



ENDOTEC

20 Valley Street, Suite 210, South Orange, New Jersey 07079 • (973) 762-6100 • (973) 762-6355

October 22, 2004

Division of Dockets Management
Office of Management Programs
9200 Corporate Blvd.
Rockville, MD 20857

Re: Docket Number 2004P-0457/CCP 1: Reclassification of Non-constrained, Mobile-Bearing Ankle Prosthesis

Dear Mr. Jaffe:

In response to the FDA letter dated September 27, 2004, and to our telephone conference on September 13, 2004 please find attached an updated version of the reclassification of non-constrained, mobile-bearing ankle prostheses. We have integrated more recent references to bring the Agency up to date with current publications and have added sections including Engineering drawings/Specifications and Special Controls.

If you have any questions, please do not hesitate to call.

Sincerely



Michael J. Pappas Ph.D., P.E.
President, Endotec

Encl.

2004P-0457

SUP 1

**ANKLE JOINT METAL/POLYMER/METAL ANATOMICALLY SEMI-
CONSTRAINED, CONGRUENT, MOBILE BEARING, POROUS-COATED,
UNCEMENTED PROSTHESIS**

Reclassification Petition - Amendment

Dated: October 22, 2004

Sponsor:

Endotec, Inc.
20 Valley Street
South Orange, NJ 07079
Tel: 973-762-6100
Fax: 973-762-6355

Contact Person:

Mr. Jared Pappas
20 Valley Street
South Orange, NJ 07079
Tel: 973-762-6100
Fax: 973-762-6355

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CDRH SUBMISSION COVER SHEET

Date of Submission: October 21, 2004

FDA Document Number: 2004P-0457/CCP 1

Section A Type of Submission

<p align="center">PMA</p> <input type="checkbox"/> Original Submission <input type="checkbox"/> Modules Submission <input type="checkbox"/> Amendment <input type="checkbox"/> Report <input type="checkbox"/> Report Amendment	<p align="center">PMA Supplement</p> <input type="checkbox"/> Regular <input type="checkbox"/> Special <input type="checkbox"/> Panel Track <input type="checkbox"/> 30 day Supplement <input type="checkbox"/> 30 day Notice <input type="checkbox"/> 135 day Supplement <input type="checkbox"/> Real-time Review <input type="checkbox"/> Amend PMA Supp	<p align="center">PDP</p> <input type="checkbox"/> Presubmission summary <input type="checkbox"/> Original PDP <input type="checkbox"/> Notice of intent to start clinical trials <input type="checkbox"/> Intention to submit <input type="checkbox"/> Notice of Completion <input type="checkbox"/> Amendment to PDP <input type="checkbox"/> Report	<p align="center">510(k)</p> <input type="checkbox"/> Original submission <input type="checkbox"/> Traditional <input type="checkbox"/> Special <input type="checkbox"/> Abbreviated <input type="checkbox"/> Additional Information <input type="checkbox"/> Traditional <input type="checkbox"/> Special <input type="checkbox"/> Abbreviated	<p align="center">Meeting</p> <input type="checkbox"/> Pre-IDE meeting <input type="checkbox"/> Pre-PMA meeting <input type="checkbox"/> Pre-PDP meeting <input type="checkbox"/> 180-day meeting <input type="checkbox"/> Other (specify)
<p align="center">IDE</p> <input type="checkbox"/> Original Submission <input type="checkbox"/> Amendment <input type="checkbox"/> Supplement	<p align="center">Humanitarian Device Exemption</p> <input type="checkbox"/> Original Submission <input type="checkbox"/> Amendment <input type="checkbox"/> Supplement <input type="checkbox"/> Report	<p align="center">Class II Exemption</p> <input type="checkbox"/> Original Submission <input type="checkbox"/> Additional Information	<p align="center">Evaluation of Automatic Class III Designation</p> <input type="checkbox"/> Original Submission <input type="checkbox"/> Additional Information	<p align="center">Other Submission</p> <p>Describe Submission; Reclassification</p>

Section B Applicant or Sponsor

Company/Institutional name: Endotec Inc.		Establishment registration number: 2280596	
Division name (if applicable)		Phone number (include area code) (973) 762-6100	
Street Address: 20 Valley Street		Fax number (include area code) (973) 762-6355	
City: South Orange	State/Province: NJ	Country: USA	
Contact name: Jared Pappas			
Contact title: Regulatory Affairs		Contact e-mail address: jpappas @endotec.com	

Section C Submission correspondent (if different from above)

Company/Institutional name:		Establishment registration number:	
Division name (if applicable)		Phone number (include area code)	
Street Address		Fax number (include area code)	
City	State/Province	Country	
Contact name:			

Contact title:

Contact e-mail address:

Section E Additional Information on 510(k) Submissions

Product codes of devices to which substantial equivalence is claimed				Summary of, or statement concerning safety and effectiveness data: <input type="checkbox"/> 510(k) summary attached <input type="checkbox"/> 510 (k) statement
1 HSN 888.3120	2	3	4	
5	6	7	4	

Information on devices to which substantial equivalence is claimed:

510(k) Number	Trade or proprietary or model name	Manufacturer
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6

Section F Product Information ---Applicable to All Applications

Common or usual name or classification name:

Total Ankle Replacement

Trade or proprietary or model name	Model Number
1 Buechel-Pappas Total Ankle Replacement System	1
2	2
3	5
4	4
5	5
6	6

FDA document numbers of all prior related submissions (regardless of outcome):

1 K992944	2	3	4	5	6
7	8	9	10	11	12

Data included in submission: Laboratory testing Animal trials Human trials

Section F Product Classification - Applicable to All Applications

Product code HSN	C.F.R. Section: 888.3120	Device class:	
Classification panel: ORTHOPEDIC		<input type="checkbox"/> Class I	<input checked="" type="checkbox"/> Class II
		<input type="checkbox"/> Class III	<input type="checkbox"/> Unclassified

Indications (from labeling):
 The **BUECHEL-PAPPAS™ Total Ankle Replacement System** is intended for the reconstruction of painful and/or severely disabled ankle joints resulting from osteoarthritis and rheumatoid arthritis

Note: Submission of this information does not affect the need to submit a 3891 or 2891a Device Establishment Registration form.	FDA Document Number:
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Section H Manufacturing / Packaging / Sterilization Sites

<input checked="" type="checkbox"/> Original <input type="checkbox"/> Add <input type="checkbox"/> Delete	FDA establishment registration number: 2280596	<input checked="" type="checkbox"/> Manufacturer <input type="checkbox"/> Contract manufacture	<input type="checkbox"/> Contract Sterilizer <input type="checkbox"/> Repackager/relab eler
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Company / Institution name:
 ENDOTEC, INC.

