows (Table 7):

Table 7. Sample Characteristics of GLM Analysis.

|         | A-1   | A-2   | A-3   | A-4   |
|---------|-------|-------|-------|-------|
| n       | 157   | 172   | 169   | 161   |
| minimum | -4.47 | -5.22 | -5.66 | -5.96 |
| maximum | 8.34  | 5.76  | 6.91  | 5.88  |

The results of the separate incisor groups are shown in Table 8, 9, 10, and 11 and the mean relapse responses are depicted in figures 12-1, 12-2, 12-3, and 12-4 respectively. The pooled mean relapse responses for treatments (F1) and stages (F2) are depicted in figures 12-5 and 12-6 respectively. The findings are outlined.

Table 8.            A-1    MANDIBULAR LEFT LATERAL INCISOR

| SOURCE OF VARIATION | df  | SS      | MS     | F        |
|---------------------|-----|---------|--------|----------|
| F1                  | 1   | 135.70  | 135.70 | 21.02 ** |
| F2                  | 2   | 23.22   | 11.61  | 1.80     |
| F1 x F2             | 2   | 121.79  | 60.89  | 9.44 **  |
| Error               | 151 | 974.71  | 6.46   |          |
| Total               | 156 | 1255.42 |        |          |

COMPARISON OF CRD AND GLM ANOVA

|           | n   | s     | R-sq% | CV%    |
|-----------|-----|-------|-------|--------|
| CRD ANOVA | 213 | 5.336 | 2.0%  | 271.9% |
| GLM ANOVA | 157 | 2.84  | 22.4% | 235.0% |

MEANS

|      | T-R <sub>2</sub> | T-R <sub>3</sub> | R <sub>2</sub> -R <sub>3</sub> | ALL    |
|------|------------------|------------------|--------------------------------|--------|
| F1-N | 1.9520           | 5.3201           | 1.3237                         | 2.5282 |
| F1-E | 0.5042           | 0.2394           | 0.8305                         | 0.5528 |
| ALL  | 0.9775           | 1.7754           | 1.0055                         | 1.2071 |

Findings:

1.    F1 differences are highly significant at 5% level and significant at 1% level.
2.    F2 differences are not significant at 5% level.
3.    F1 and F2 interactions are highly significant at the 5% level and significant at 1% level.
4.    The CV% is high, indicating a sample with many variations between experimental units.

5. The standard deviation has reduced significantly with GLM, to be now similar in value to Edwards (1988) results.
6. The contribution of the factor elements (see overview page 153) to the total variation has increased, thus increasing their consideration in the study.

### Discussion:

Statistically, the extraction group show less mean relapse than the nonextraction group, at all three stage intervals, posttreatment.

Clinically, as observed on model casts, the relapse appears negligible in the extraction group but detectable within the nonextraction group especially at stage T-R<sub>3</sub>, with over 5 degrees of change.

The direction of relapse towards one direction in the nonextraction group for stage T-R<sub>3</sub>, at 2 standard deviations, is strong, and the mean relapses are towards this direction at all stages and for both groups.

The interactions between the variables of factors indicate a firm dependency for it to show a significant change.

Fig. 12-1. A-1 Mean response of stages

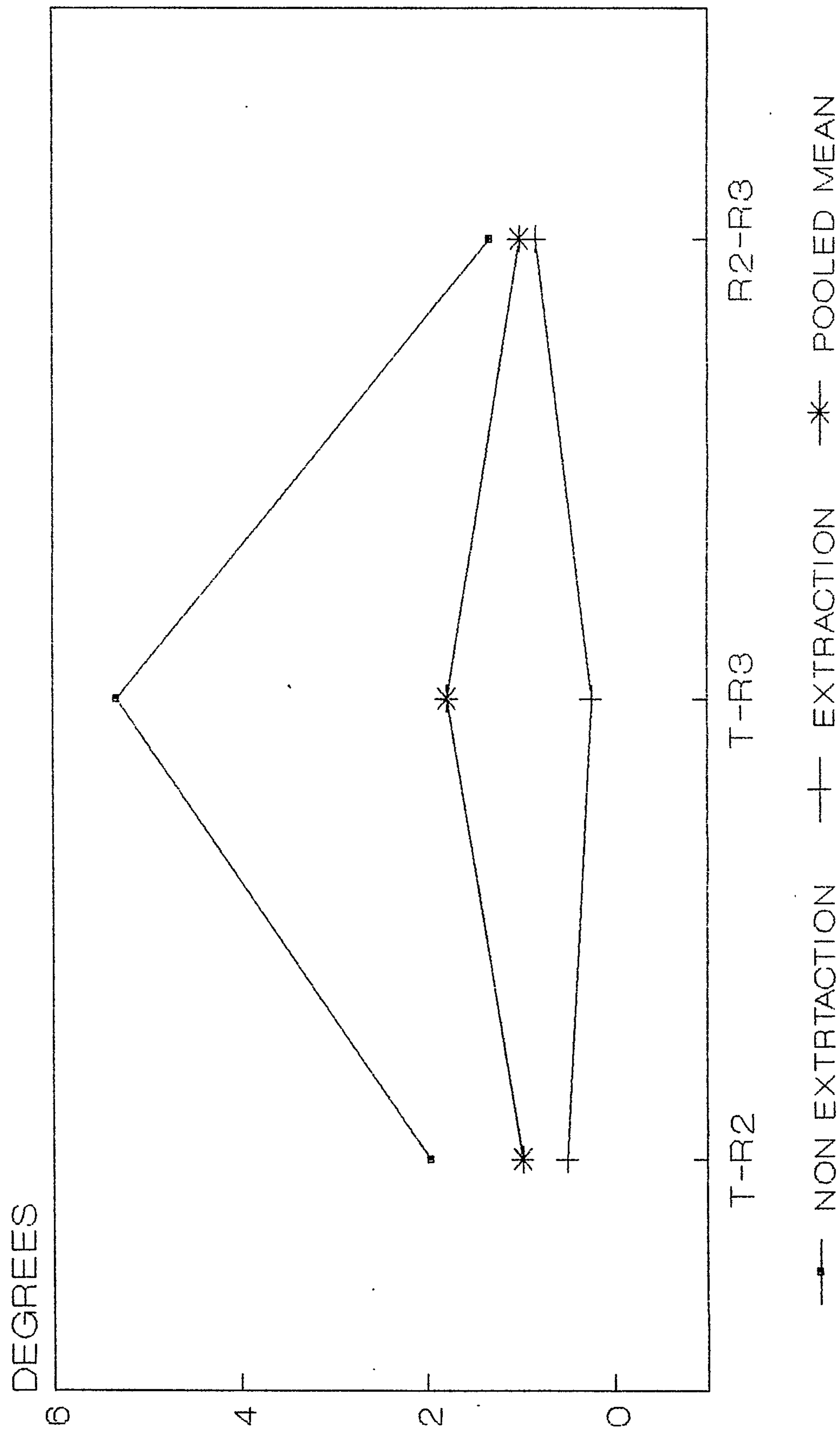


Table 9. A-2 MANDIBULAR LEFT CENTRAL INCISOR

| SOURCE OF VARIATION | df  | SS       | MS     | F     |
|---------------------|-----|----------|--------|-------|
| F1                  | 1   | 2.294    | 2.294  | 0.271 |
| F2                  | 2   | 20.064   | 10.032 | 1.183 |
| F1 x F2             | 2   | 0.974    | 0.487  | 0.057 |
| Error               | 166 | 1407.422 | 8.478  |       |
| Total               | 171 | 1430.752 |        |       |

## COMPARISON OF CRD AND GLM

|           | n   | s     | R-sq% | CV%     |
|-----------|-----|-------|-------|---------|
| CRD ANOVA | 213 | 4.570 | 1.8%  | 707.2%  |
| GLM ANOVA | 171 | 2.89  | 1.6%  | 2583.0% |

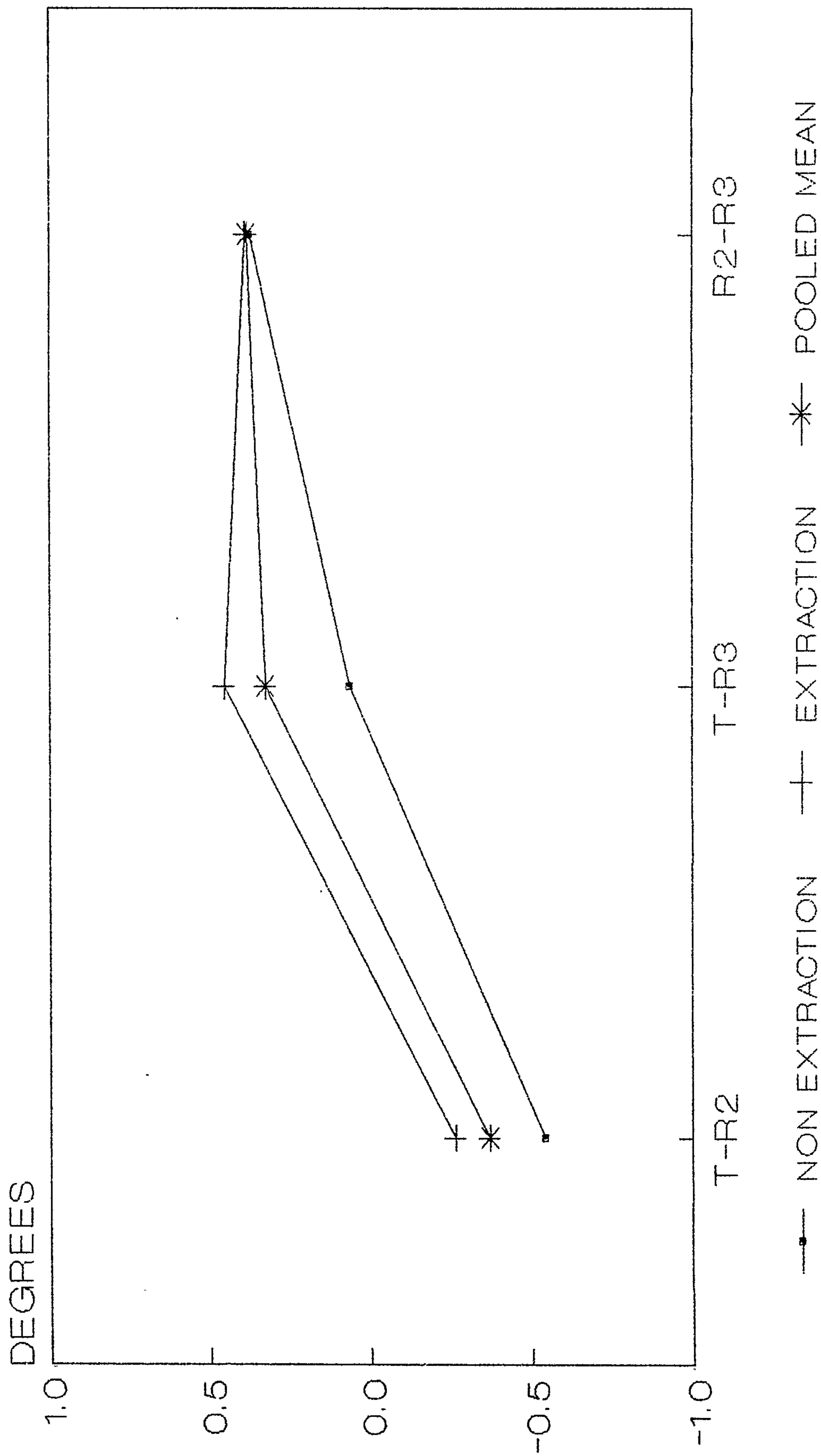
## MEANS

|      | T-R <sub>2</sub> | T-R <sub>3</sub> | R <sub>2</sub> -R <sub>3</sub> | ALL     |
|------|------------------|------------------|--------------------------------|---------|
| F1-N | -0.5444          | 0.0631           | 0.3737                         | -0.0440 |
| F1-E | -0.2655          | 0.4541           | 0.3895                         | 0.1974  |
| ALL  | -0.3713          | 0.3263           | 0.3839                         | 0.1118  |

## Findings:

1. F1 differences are not significant at 5% level.
2. F2 differences are not significant at 5% level.
3. F1 and F2 interactions are not significant at 5%.
4. The CV% is high, indicating large variations within the experimental units in both directions of movement.
5. The s value is reduced significantly.
6. The contribution of the factors to the total variation has slightly decreased.

Fig. 12-2. A-2 Mean response of stages



### Discussion:

Although, from observing the casts, the mean changes are negligible within all factors considered, statistically, slight changes and possibly minor trends can be detected.