Division name (if applicable):	Phone number (include area code): (407) 822-0021
--------------------------------	--

Street address: 2546 Hansrob Road	Fax number (include area code): (407) 822-0154
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City: Orlando	State/Province: FL	Country: USA	Zip/Postal Code: 32804
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Contact name:
 Robert Riffle

Contact Title:
 Machining Shop Supervisor

<input type="checkbox"/> Original <input type="checkbox"/> Add <input type="checkbox"/> Delete	FDA establishment registration number: 2528981	<input type="checkbox"/> Manufacturer <input type="checkbox"/> Contract manufacture	<input checked="" type="checkbox"/> Contract Sterilizer <input type="checkbox"/> Repackager/relab eler
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Company / Institution name:
 MEDICAL MANUFACTURING CORPORATION

Division name (if applicable):			Phone number (include area code): (814) 899-4500	
Street address: 2205 EAST 33 RD STREET			Fax number (include area code): (814) 899-7089	
City: ERIE	State/Province: PA	Country: USA	Zip/Postal Code: 16510-2555	
Contact name: PAUL NIEMET				
Contact Title: SUPERVISOR MICROBIOLOGY LABORATORY				
<input checked="" type="checkbox"/> Original <input type="checkbox"/> Add <input type="checkbox"/> Delete	FDA establishment registration number: 1221051		<input type="checkbox"/> Manufacturer <input type="checkbox"/> Contract manufacture	<input type="checkbox"/> Contract Sterilizer <input checked="" type="checkbox"/> Repackager/relab eler
Company / Institution name: J-PAC CORP.				
Division name (if applicable):			Phone number (include area code): (603) 742-1581	
Street address: P.O. BOX 854			Fax number (include area code): (603) 749-0082	
City: DOVER	State/Province: NH	Country: USA	Zip/Postal Code: 03820	
Contact name: JIM NELSON				
Contact Title: MANAGER OF REGULATORY AFFAIRS				

III. Financial Disclosure Statements

Endotec does not believe the financial disclosure by clinical investigators is applicable in this reclassification petition for the following reasons:

- ❖ The retrospective collation of most of the clinical data from studies performed on commercially available devices does not meet the definition of a clinical trial.
- ❖ Well-controlled studies conducted by physicians presented in peer-reviewed publications overseas may not meet the criteria of a clinical trial.
- ❖ The subjects were patients treated during the physicians' normal course of practice, and were not research subjects.

IV. Introduction

It has been found from extensive clinical experience with ankle replacement on the part of users of the Buechel-Pappas Ankle Replacement that almost all pathology encountered where replacement is indicated is associated with the talar dome and its corresponding distal tibial articulating surface. The malleolar articulations are usually viable as are the ankle ligaments.

For such pathology it seems undesirable to remove any viable articulation and structure and desirable to retain them and their function. Further it is desirable to minimize bone loss associated with any procedure to implant a replacement. Thus a resurfacing device that replaces essentially only the degenerate superior surface of the talar dome and its corresponding distal tibial articulating surface seems most appropriate.

Further to provide sufficient load bearing capacity a congruent, mobile bearing is needed if the joint is to avoid overconstraint by providing needed motions such as axial rotation.

Endotec has tried, without success, to obtain clearance to make available its B-P Ankle through the use of the 510k exemptions. The FDA has designated this device as Class III based on its stability characteristics. They consider the device an unconstrained joint. The rejection of Endotec's 510k application and appeals arise from the interpretation of the definition of semi-constrained by the FDA. They do not consider the effect of the constraint of the natural surfaces retained by a device but consider only the mechanical constraints provided by the device.

Yet the device, after implantation, provides essentially natural stability. Further it achieves this stability without resort to unnecessary mechanical constraints. Such

constraints are well known to produce increased risks of component loosening. Thus the current interpretation of the classification definitions encourages the use of devices with unnecessary and undesirable constraints while preventing the general sale of devices without such undesirable features. The proposed reclassification would designate devices, which are anatomically semi-constrained as Class II.

Stability, although of great importance, is not the only criterion that needs to be considered in evaluating whether an ankle device is likely to be safe. Its ability to carry expected loads is also of critical importance. This is particularly true in the superior tibiotalar joint where loads are comparable to those in the hip and knee, while the articulating surface area is much less. Thus the proposed new classification description includes a requirement of articulating surface congruity with the mobility to allow needed axial rotation.

The current classification was developed more than twenty years ago based on evidence that devices that fit the mechanically semi-constrained criteria were safe and those that fit the non-constrained definition were not safe.¹ Since that time much new data has been generated. This data shows that the long-term success of those devices that were used to support the classification of semi-constrained devices as Class II is generally unsatisfactory.²⁻⁴ None of these devices are in general use today.

Further new mechanically unconstrained devices have been developed and extensively clinically used.^{5, 6} These devices are fundamentally different than the only unconstrained device cited in the classification action of more than twenty years ago.⁷ The results of studies on these new devices indicates that non-constrained devices which are congruent and which substantially retain normal stability are sufficiently safe and effective to be designated as Class II.⁸⁻¹⁶ Thus a new classification for ankles is needed.

Endotec will present clinical data that is, at least, as scientifically valid as the data used to support the current ankle classification criteria to demonstrate the safety and effectiveness of devices falling within this new classification description. Further it will show that such devices are, at least, as safe as commercial devices in current and past use.

V. Proposal of a Class II sub-type

1. Description of the purpose of ankle prosthesis

A total ankle replacement prosthesis (TAR) is an orthopaedic reconstructive device intended to replace the articulating surfaces of the talar dome and corresponding distal tibial articulation in patients with rheumatoid arthritis, osteoarthritis, post-trauma arthritis and avascular necrosis, provided that viable malleoli and ligaments are present.

Considering the current state of scientific knowledge and clinical experience with ankle joint replacement devices, Endotec proposes a *new generic sub-type* for ankle joint replacements in 21 CFR 888.3120.

2. Description of the ankle prosthesis

The name of this sub-type will be:

Ankle joint metal/polymer/metal anatomically semi-constrained, congruent, mobile bearing, porous-coated, uncemented prosthesis

A description of the new sub-type is as follows:

- ❖ A three part partial ankle joint metal/polymer/metal anatomically semi-constrained uncemented prosthesis for the replacement of the superior articulating surface of the talus with a metal talar component and the corresponding surface of the tibia with a metal tibial component, both with polished articular surfaces and sintered bead porous coating, falling within 21 CFR 888.3358 and ASTM F1147 on the fixation surfaces, and an intermediate, congruent, polymer bearing that under compressive loading limits only rotation in the frontal plane between the talar and tibial components and provides only rotation in the lateral plane between the bearing and the talar component by their respective articulating surfaces but where anterior-posterior and medial-lateral translation and axial rotation limitations of the tibia relative to the talus are provided by the natural malleolar articulations and the ankle ligaments and not by the prosthetic elements.

This device consists of tibial and talar components made of cobalt-chromium-molybdenum alloy or ceramic-coated titanium alloy and an ultra-high molecular weight polyethylene bearing. The tibial component is a flat plate that through its superior surface transfers loads from the ankle to the subcondral bone of the distal tibia. The tibial component has fixation augments, such as fins or pegs, on the superior surface of the plate to provide tipping resistance to off-center loads. The inferior surface of the tibial plate is polished and articulated with the superior, flat, surface of the intermediate, mobile bearing. Since both these articulating surfaces are flat they offer minimal, frictional, resistance to medial-lateral, anterior-posterior translation and axial rotation. Constraint against these motions is provided primarily by the malleolar articulations and ankle ligaments that must be present and viable to provide needed normal stability.

The talar component is an onlay whose superior articulating surface is a surface of revolution whose arc and radius of revolution is approximately equal to those of the lateral aspect of the natural superior talar surface that it is intended to replace. The generating curve of this surface is such that when held against the matching

bearing surface it provides essentially normal inversion-eversion stability and prevents the bearing from moving medially or laterally, or to axially rotate relative to the talar component. Under the action of compressive load on the implanted joint the bearing whose inferior surface is also a surface of revolution that matches and articulates with that of the talar component, The configurations of the articular surfaces are such that in the event of inversion or eversion of the talus relative to the tibia all prosthetic articulation contact remains congruent. The inferior surface of the talar component is likewise a surface of revolution whose shape approximates the shape of the talar bone under the natural articulating surface so that the talar component can be implanted with minimal removal of bone. This surface transfers talar loads to the tibia through the bearing and tibial plate to the distal tibia. The talar component also has short fixation augments such as fins or pegs to help resist tipping of the talar component under off-center loads. These fixation augments should be configured so as to produce minimal disruption of the inferior blood supply to the distal talus.