At stage  $T-R_2$ , the nonextraction groups undergo approximately twice as much change as the extraction group, but are similar in the longer stage period  $R_2-R_3$ .

The nonextraction group experiences greater amounts of change regardless of the direction of movement and final position of the incisors at 6 months posttreatment.

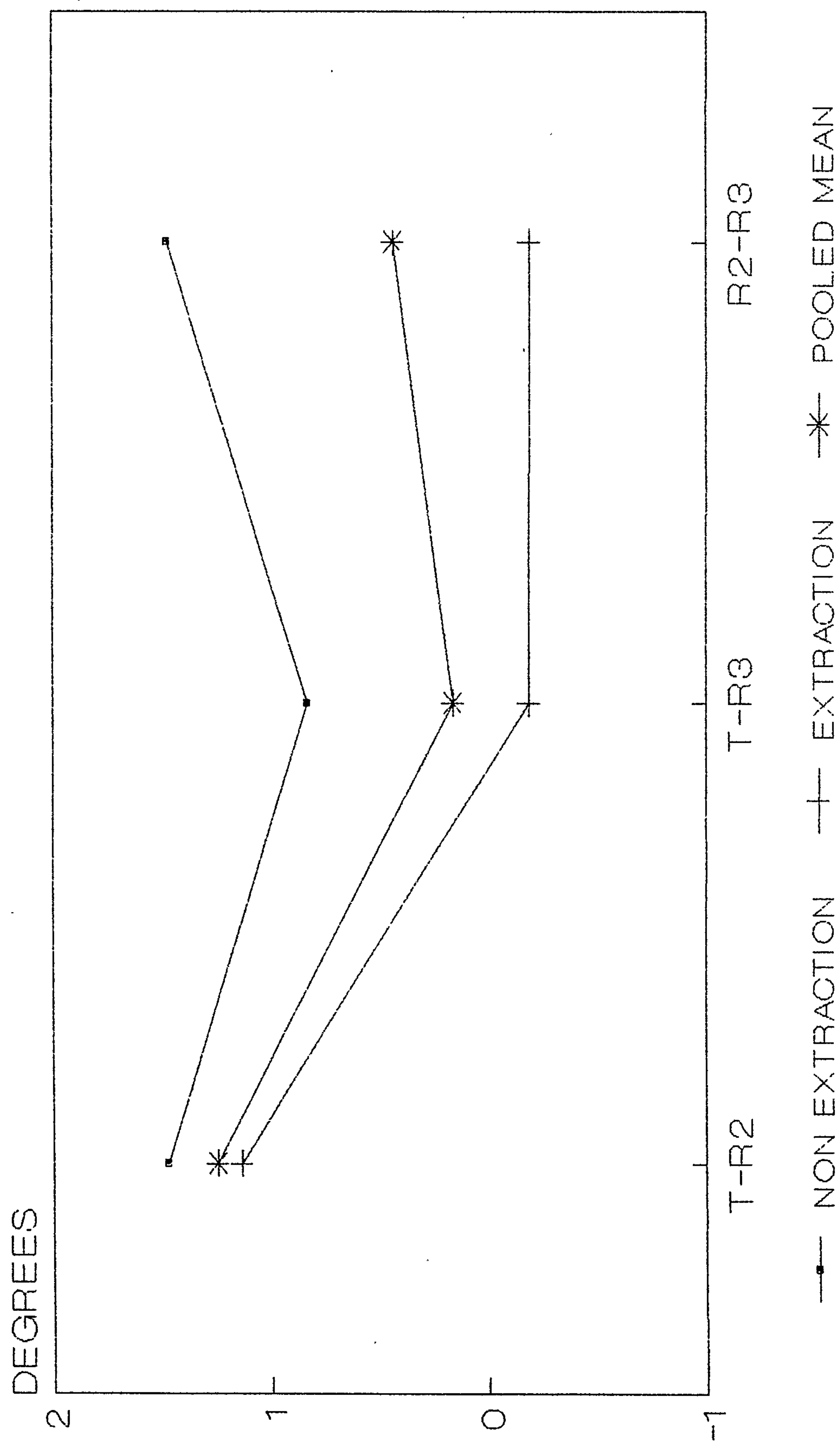
This is indicated by the absolute sum mean relapse at  $T-R_2$  and  $R_2-R_3$ .

Overall, the direction of the change again is in one direction only away from the corrected condition, but it alternates within stages.

Table 10. A-3 MANDIBULAR RIGHT CENTRAL INCISOR

| SOURCE OF VARIATION | df  | SS       | MS      | F      |
|---------------------|-----|----------|---------|--------|
| F1                  | 1   | 37.164   | 37.164  | 4.566* |
| F2                  | 2   | 46.563   | 23.2815 | 2.86   |
| F1 x F2             | 2   | 16.341   | 8.1705  | 1.004  |
| Error               | 163 | 1326.891 | 8.140   |        |
| Total               | 168 | 1426.959 |         |        |

Fig. 12-3. A-3 Mean response of stages



## COMPARISON OF CRD AND GLM

|           | <i>n</i> | <i>s</i> | <i>R-sq%</i> | <i>CV%</i> |
|-----------|----------|----------|--------------|------------|
| CRD ANOVA | 213      | 4.638    | 1.3%         | 13,848.3%  |
| GLM ANOVA | 168      | 2.91     | 7.0%         | 458.5%     |

## MEANS

|             | <i>T-R<sub>2</sub></i> | <i>T-R<sub>3</sub></i> | <i>R<sub>2</sub> -R<sub>3</sub></i> | <i>ALL</i> |
|-------------|------------------------|------------------------|-------------------------------------|------------|
| <i>F1-N</i> | 1.4707                 | 0.8294                 | 1.4733                              | 1.2760     |
| <i>F1-E</i> | 1.1348                 | -0.1873                | -0.1912                             | 0.2922     |
| <i>ALL</i>  | 1.2467                 | 0.158                  | 0.433                               | 0.6357     |

## Findings:

1. *F1* differences are significant at 5% level.
2. *F2* differences are not significant at 5% level but significant at 10%.
3. *F1* and *F2* interactions are not significant at the 5% level.
4. The *CV%* is high, indicating large variations within the experimental units, but a more homogeneous sample than the CRD.
5. The *s* value has reduced significantly.
6. The contribution of the factors to the total variation has increased.

## Discussion:

Statistically, the extraction group show less mean relapse than the nonextraction group, at all three stage intervals, regardless of the direction of change. When viewed on the casts, the relapse appears negligible in both the extraction and nonextraction groups.

The direction of the combined mean relapse for both groups is towards the one direction moving away from the bands off condition for all stages. The extraction group does indicate greater relapse in the T-R<sub>2</sub> stage than the R<sub>2</sub>-R<sub>3</sub> stage, whereas the nonextraction group is similar at both stages.

The indication that the mean differences between stages is independent of treatment mode, is because they follow a similar pattern shown clearly by Fig. 12-3.

Table 11. A-4 MANDIBULAR RIGHT LATERAL INCISOR

| SOURCE OF VARIATION | df  | SS       | MS     | F     |
|---------------------|-----|----------|--------|-------|
| F1                  | 1   | 23.513   | 23.513 | 3.070 |
| F2                  | 2   | 12.878   | 6.439  | 0.866 |
| F1 x F2             | 2   | 44.127   | 22.064 | 2.881 |
| Error               | 155 | 1187.036 | 7.658  |       |
| Total               | 160 | 1267.554 |        |       |

COMPARISON OF CRD AND GLM

|           | n   | s     | R-sq% | CV%     |
|-----------|-----|-------|-------|---------|
| CRD ANOVA | 213 | 5.599 | 0.8%  | 908.4%  |
| GLM ANOVA | 160 | 2.82  | 6.4%  | 7407.9% |

MEANS

|      | T-R <sub>2</sub> | T-R <sub>3</sub> | R <sub>2</sub> -R <sub>3</sub> | ALL     |
|------|------------------|------------------|--------------------------------|---------|
| F1-N | -0.0686          | 0.6924           | 0.7280                         | 0.4391  |
| F1-E | 0.5972           | -0.8371          | -0.3439                        | -0.3439 |
| ALL  | 0.3402           | -0.2440          | -0.2451                        | -0.0375 |

**Findings:**

1. F1 differences are not significant at 5% level but significant at the 10%.
2. F2 differences are not significant at 5% level.
3. F1 and F2 interactions are not significant at the 5% level but significant at the 10% level.
4. The CV% is increased significantly, indicating a sample with many variations between experimental units in both directions of movement.
5. The s value has decreased significantly.
6. The contribution of the factors to the total variations is increased.

**Discussion:**

The extraction group show less mean relapse than the nonextraction group, overall.

Inspection of the model casts, suggests that the relapse is negligible in the extraction and nonextraction group and the direction for all stages and treatments alternates.

The interactions between the factors indicate a dependency for stages and treatments as shown on Fig. 12-4 where the lines indicate different patterns that intersect.

Fig. 12-5 and 12-6 show on one plot the mean responses considered in the discussions mentioned, for the two treatment modes and the three stages investigated.