The planform of the bearing is similar, but somewhat smaller, in shape to the tibial component plate. The medial-lateral and anterior posterior dimensions of the bearing are smaller than those of the plate so as to provide the expected relative motion between the two to occur without the bearing overhanging the plate to avoid contact with adjacent tissue.

There are no interconnection mechanisms or linkages between components

The device is intended for patients with Rheumatoid Arthritis, Osteoarthritis, Post-trauma arthritis and avascular necrosis, provided that viable malleoli and ligaments are present.

VI. The Prototype, The Buechel-Pappas Ankle Replacement System

Description

1. Number of components

The Buechel-Pappas Total Ankle Replacement System^{5, 17} consists of three components, a tibial component, talar component, and an interlaying mobile bearing.

2. Description of each the components' physical properties

Summary

The tibial and talar components are available in six sizes, as shown in Appendix A, and are manufactured from Ti-6Al-4V titanium alloy castings per Endotec specification S-006, S-007 and S-008 with the bone/prosthesis interfaces covered with a sintered porous coating meeting 21 CFR 888.3358 and ASTM F1147 per Endotec specification S-010. The entire component surface covered with a ceramic titanium nitride (TiN) coating per Endotec specification S-011. All articulating surfaces are made according to Endotec specification S-013. The bearing insert is manufactured from ram extruded Hostalen GUR 1050 Ultra High Molecular Weight Polyethylene (UHMWPE) per Endotec specification S-017. Parts are cleaned Endotec specification S-024. The metal components are Gamma sterilized as per Endotec specification S-023 and the polymer component sterilized by ETO according to Endotec specification S-022 and packaged per Endotec specification S-021. All manufacturing specifications are given in Appendix B.

The tibial component

The tibial component consists of a flat plate with a short, integrally attached, tapered fixation stem on the superior face. The fixation stem and superior surface of the plate are porous coated. The inferior surface of the plate is polished.

The talar component

The primary talar component is an onlay where the articular surface is formed by revolving a common generating curve about a single radius. The common generating curve is composed of two convex curves with one, interlying convex curve or sulcus. The inferior surface of the component contains two integrally attached, short fixation fins. A porous coating is applied to these fins and the entire inferior interface of the prosthesis. This superior surface is then highly polished. In cases where talar erosion is significant, either in revision cases or patients normal pathology, an alternate, thick talar component is available.

The bearing component

The bearing is placed between these two components. The superior surface is flat and mates with the flat tibial component. The inferior bearing surface utilizes the same common generating curve as the talar component. Thus the bearing is fully congruent on both articulating surfaces. The bearings are available in six sizes to match the talar component. Each size bearing is available in with a minimum thickness of 3, 5, 7, 9, and 11mm.

3. Functional description of each component

The tibial/ talar component

The tibial component's inferior surface or load plate geometry tapers posteriorly to mimic the natural tibial geometry. The talar component "resurfaces" the dome of the talus. The thick talar component is to be used where there is insufficient talar bone stock to provide an adequate base for support of the onlay type talar component.

The bearing component

This design allows the loading surfaces to be congruent throughout all ranges of motion. When properly installed, the bearing resists medial/lateral dislocation by engaging the deep sulcus of the talar component. This congruency will lower the contact stress while allowing for rotational and translational motions. Total ankle replacements have been plagued by torsional loosening of the components due to the ankles "corkscrew" type motion patterns. By allowing the bearing to "float" between the two components, the only torsional loads transmitted to the prosthesis are through friction that is minimal.

4. Description of interconnection mechanism between components

There are no interconnection mechanisms or linkages between components.

5. Manner of device fixation

The fixation is cementless using biological means. The fixation surfaces are three-layer commercially pure titanium (CPTi) sintered bead porous coating on a titanium alloy substrate. The sintered porous coating beads have a 350-micron pore size and a porosity of 35%. The coating is substantially equivalent to that used on other orthopedic implants sold by Endotec (i.e. Buechel - Pappas Resurfacing Hip K904870, Buechel-Pappas Extended Collar Stem K904870 and Buechel-Pappas Femoral Head K892059).

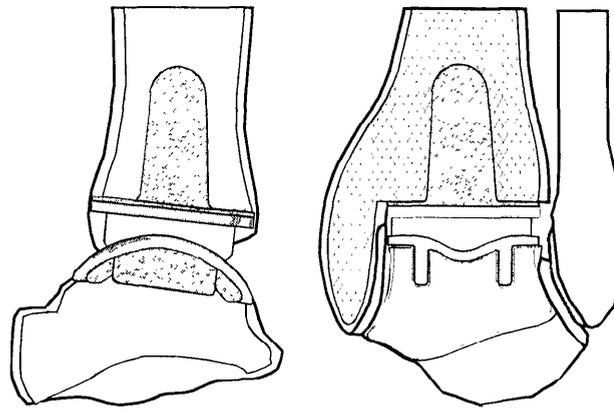


Fig.1 The B-P ankle fixation geometry

The dual fin fixation (See Fig. 1.) of the talar component is for the purpose of obtaining fixation on both sides of the talus so as to eliminate the resorption, and associated talar component tilt, encountered in the earlier single fin design. In addition, the dual fin fixation minimizes disruption of the talar blood supply produced by the single, central fin. The short fixation peg of the tibial component is designed to help resist tilting forces on the talus resulting from off-center loads.

6. Kinematic properties of the device

The kinematic and stability properties of the implanted B-P ankle replacement are illustrated in Fig. 2.

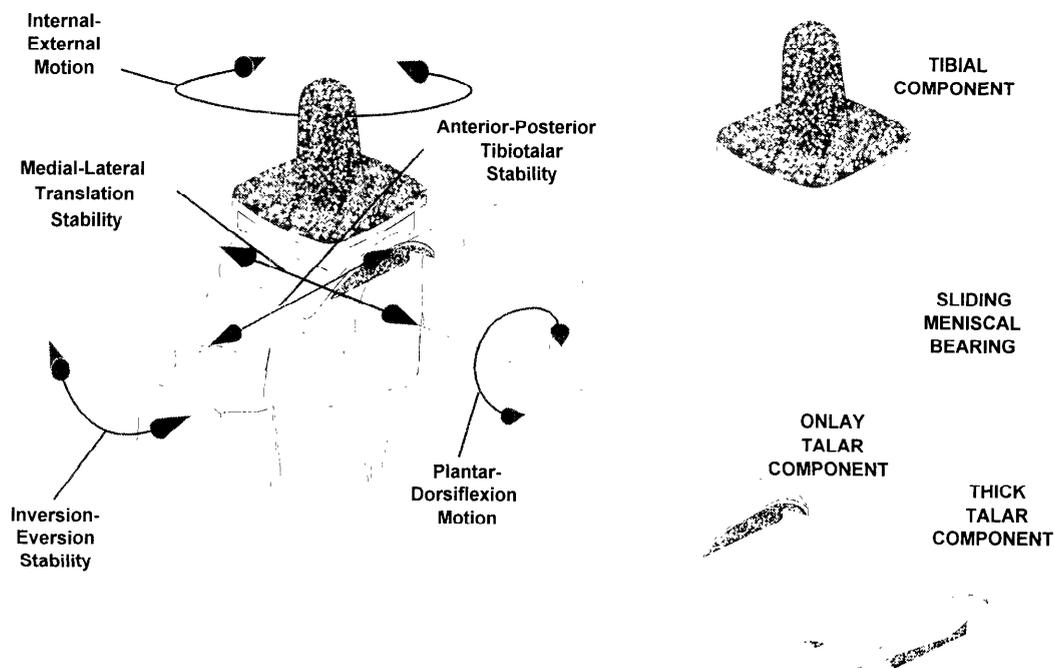


Fig. 2 The components and ankle motions of the B-P Total Ankle Replacement System

Medial-Lateral stability is primarily provided by the natural malleoli only. The ankle ligaments provide anterior-posterior tibiotalar stability although

the posterior inclination of the talar component plate provides some resistance to posterior shearing forces on the talus. The implanted device provides normal inversion-eversion stability.

The device allows plantar-dorsi flexion within normal limits. Axial rotation and translation are limited only by the action of the natural malleoli and ligaments. Komistek et al ⁸ show that the stability and axial rotational properties of this device are essentially normal.

7. Surgical procedure and Instrumentation

The surgical procedure and instruments used are described in Appendix C.

VII. Historical Background

1. Early Problems with ankle replacement

Early experimentation with ankle replacement was unsuccessful leading largely to the abandonment of ankle development and use.^{9, 10, 18} The primary problems with the early designs (1970-1980) included:

- ❖ EXCESSIVE WEAR
- ❖ EXCESSIVE CONSTRAINT
- ❖ LACK OF STABILITY

These problems produced clinical loosening, pain and loss of function leading to the failure of almost all the early designs.

2. Evolution of the Prototype, B - P Total Ankle Replacement System

The first ankle developed by Buechel-Pappas was a cylindrical design with congruent articulating surfaces, first implanted in 1974 (Fig. 3).¹⁹

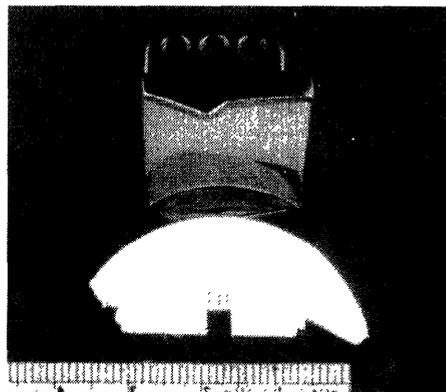


Fig. 3 Cylindrical Ankle Replacement

The cylindrical design failed due to its inability to provide needed axial rotation.^{10, 17} Although axial rotation in the ankle is small; failure to

accommodate even this small motion produces excessive fixation torque leading to loosening of both the tibial and talar components. In other words, the device's main failure was a result of excessive constraint. Curiously, this device under the current FDA classifications could be legally marketed today as a class II device. Yet as far back as 1976, Drs Buechel and Pappas were convinced that this over-constraint would lead to serious safety and effectiveness concerns.

Shortly thereafter, a design with a spherical articulating surface was developed and implanted in 1975 (Fig. 4).¹⁷ The spherical design provides needed axial rotation but is inferior to the natural ankle in inversion-eversion stability since the pivot is at the center of the sphere and thus the ligament lever arm is much shorter than normal, as shown in Fig. 6. This lack of stability produces loss of function and pain leading to failure.

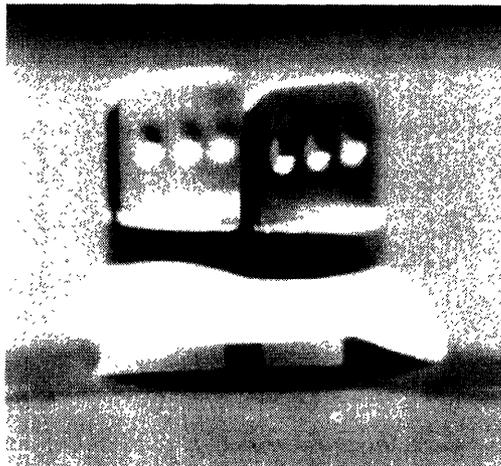


Fig. 4 Spherical Ankle Replacement

Fig. 5 The Trunion Ankle Replacement

These problems and the need to have congruent articulating contact lead to the development of a "Trunion" ankle replacement, first implanted in 1976 (Fig. 5).¹⁷ The rotating trunion device allowed axial rotation with congruity. It worked well clinically.

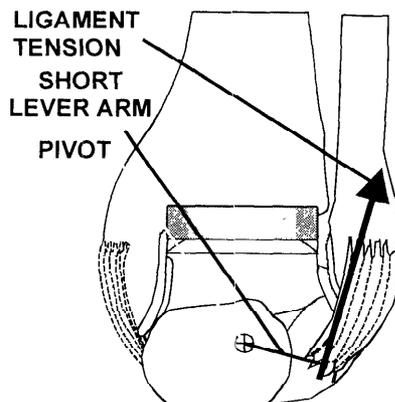


Fig. 6 Poor spherical Joint I-E Stability

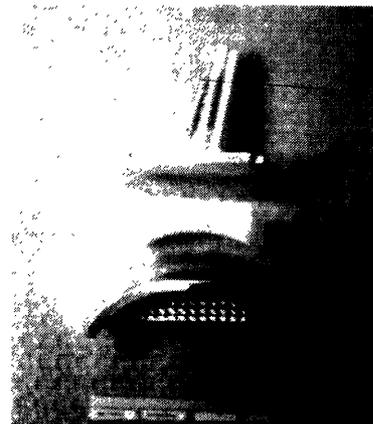


Fig. 7 Mark 1 Meniscal Bearing Ankle Replacement

It was later determined that eliminating the intrinsic A-P constraint would provide a more mobile joint without substantially compromising A-P stability. It was thought that it would be better to allow the natural structures to provide the stability, instead of constraining them through a prosthetic articular surface. This concept led to the development of the Mark I Meniscal Bearing ankle replacement (Fig. 7).^{10, 17, 20}

Early results with this design were quite encouraging. A late problem of talar component subsidence with tilting and associated bearing extrusion, however, developed. This problem is illustrated in Fig. 8.

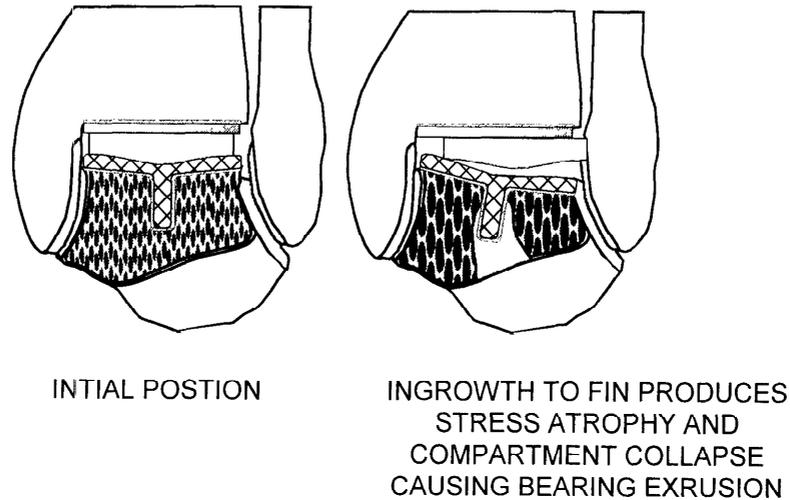


Fig. 8 Failure of Mode of the Mark I

The problem was solved by a Mark II device that uses two fixation fins on the talar component, rather than the single, longer fin of the Mark I. This dual fin arrangement reduces the tendency of a fin to transfer load distally, thus reducing stress protection. Further it eliminates disruption of the talar blood supply, reducing talar necrosis. The sulcus of the Mark II is also made deeper to better resist the effect of any tilting that may occur. The differences between the Mark I, and II are shown in Fig. 9.