Fig. 12-4. A-4 Mean response of stages

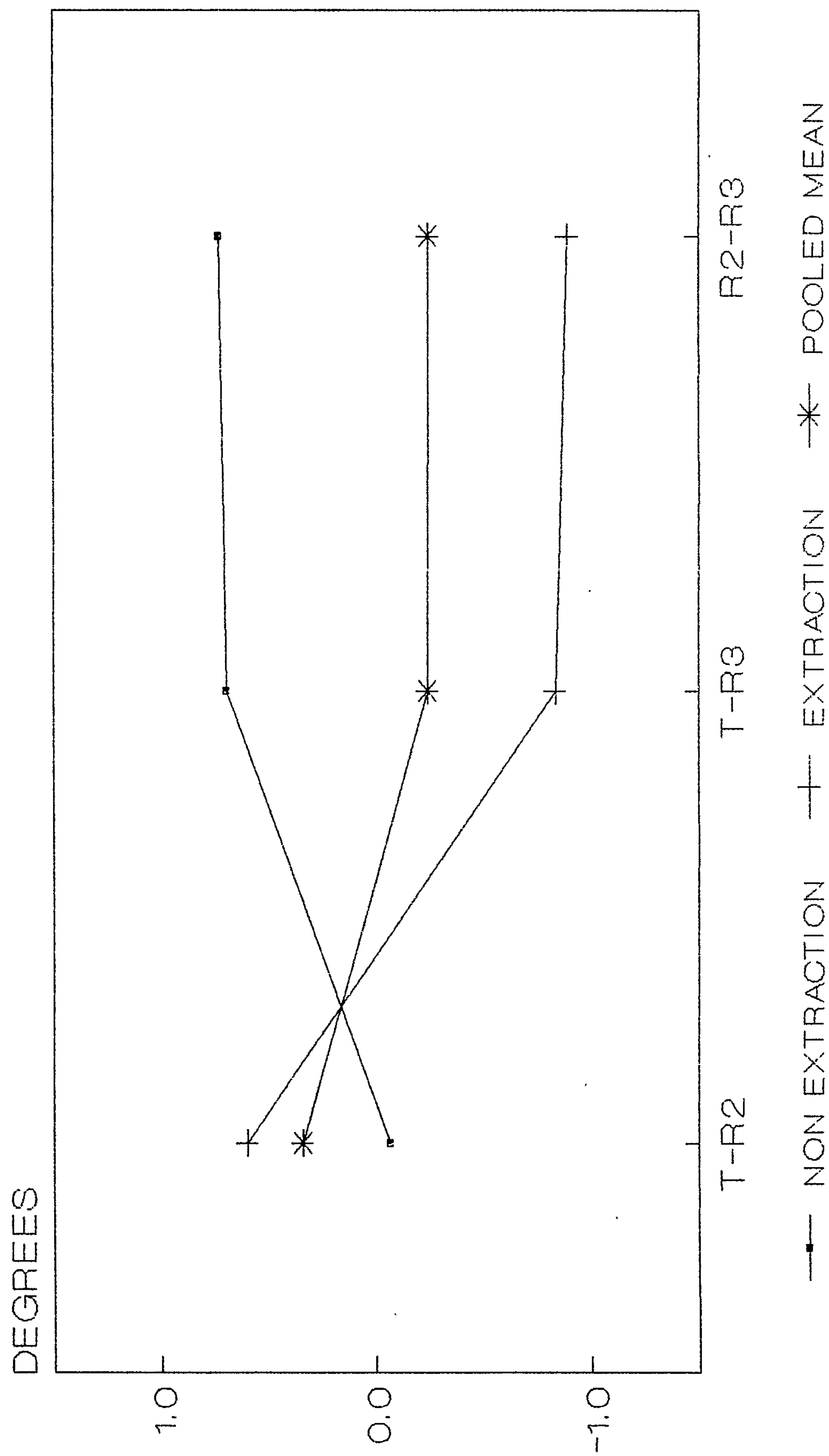


Fig. 12-5 Pooled mean responses for F1

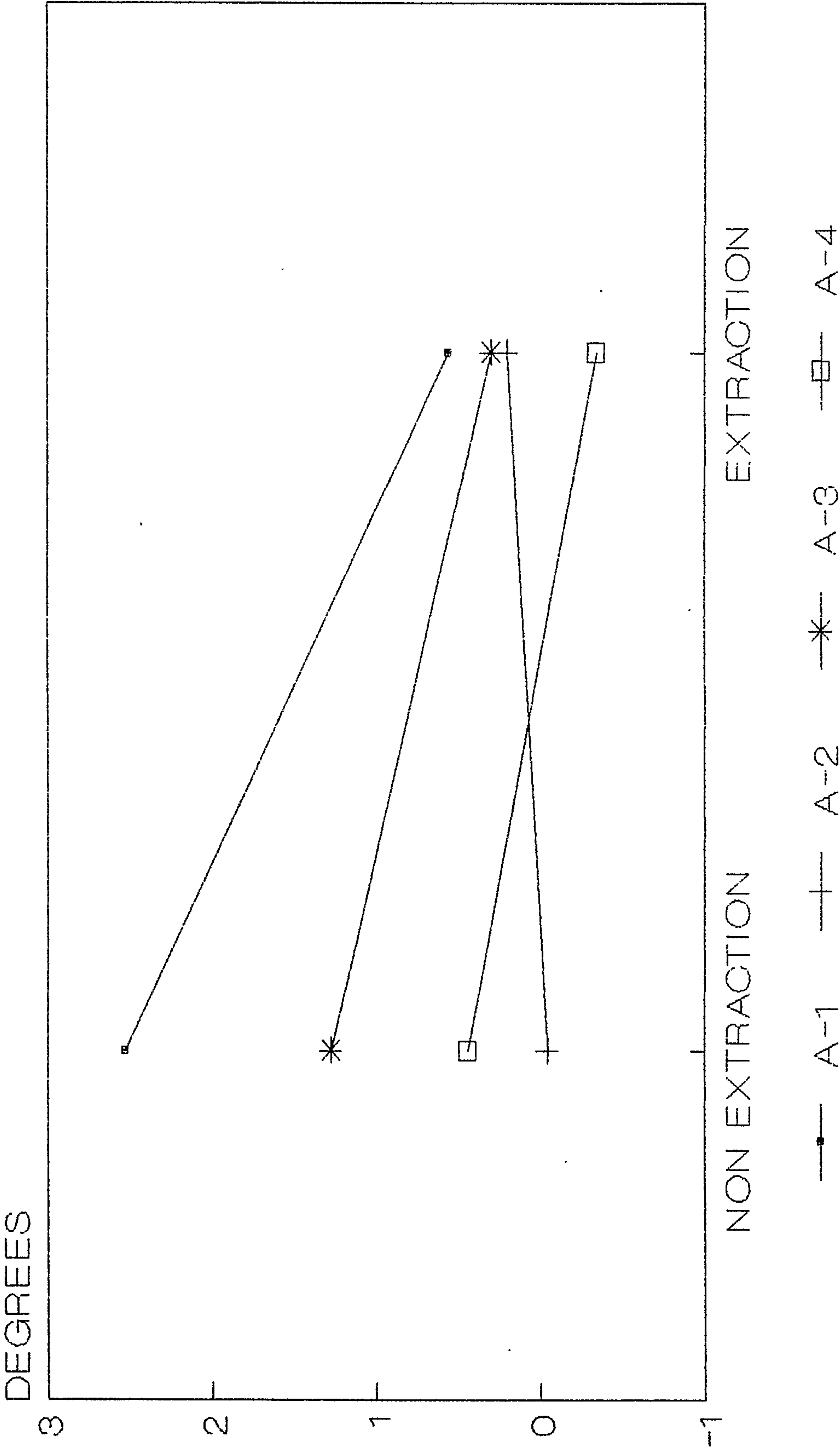
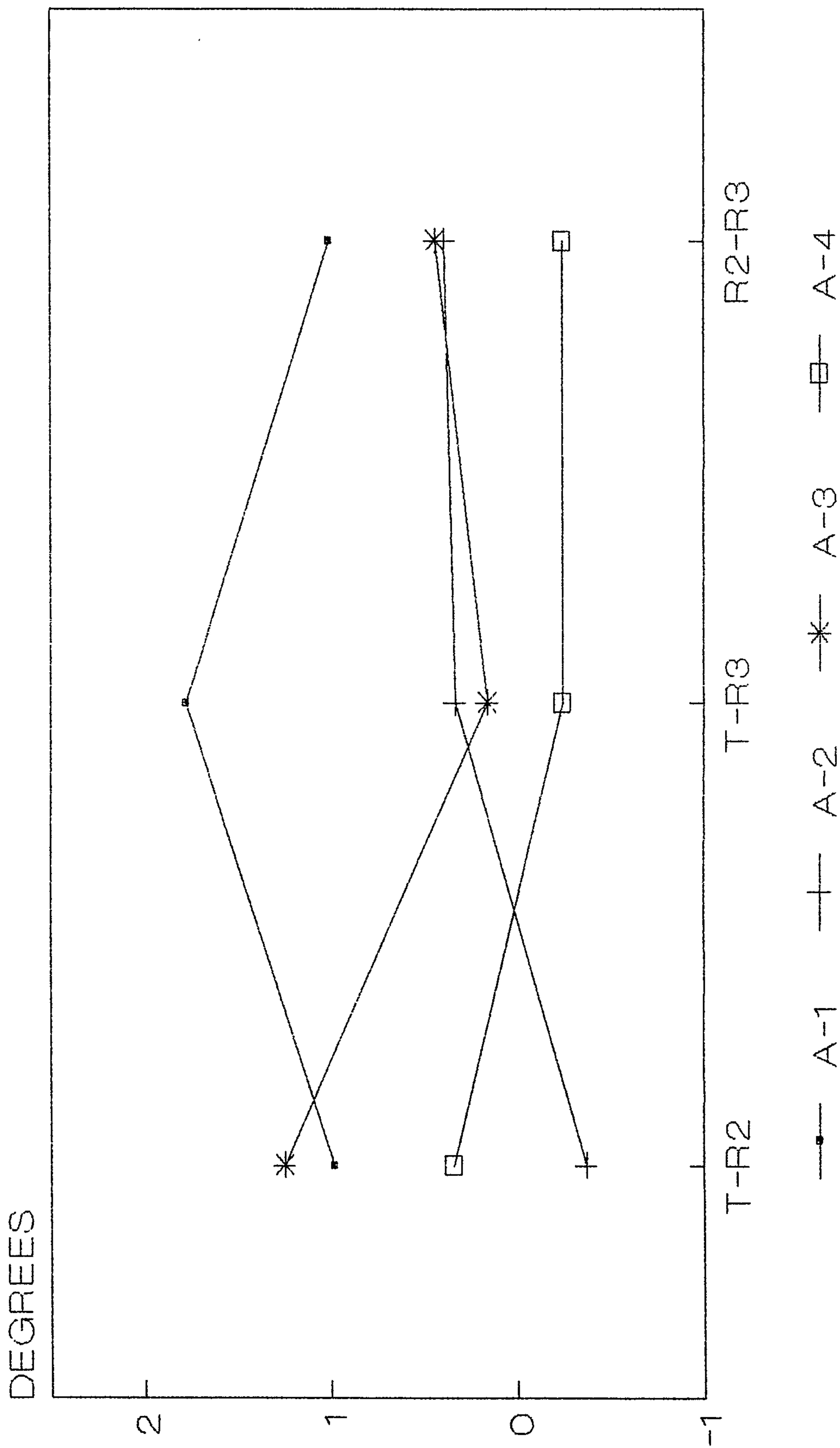