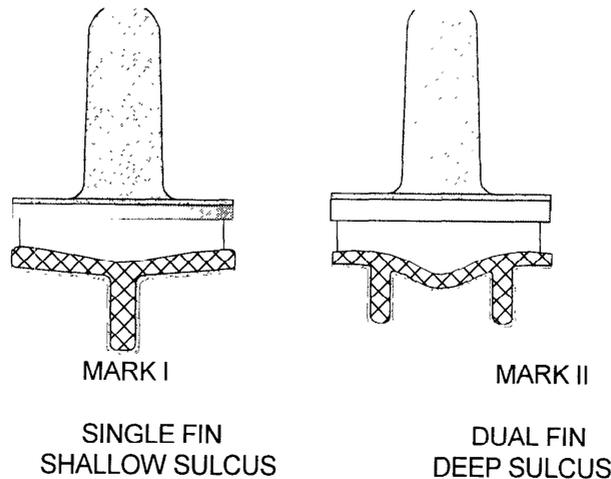


Fig. 9 Differences between the Mark I and Mark II

Further Finite Element analysis of the Mark I disclosed a weakness in the tibial component plate and thus the plate was made thicker on the Mark II.

The Mark II device is shown in Fig. 10.

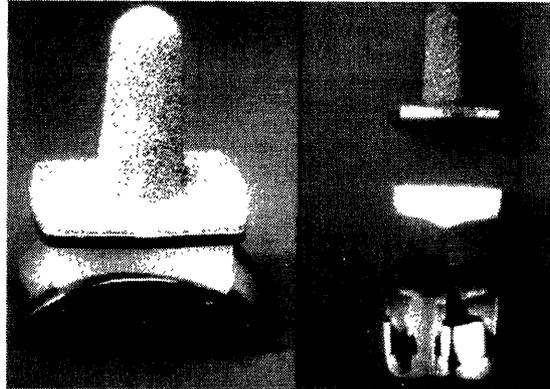


Fig. 10 The Mark II B-P Ankle Replacement

The Mark II B-P Ankle Replacement was developed in 1989. By this time Buechel-Pappas had also developed a ceramic coating, which greatly improved wear resistance and enhanced biocompatibility²¹.

VIII. Current Classification

1. 21 CFR Classification (Current and Proposed)

Endotec provides the current CFR Identification and Classification for Ankle joint metal/polymer non-constrained prostheses (888.3120) and proposes the following sub-type:

Current:

888.3120 Ankle joint metal/polymer non-constrained cemented prosthesis

(a) *Identification.* An ankle joint metal/polymer non-constrained cemented prosthesis is a device intended to be implanted to replace an ankle joint. The device limits minimally (less than normal anatomic constraints) translation in one or more planes. It has no linkage across-the-joint. This generic type of device includes prostheses that have tibial components made of alloys, such as cobalt-chromium-molybdenum, and a talar component made of ultra-high molecular weight polyethylene, and is limited to those prostheses intended for use with bone cement.

Classification: Class II

Proposed:

888.3120 Ankle joint metal/polymer/metal anatomically semi-constrained, congruent, mobile bearing, porous-coated, uncemented prosthesis

(a) *Identification.* A three-part partial ankle joint metal/polymer/metal anatomically semi-constrained uncemented prosthesis is a device intended to be implanted for the surface replacement of the superior articulating surface of the talus and the corresponding surface of the tibia. This generic type of device includes prostheses that have a metal tibial component, a metal talar component with polished articular surfaces and sintered bead porous coating, falling within 21 CFR 888.3358 and ASTM F1147 on the fixation surfaces and an intermediate, congruent, ultra-high molecular weight polyethylene bearing. The device has no linkage across-the-joint. The device under compressive loading, limits only rotation in the frontal plane between the talar and tibial components and provides only rotation in the lateral plane between the bearing and the talar component by their respective articulating surfaces but where anterior-posterior and medial-lateral translation and axial rotation limitations of the tibia relative to the talus are provided by the natural malleolar articulations and the ankle ligaments and not by the prosthetic elements.

Classification: Class II (Special Controls)

2. The Basis for Disagreement with the Current Classification

The current FDA classification system of 888.3110 and 888.3120 for ankle devices is deficient and antiquated. It was developed more than twenty years ago based on relatively short-term clinical trial data which later experience has shown, ^{2,4} presented an overly optimistic picture of the performance of the designs used to justify the classification criteria.

Drs Buechel and Pappas describe the state of the art in ankle replacement more than twenty-five years ago in a talk given before the ninth annual meeting of the Foot and Ankle society.⁹ They conclude that ankle replacements of the period are unsatisfactory. Not much has changed as can be seen from the recent surveys of Buechel ¹⁰ and Nuefeld and Lee ¹⁸, which draw essentially the same conclusion for most designs. The exception is mobile bearing ankles that were introduced in 1978.

The FDA based its current classification rationale primarily on the relatively early results of the clinical performance of the Oregon, UCI, and Beck-Stefee (Conaxial) devices as described in the Federal Register Vol. 47, No. 128 Friday, July 2, 1982, p 29070, Section 888.3110.¹ Later clinical studies, however, demonstrate that these early results presented an overly optimistic picture of the expected clinical performance of these devices. Wynn and Wilde conclude that the Conaxial ankle should not be used ². Groth and Fitch draw a similar conclusion for the Oregon ankle ³. Kitoaka et al ⁴ show that the early optimism for the Mayo ankle mentioned in the 888.3110 is unwarranted ⁴. Tables I and II of Ref. 18 provide an excellent comparison of the early promising results on which the current classification is based with the later disastrous results.

The orthopaedic community has now abandoned all of these early designs. Most of these early devices that fell within 888.3110 were over

constrained. Raikin et al²² and Matejczyk and Greenwald et al²³ discuss the problems of over constraint. The classification of ankle devices based on 888.3110 and 888.3120, particularly as interpreted by the FDA, accept and encourage over constraint. Thus, the criteria of 888.3110 have failed. They have been shown not to produce reasonably safe devices.

Both 888.3110 and 888.3120 have several additional major deficiencies. They are not definitive. Since a device can limit motion in one plane and not another it is possible for such a device to fall within both 888.3110 and 888.8120.

The FDA interpretation of these definitions has accepted and encouraged the use of over constrained devices. The current FDA rationale requires the use of unnecessary mechanical constraints where viable natural constraints are present if the ankle device is to be defined as Class III. It is preferable, however, to use natural, rather than mechanical structures to provide needed function since such use reduces risk associated with loosening and wear without sacrificing the functional characteristics of the joint after prosthetic replacement. The maintenance of joint stability is important. Where possible, however, such stability should be provided by the natural structures where they are available and not mechanically. There is no logical or scientific basis to believe that unneeded mechanical constraints significantly reduce risk. Just the opposite is true and is demonstrated by the clinical results cited here. Thus the interpretation of 888.3110 that retained anatomical structures providing needed constraint should not be considered is fundamentally flawed. The classification criteria for Class II should define the device so that it provides essentially normal stability after implantation rather than define its stability when held in one's hands.

Further, the current classification criteria allow unnatural rotation in the frontal plane, which produces less than normal inversion-eversion stability increasing risk of ankle ligament injuries. Pappas M.J. discusses this issue in Ref. 24.

The current classification also allows the use of incongruent articulations, which unnecessarily increases risk associated with wear. Bartel et al²⁵ in their papers on surface damage and conformity, discuss the issue of the load bearing capacity of plastic and metal joint articulations. Refs. 5, 10 and 20 discuss the implications of the inadequacy of incongruent contact in ankle devices. All ankle and knee articulations that Endotec, or any one who has published their results, have examined show that contact stresses in incongruent ankle replacements is expected to be excessive. Excessive contact stresses are typical in incongruent knees²⁶. Given the fact that the loading in the ankle is at least equal to the knee coupled by the ankle contact area being much smaller, one would expect the situation in ankle devices to be worse. We know of no credible evidence that incongruent ankle contact stresses are not excessive. As a result, the device type that we request reclassification for must be congruent.

Wynn et al ², Groth and Fitch ³, Kofoed ²⁷, and Buechel and Pappas ⁵ demonstrate that even congruent ankle devices that have unnecessary constraint have a high loosening and wear risk associated with them. Thus, the device type that Endotec requests reclassification for must also allow the natural retained structures to function where they are present and viable thus eliminating or reducing undesirable and unneeded loading of the fixation–bone interfaces and thus reducing risks associated with loosening.

The current classification definitions, or special controls, ignore the issue of adequate fixation. Clinical experience has shown that proper fixation is an important element of risk management. Buechel et al ⁵ and Keblish et al ²⁸ demonstrate that fixation is an important element in clinical success. These studies show that unexpected fixation problems that may not develop in relatively short-term clinical use can significantly degrade device performance. Thus it seems proper to include fixation elements as well as constraint elements in evaluation criterion. For example, if the fixation criteria were not included in the definition the predecessor device of Ref. 20 the LCS NJ ankle, would be Class II and could be granted 510(k) status. This early design is, however, not as safe as its successor, the B-P ankle, and thus should not be used ⁵.

IX. Regulatory History

1. Regulatory History of the ankle joint metal/polymer non-constrained prosthesis

On Friday, July 2, 1982, in the Federal Register, Vol. 47, No. 128, the FDA published the proposed Rules for 888,3120: Docket No 78N-3061: Ankle joint metal/polymer non-constrained prosthesis.¹ The FDA agreed with the Orthopedic Device Classification Panel's recommendations that found there was insufficient scientific evidence to support a Class II designation. The only device that fit this generic type, the Newton, had 50 devices implanted with 20 reported failures (40%).⁷ Thus, the FDA concluded that 888.3120 should remain Class III.

- ❖ The panel recommended that the premarket approval of this device be a high priority.
- ❖ Summary of reasons for the recommendation of Class III:
 - (a) These devices are implanted and intended to be used in relieving disabling pain and in restoring or minimizing further loss of functional use of a joint or limb. The panel believed that these uses are of substantial importance in preventing impairment of human health.
 - (b) The panel believed that general controls alone would not provide sufficient control over these characteristics. The panel also believed that it is not possible to establish an

adequate performance standard for the device. The panel has found that insufficient information exists to support the conclusion that general controls of performance standards will be adequate to provide reasonable assurance of the safety and effectiveness of the device. Therefore, the device must be subject to premarket approval to assure safety and effectiveness.

- ❖ The panel based its recommendation on the Panel Members' *personal knowledge* of the device and on the available medical literature.
- ❖ Risks to health included:
 - (a) Loss or reduction of Joint function: Improper design or inadequate mechanical properties of the device such as, its lack of strength and resistance to wear, may result in a loss or reduction of joint function due to excessive wear, fracture, deformation of the device, or loosening of the device from the surgical cavity;
 - (b) Adverse tissue reaction: Inadequate biological or mechanical properties of the device, such as its lack of biocompatibility and resistance to wear may result in an adverse tissue reaction due to dissolution or wearing away of the surfaces of the device and the release of materials from the device into the surrounding tissues and systemic circulation;
 - (c) Infection: The presence of the prosthesis within the body may lead to an increased risk of infection;
- ❖ The FDA agreed with the panel that the uses for the device described above are of substantial importance in preventing impairment to human health. The FDA believes that insufficient clinical experience exists to fully establish the persons for whose benefit the devices are intended and the pre-conditions of use. The agency believed that the probable benefit to health for use of the devices does not compare favorably with the likelihood of illness or injury resulting from their use.

This decision was based on the only clinical study available, which was performed by S.E. Newton.⁷ This ankle joint metal/polymer non-constrained prosthesis had a 40% (20 of a 50 patient population) failure rate. This fact convinced the FDA that "insufficient information exists to support the conclusion that general controls or performance standards will provide reasonable assurance of the safety and effectiveness of these devices".

This statement is a fair one. The Newton prosthesis under mechanical scrutiny was found wanting. The maximum load that

could be applied to the prosthesis was 262 N (59 lbs). This is substantially below the loads exerted in normal activity. During level walking, a man weighing 700 N (157 lbs) would produce a joint load of about 1,050 N (236 lbs) and as much as 2,800 N (629 lbs) in stair ascent. Furthermore, its stability characteristics in inversion-eversion were insufficient, and led to a relatively high incidence of ankle sprains. Thus, its failure rate can be explained by incongruent contact resulting in excessive wear, deformation and poor stability as a result of normal activity. However, the FDA statement in concurrence with 'The Orthopedic Classification Panel' was made in 1982. It is now 2004, and all these issues have been addressed by the proposed generic type (See 'XII. Control of Risks: 3. Primary Safety Considerations).

On September 27, 1996, the Federal Register, Vol. 61, No. 189, called for PMAs or PDPs (by December 26, 1996) for any non-constrained ankle joints in commercial distribution prior to May 28, 1976 or that was determined substantially equivalent after May 28, 1976. After December 28, 1996 all other ankle joints, metal/polymer non-constrained cemented, will have an approved PMA or a declared completed PDP in effect prior to commercial distribution.

On August 31, 1999 a 510 (k) was submitted for the Buechel-Pappas Total Ankle. It was found to be NSE on October 19, 1999. From that date until December 1, 2000 Endotec attempted in vain, to persuade the FDA to change its mind, but to no avail.

It is now felt that the subsequent three-piece construction, uncemented device has developed sufficient scientific evidence to merit a Class II designation. Thus, it is proposed that a sub-generic device, ankle joint metal/polymer/metal anatomically semi-constrained, congruent, mobile bearing, porous-coated, uncemented prosthesis, be added to 888.3120 and on the weight of its evidence be shown to be Class II.

2. 510 (k) Submission and subsequent correspondence

Date	
8/31/99	Endotec submitted a 510(k) notification for the Buechel-Pappas Total Ankle Replacement System. It was acknowledged on 9/1/99 and given number K992944.
9/21/00	An ODE reviewer in her substantive review queries the differing technology of the flat, secondary articulating, mating surface of inferior tibial component and the superior surface of the underlying bearing, whether there are any significant new risks. She spoke with Dr Pappas twice. An Endotec representative spoke with her and she mentioned no dissatisfaction with Dr Pappas' explanation that the differing technology was not a significant risk. At that point, our expectation was that it would be approved, since phone calls usually involve minor deficiencies; or at worst, we would receive a letter requesting additional information.
10/19/99	Endotec received an NSE letter from an ODE representative for the director. He rejected K992944 on grounds that they considered our device to be a non-constrained device because of the flat mating surfaces, and therefore it was a new class III ankle device [Section 513 (f) of the Federal Food, Drug, and Cosmetic Act].
10/25/99	Endotec replied changing the indications to include only those patients with sufficient malleoli and ligaments. "When used as herein indicated, with these normal anatomic constraints in place and functioning, the B-P Ankle Replacement is clearly a semi-constrained ankle joint as defined by the regulations, 21 CFR 888.6, and 21 CFR 888.3110." This is a crucial concession that was, unfortunately, totally ignored by the DGRND.
10/28/99	In a supplemental letter, Endotec explained that the device did not meet the definition of a non-constrained ankle device. "It is not a replacement of the entire ankle articulations. Thus a comparison of the B-P ankle with regard to constraint must be against that portion of the ankle that it replaces rather than against the entire ankle articulations."
11/17/99	The second NSE letter from the Acting Director of the Division of General and Restorative Devices (DGRND), refers only to our letter of 10/28/99. He states that we do meet the definition of 888.3120 because the characteristics of our device met the "scenario"...as described within 21 CFR 888.3120. " He dismisses all the other information contained in the two letters by stating the original decision of 10/19/00 still stood.
11/29/99	Endotec's reply gave a long and detailed explanation of how the device does not fit 888.3120, the bulk of which is incorporated into Dr Pappas' Statement of 9/22/00 and 10/2/00.
12/10/99	In the third and final NSE letter, The ODE Representative clearly states that the B-P Ankle device most definitely meets the definition of 888.3120. He repeats again, without any explanation, that the original NSE still stood. He suggested we appeal to the director if we wished.
12/20/99	Endotec appealed to the director for an Internal Review of the NSE decision (which includes a letter to the former Director of the ODE, dated 12/1/99, but she had moved to another assignment). " We submit that the Non-SE decision should be changed not only because we meet the definition of 'semi-constrained' and do not fit a reasonable definition of 'non-constrained', but because we significantly reduce risk." Endotec went on to say, " Frankly, we are puzzled. We have offered scientifically based reasons why Endotec believes that this device should be considered a semi-constrained device, why it better fits the definition contained in 21 CFR 888.3110. The ODE