Fig. 12-6 Pooled mean responses for F2



Finally, the lateral incisors, A-1 and A-4, and the central incisors, A-2 and A-3, were pooled and analysed by GLM. The means for the separate stages and the different treatments are shown in Table 12 and Table 13, and plotted in Fig. 12-7 and Fig 12-8.

Table 12 Mean responses of pooled A-1 and A-4

|      | T-R <sub>2</sub> | T-R <sub>3</sub> | R <sub>2</sub> -R <sub>3</sub> | ALL   |
|------|------------------|------------------|--------------------------------|-------|
| F1-N | 0.417            | 0.142            | 0.453                          | 0.333 |
| F1-E | 0.859            | 0.829            | 0.274                          | 0.641 |
| ALL  | 0.682            | 0.579            | 0.335                          | 0.529 |

Table 13 Mean responses of pooled A-2 and A-3

|      | T-R <sub>2</sub> | T-R <sub>3</sub> | R <sub>2</sub> -R <sub>3</sub> | ALL   |
|------|------------------|------------------|--------------------------------|-------|
| F1-N | 0.152            | -0.204           | 1.040                          | 0.350 |
| F1-E | 0.370            | 0.228            | 0.140                          | 0.245 |
| ALL  | 0.290            | 0.076            | 0.462                          | 0.283 |

Statistically, there were no significant differences for treatment (F1) or stages (F2) or the interactions (F1/F2), at the 5% level nor the 10% level.

When observing the model casts, relapse values did not represent any significant change with the greater response being just over 0.5 degrees and standard deviation of 3.0 degrees.

Fig. 12-7 Response of pooled A-1 & A-4

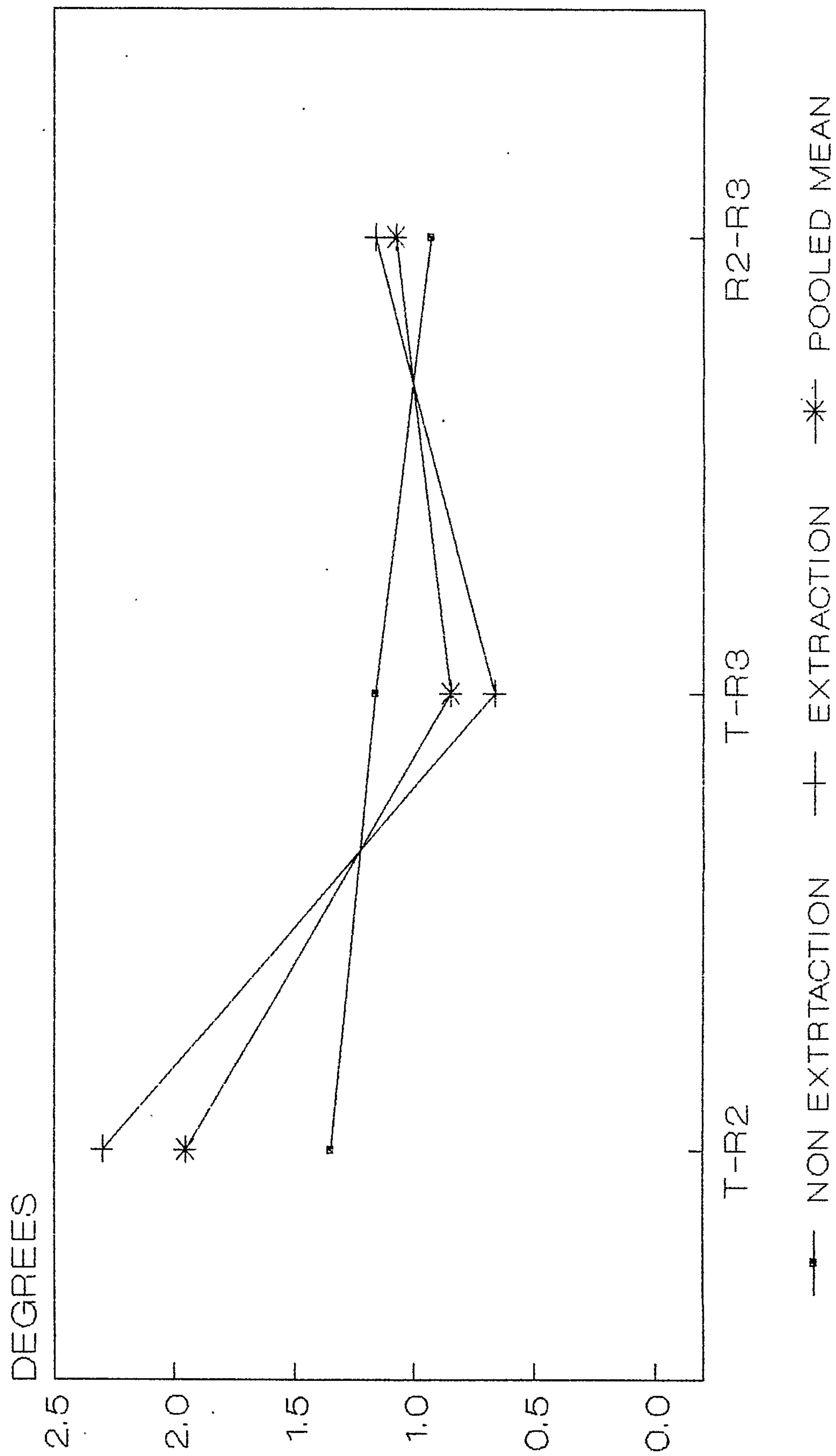
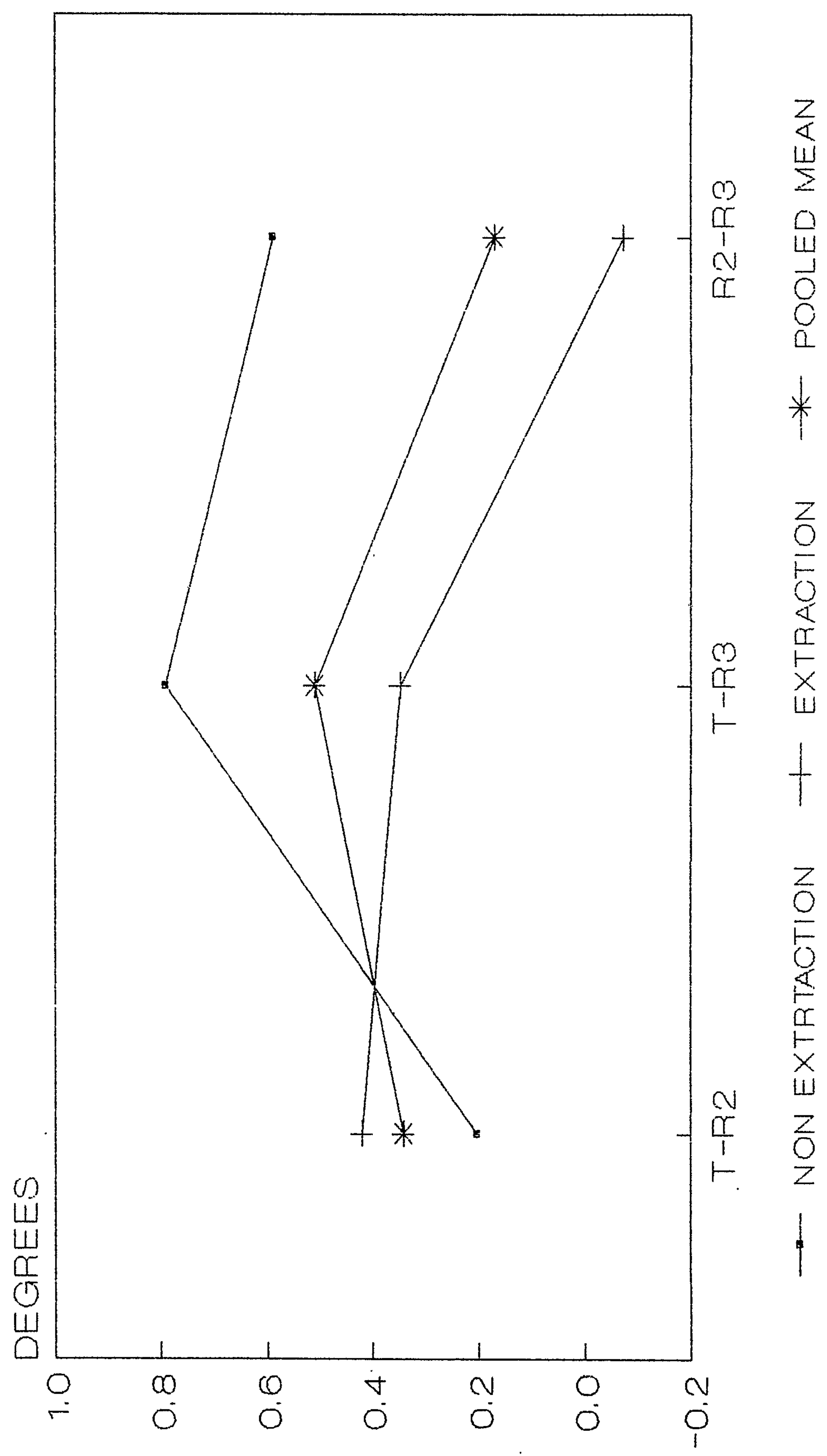


Fig. 12-8 Response of pooled A-2 & A-3



However, on examining the means for any trends, we can detect:

1. The overall mean relapse for the laterals is almost twice as large as the centrals (0.528, 0.283).
2. The mean relapse for nonextraction is similar in both incisor groups (0.333, 0.350).
3. The mean relapse for lateral in extraction cases is greater than centrals (0.641, 0.245).
4. The mean relapse for the pooled stages,  $T-R_2$ , is greater for laterals than centrals (0.682, 0.290).
5. The mean relapse for the pooled stages,  $T-R_2$ , is greater than  $T-R_3$  in laterals than centrals (0.682, 0.335 vs 0.290, 0.462).
6. The mean relapse for extractions is greater than nonextractions in laterals, but almost similar in the centrals (0.641, 0.333 vs 0.245, 0.350).
7. The direction of mean relapse is in one direction only away from the corrected condition.
8. The mean relapse for extraction is greater than nonextraction at  $T-R_2$  for laterals and central, but the opposite is at  $R_2-R_3$ .

## 12.1 Overview

The tendency of rotated teeth to return to their original pretreatment positions is apparently inherent in the periodontal fibres in the marginal alveolar crest. Many studies, discussed previously, have investigated rotational relapse changes at different time intervals posttreatment,

using many clinical methods, such as long retention periods, surgical severing of the gingival and periodontal fibres, early treatment, proper contact points, and overrotation to minimise or prevent relapse. This relapse tendency reflects the importance of tooth rotation stability after orthodontic treatment especially with the mandibular incisors.