	representative in his three letters did not even attempt to answer any of the points we put to him. He offered no explanation, no scientifically based reasons why our device demonstrates constraints that are less than the normal anatomical constraints of the surface that it replaces." Endotec closed by requesting a meeting.
1/20/00	Endotec filed a formal petition for a 'de novo' reclassification per 513 (f)(2).
1/24/00	The petition was acknowledged.
2/8/00	Since the decision stated that the device was considered a 'new' non-constrained device, and it seemed that the Internal Review appeal might take a very long time to resolve, Endotec wrote to the 'Orthopedics and Rehabilitation Devices Panel of the Medical Devices Advisory Committee' to petition for a reclassification of Class III ankle devices.
3/7/00	Endotec queried for the status of the Internal Review.
3/21/00	An ODE representative rejects the petition for reclassification under his authority to rule on 'de novo' Class III exemptions in his letter, determining that because we <u>DID</u> meet the definition contained in 888.3110, which he quotes in full. He, however mistakenly refers to the definition to 888.3120, and therefore the device is considered to be an 'old' device.
3/24/00	Endotec replied, "After careful review and analysis, our petition for evaluation under automatic Class III designation the Buechel-Pappas Total Ankle Replacement System K992944, has been rejected because our device fit the definition '...a device intended to be implanted to replace an ankle joint. 'and that our device, '...limits translation and rotation in one or more planes via the geometry of its articulating surfaces and has no linkage across-the-joint.'" "We are in the fullest agreement with this determination. This is precisely what we have been arguing all along with the ODE. However, the number of the generic ankle devices that this definition describes is not 21 CFR 888.3120 but 21 CFR 888.3110, and therefore the classification is mistaken, and should be Class II."
4/3/00	The ODE representative replies to our Internal Review request for K992944 in which he states, "...you have not demonstrated that your device has sufficient intrinsic constraint (i.e., without the support of soft tissues) to meet the definition of a semi-constrained device." (This is 888.6, and not 888.3110.) Further he denies our request for a meeting saying, "I did not feel that in this case a meeting would help to resolve the scientific dispute over the non-constrained decision." As they had never offered any scientific evidence to refute our case or to substantiate theirs, Endotec did not know that there was a scientific dispute.
4/4/00	As a result of the ODE representative's refusal to meet with us, and his decision concerning our petition for a 'de novo' reclassification of the B-P Ankle device, an Endotec representative e-mailed The Director of the CDRH protesting the decisions of the ODE and the manner in which Endotec was treated.
4/6/00	An ODE representative replies to our letter of 3/24/00 (13 above) that he meant we <u>do</u> fit 888.3120; therefore the B-P Ankle device is not a 'new' device. The FDA position can be surmised as is: 510(k) approval is refused because the device is a 'new' device (10/19/99), and 'de novo' reclassification is refused because the device is an ' <u>old</u> ' device (3/21/00). In his decision on our Internal Review (4/3/00), he agrees with the original finding that the device is a 'new' device in the second paragraph, and in his last paragraph reiterates his finding on 'de novo' reclassification that the device is an 'old' device.
4/17/00	Endotec sent a letter of appeal to the CDRH Ombudsman, outlining the unfair treatment by the ODE, thwarted at every turn, and how mobile bearing devices, especially ones like the B-P Ankle device were sorely needed for the public well-

	being.
7/14/00	The meeting with FDA was set for 7/25/00. Endotec was asked to set the agenda. Endotec's letters proposed, the mobile bearing ankle (K992944), and mobile bearing devices in general. Dr Pappas also wrote a letter explaining the origin and evolution of mobile bearing devices, and why such devices were needed and safe. Despite two weeks advance notification, they came prepared to discuss only Rotating Bearing Ankle, K000436. Endotec was grateful that they reversed their arbitrary withdrawal of K000436 and <u>deletion from their records</u> , and reinstated it at the meeting on 7/25/00, allowing 30 days from that date to respond to deficiencies.
7/27/00	Endotec submitted the additional information on K000436, and that device is currently being reviewed. Also, letters were sent to the Director of the CDRH, and the CDRH Ombudsman, to report on the meeting of 7/25/00. It was felt that the primary error was that the definition of 21 CFR 888.3110, which is the generic type for Class II ankle devices, was never directly applied. Could the device or could the device not meet that definition of semi-constrained. This is still the issue.
10/4/00	Endotec had a further meeting with the Director of the CDRH and others concerned with the device. After the meeting Endotec presented the Statement of Dr. Pappas and a letter addressed to The Director and to the ombudsman.
12/1/00	We received the rejection by The Director of the CDRH, which admits that we do inhibit translation and rotation in the frontal plane. We have "...one semi-constrained articulation....".
12/7/01	We replied to this rejection.
1/17/01	We submitted the reclassification document.
2/2/01	The Director of the CDRH said he was aware of our reclassification and would aid us in it.
3/21/01	Dr. Pappas asked what the delay was.
3/31/01	Letter written to Dr Feigal asking for update on status of petition.
5/21/01	We received an answer to our reclassification effort of 1/17/00. The FDA determined the reclassification petition to be "administratively incomplete" and therefore requested additional information.
6/25/01	A teleconference between Endotec and the FDA was scheduled for 6/28/01.
6/28/01	A teleconference was held between representatives of Endotec and the FDA. The FDA cited the main issue where the reclassification petition was deficient. This being, Endotec's failure in presenting a generic-type for reclassification. As of now, Endotec is compiling a reply to the FDA letter dated May 21 2001, with this in mind.
9/3/01	Amended Reclassification petition submitted as per requirements stated in last letter from FDA.
2/14/02	Received AIP Letter, thus suspending review of all submittals to and at the FDA.
3/06/02	Responded and appealed the applying of the AIP.
3/26/02	Amended Reclassification petition submitted as per requirements stated in last letter from FDA.
12/20/02	Submitted CAP to FDA to resolve AIP.

6/14/03	Re-submitted CAP to FDA to resolve AIP.
7/17/03	Re-submitted CAP to FDA to resolve AIP.
9/16/03	Received phone call from the FDA Ombudsman office from Laurie Lenkel
10/08/03	Submitted Citizens' petition. Faxed cover letter and Sections 10:30 c and e to Jenny Butler.
3/19/04	Spoke to Ms Lenkel, she assured me that they are working on the petition and that we will get a response soon
4/27/04	Spoke to Laurie Lenkel, she informed me that the final response is in its last stages and should be sent in the next few weeks.
6/9/04	Spoke to Laurie Lenkel and she informed me that she has seen in the form of emails and memos, a high level of activity on the appeal and is very optimistic that this issue will be resolved soon. However, she was reluctant to give me a date of resolution
9/13/04	Teleconference held between Dr Pappas and FDA, regarding the filing of the Reclassification petition.
9/27/04	Received letter from the FDA regarding promise to file petition but the need for additional information would be needed for further review.
10/13/04	Received letter from the FDA confirming that the Reclassification Petition for the Buechel-Pappas Ankle Prosthesis was filed and assigned docket number 2004P-0457/CCP 1.