Therefore, it is important to be able to identify and establish any interrelationships between certain factors involved in the correction and stability of rotated teeth and minimising relapse, in particular, as pointed out by Swanson (1973), extraction or nonextraction treatments. This is indicative of also the original malocclusion, both in terms of severity of crowding and the Angle's dental classification.

This study has attempted to examine the possible relationship of extraction and nonextraction treatment therapy to relapse changes, the significant changes at two posttreatment time intervals and any possible interactions between them, in cases treated by Begg mechanotherapy. The direction of rotational relapse has also been analysed as in many other studies, although reporting on observation of individual cases have only considered relapse in the direction of the original pretreatment rotation.

Overall, a significant association between the treatment groups, extraction and nonextraction, and different posttreatment stage intervals could not be demonstrated. However, this study indicated significant difference between

the two treatment modes, stage intervals and interactions with posttreatment time stages, for some incisor change groups especially in the "mild" category. Swanson (1973) reported that the amount of rotational relapse is unrelated to extraction or nonextraction.

The findings from this study suggest that certain mandibular incisors undergo more rotational relapse than others.

The lateral incisor is more prone than the central incisor to relapse from its corrected position, and supposedly in the direction of the pretreatment rotation. This agrees with Swanson (1973) in that the mandibular lateral incisor has a higher incidence (11.3%) of relapse than the central incisor (8.7%) which is the tooth with least tendency to relapse in the mandibular dentition.

Also the extraction groups tend to experience less relapse than the nonextraction when examining the separate incisor groups. Interestingly, the extraction group relapse more than the nonextraction group in the short interval period, bands-off to 6 weeks posttreatment, for all incisors; but the opposite tends to occur in the long interval period, 6 weeks to 6 months posttreatment.

The findings appear to agree with Begg's theory that when extraction is carried out and it simulates approximal attrition, then the relapse potential of the lower incisors, although greatest in the early period after end of treatment, should be more stable in the long term stages posttreatment.

In general, the incidence of rotational relapse in the mandibular incisors agrees with Reitan's (1969) conclusion that they tend to rerotate, usually in one direction presumably towards their initial pretreatment position, as Reitan reported.

Using the multivariate regression analysis, the findings suggest that certain teeth on one side of the dental arch tend to relapse more than counterparts on the opposite side. According to Swanson (1973) this is perhaps the least important finding since the data indicates very small differences between tooth positions on opposite sides of the dental arch and the GLM was sensitive enough to detect these small differences, but concluding that generalised differences exist would not be justified.

This study agrees with Edwards (1988) findings that the amount and even the direction of tooth movement after treatment is very unpredictable from observation of the individual teeth, due to extreme individual variations. The term "relapse" may not be appropriate in situations where teeth did not rerotate toward their pretreatment malpositions, according to Edwards.

The unpredictability of the direction of rotational relapse, may be explained by the inelastic, noncontractile wavy collagen fibres of the periodontium not exerting a recoil force following rotational correction within the "mild" category of angles. It is suggested that retention of the mandibular incisors may need to be considered after active treatment.

The large contribution of the residual error in the statistical analyses has diluted possible detection of other stronger trends. This error can be due to a combination of alterations to the reference line by movement of teeth posttreatment, the narrow width of the mandibular incisors, and measurement method.

The present study has shown:

1. All mandibular incisors demonstrate rotational relapse in the posttreatment stages, and can be both clinically observable, from viewing the model casts, and statistically significant.
2. Lateral incisors are more prone to relapse than central incisors in the posttreatment stages.
3. The tooth which has been treated orthodontically shows a great tendency to rotate away from the corrected position and usually in one direction.
4. Some statistically significant differences have been shown between the treatment modes, extraction versus nonextraction, for correction of incisor irregularities.

The investigation into rotational relapse of the mandibular incisors, in this study, has indicated some trends and statistical data to warrant further research. My recommendations in this regard are:

1. to consider extending the interval stages posttreatment to 12 months or more.

2. to consider a more homogeneous sample, grouped into categories of rotation angles present in the pretreatment casts.
3. to consider the original malocclusion and its association to the treatment selected, extraction or nonextraction, and possibly the extraction regimen carried out.
4. to include the pretreatment casts for analysis, so that the direction of incisor relapse posttreatment, can be determined when compared with the pretreatment incisor position.
5. to acquire information concerning overrotations, as to when they were placed and for how long they were maintained during treatment.

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The statistical information in text was produced from software packages:

1. Genstat V - Lawes Agricultural Trust  
(Rothamsted Experimental Station)
2. Minitab Incorporation Pennsylvania State University and Washington State University.

The general formulas are:

$$\text{EXPERIMENTAL UNITS} = n$$

$$\text{STANDARD DEVIATION (s)} = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n - 1}}$$

$$\text{VARIANCE} = s^2$$

$$\text{STANDARD ERROR OF MEAN (SE[x])} = \frac{s}{\sqrt{n}}$$

$$\text{COEFFICIENT OF VARIANCE (v)} = \frac{s}{\bar{X}} \times 100\% = \frac{MS_e}{\bar{X}}$$

#### ANALYSIS OF VARIANCE (ANOVA):

$$\text{Degree of Freedom (df)} = n - 1$$

$$\text{Sum of Squares (SS)} = \sum (X_i - \bar{X})^2$$

$$\text{Sum of Squares Percentage (SS\%)} = \sum (X_i - \bar{X})^2 \times 100$$

$$\text{Mean Square Deviation (Variance) (MS)} = \frac{SS}{df}$$

Mean Square Deviation for Error =  $(MS_e)$

Variance Ratio (F) =  $\frac{\text{Greater Mean Square Deviation}}{\text{Lesser Mean Square Deviation}}$

=  $\frac{\text{Mean Square Deviation for Factors}}{\text{Mean Square Deviation For Error}}$

=  $\frac{MS}{MS_e}$

## MEASURED ANGLES USED IN STUDY

The Reference Line is determined by a line through the dots "x" and "y".

The angles considered are the acute angles determined by the intersections of lines passing through the most mesial and distal points of the incisors and the Reference Line.

Angle "a" refers to A-1

Angle "b" refers to A-2

Angle "c" refers to A-3

Angle "d" refers to A-4