3. IDE Clinical Investigation

The investigational study received official approval in October 1998. To date a total of one hundred and twenty-three ankle systems (or 369 components) have been implanted. An interim report is given in Ref 11.

The study's findings to date have shown the prosthesis to be safe and effective and beneficial to the patient. In most cases, it has provided a relief from constant pain and the restoration of quality of life (See 'XIV. Summary of clinical findings': 5. B-P Total Ankle System (Deep Sulcus).

There have been no mechanical failures. Three prostheses were removed as a result of infection. Two were removed as a result of persistent pain. None were removed due to design. (See 'XIV. Summary of clinical findings': 5. B-P Total Ankle System (Deep Sulcus).

X. Control of Risks

Endotec recognizes the potential risks associated with total ankle replacement and has presented controls under the following sub-headings:

- ❖ Regulatory control of risks
- ❖ Potential Risks (With reference to the risks identified by the Orthopedic Device Classification panel)
- ❖ Primary safety considerations addressing a subset of risks

1. Regulatory control of risks

Endotec proposes the following regulatory control of risks. Device risks can be controlled through material standards. Patient and Surgical risks can be reduced through device labeling and device quality through GMP. The FDA has authority through the 510(k) process, as well as its general authority over misbranding and adulteration to impose controls regarding these areas. Additionally, guidance documents are utilized to provide specific provisions regarding materials, testing and labeling. Endotec acknowledges the following potential risks and the means to control or minimize them and has identified the following:

Identified potential risks	Means to control / minimize risks
Infection	510(k) Requirement – Sterility Adulteration Authority – GMP Sterility Misbranding Authority – Labeling Indications / Contraindications / Warnings / Precautions
Component Loosening	510 (k) Requirement – SE Design Misbranding Authority – Labeling Precautions / Warnings
Revision of Components Dislocation / Subluxation of Ankle prosthesis	510 (k) Requirement – SE Design 510 (k) Requirement – Pre-Clinical Testing 510 (k) Requirement – Conformance to Material Standards Misbranding Authority – Labeling Precautions / Warnings
Implant Failure / Fracture / Wear Osteolysis Sensitivity to Implant Materials	510 (k) Requirement – SE Design 510 (k) Requirement – Conformance to Material Standards 510 (k) Requirement – Pre-Clinical Testing Adulteration Authority – GMP Manufacturing and Design
Nerve impingement / damage Pain Vascular Disorders Pulmonary Embolism	Misbranding Authority – Labeling Precautions / Warnings

Please Note: *Bolded / Italics* items include special controls

In addition to the above listed items, Endotec identified 8 standards from the American Society for Testing and Materials (ASTM) and 6 FDA guidance documents as specific special controls to reasonably assure the safety and effectiveness of the ankle joint metal/polymer/metal anatomically semi-constrained congruent mobile bearing prosthesis.

ASTM Standards

- ❖ ASTM F67 Standard Specification for Unalloyed Titanium for Surgical Implant Applications;
- ❖ ASTM F75 Standard Specification for Cast Cobalt-Chromium-Molybdenum Alloy for Surgical Implant Applications;
- ❖ ASTM F136 Standard Specification for Wrought Titanium-6 Aluminium-4 Vanadium ELI (Extra Low Interstitial) Alloy for Surgical Implants Applications;
- ❖ ASTM F565 Practice for the Case and Handling of Orthopedic Implants and Instruments
- ❖ ASTM F648 Standard Specification for Ultra-High-Molecular-Weight Polyethylene Powder and Fabricated Form for Surgical Implants;
- ❖ ASTM F1044 Standard Test Method for Shear Testing of Porous Metal Coatings;
- ❖ ASTM F1108 Standard Specification for Titanium-6 Aluminium-4 Vanadium Alloy Castings for Surgical Implants;

- ❖ ASTM F1147 Standard Test Method for Tension Testing of Porous Metal Coatings;
- ❖ ASTM F1377 Standard Specification for Cobalt-28 Chromium-6 Molybdenum Powder for Coating of Orthopedic Implants;
- ❖ ASTM F1580 Standard Specification for Titanium and Titanium-6% Aluminum-4% Vanadium Alloy Powders for Coating of Surgical Implants;

FDA Guidance Documents

- ❖ Guidance Document for Testing Orthopedic Implants with Modified Metallic Surfaces apposing Bone or Bone Cement
- ❖ Draft Guidance Document for the Preparation of Premarket Notification 510(k) Applications for Orthopedic Devices – The Basic Elements;
- ❖ Data Requirements for Ultra-High-Molecular-Weight Polyethylene (UHMWPE) Used in Orthopedic Devices;
- ❖ Use of International Standard ISO – 10993, Biological Evaluation of the Medical Devices Part I: Evaluation and Testing
- ❖ 510(k) Sterility Review Guidance and Revisions of 11/18/94 and ORDB 7/3/97 (K90-1)
- ❖ EN46001 Quality Systems Medical Devices

2. Potential Risks

As in any surgical procedure, there are risks involved in total joint replacement in general. Complications that may develop include: early or late infection that may result in device removal and joint fusion, blood vessels and nerves may be damaged, bones may be fractured during the procedure, the device may loosen or break, allergic reactions to the metallic components may occur, phlebitis may develop and cause possible lung problems, long term swelling may occur, and there may be delayed wound healing. Wear products may produce osteolysis with associated component migration and loosening. Some complications may cause prolonged illness, a draining wound, a need for blood transfusions, a need for further major surgery, and/or permanent pain, deformity, and inconvenience. Very rarely some complications may be fatal. These possible complications are not unique to the proposed generic-type ankle replacement system, and may occur with any total joint replacement operation. Therefore, the risks resulting from direct use of this implant will be analyzed here with particular relevance to all of the risks stated by 'The Orthopedic Device Classification Panel'. A further discussion on how reductions are made is also provided. (*For incidence rates see 'XIV. Summary of Clinical Findings: Sections 4-5'*)

❖ Biological hazards

1. Bio-incompatibility of the materials used
May cause the following
 - a. Destruction of bone and surrounding tissues
 - b. Rejection of implant
 - c. Allergic reactions to materials
2. Toxicity of the materials
May cause similar to the above
3. Infection due to implant sterility or lack of it
May cause the following
 - a. Bone destruction
 - b. Device loosening
 - c. Skin healing problems
4. Degradation of the materials
May cause the following
 - a. Limit expected performance
 - b. Related injuries due to prosthetic fracture
 - c. Osteolysis and associated prosthetic component migration and loosening

❖ Hazards related to the use of the device

1. Improper placement of components due to inadequate surgical technique
May cause the following
 - a. Dislocation of components
 - b. Improper loading of components with associated loosening, migration and wear
 - c. Improper bone/prosthesis loading
 - d. Peri-prosthetic fracture
2. Fracture of bones and/or tissue damage during surgery
May cause the following
 - a. Need for adjunctive fixation
 - b. Inadequate stability causing dislocation
 - c. Deformity due to healing incorrectly
3. Use of system by unskilled personnel
May cause the following
 - a. Dislocation of components
 - b. Improper bone/prosthesis loading with associated loosening, migration and wear
 - c. Peri-prosthetic fracture
 - d. Nerve and/or tissue damage
 - e. Improper alignment of components
 - f. Improper tissue balancing
4. Inadequate labeling
May cause the following
 - a. Misuse of the device for applications other than indicated
 - b. Allergic reactions to materials used not noted
 - c. Non-traceability of specific lots

d. Improper combinations of components (i.e. size 2 talar component and size 3 bearing)

❖ Hazards arising from functional failure

1. Unknown long-term durability of the device
2. Loosening of the device components
3. Failure of biological fixation to occur
4. Increased pain and/or deformity.
5. Dislocation of components
6. Decreased range of motion of the joint and/or decreased patient mobility
7. Possible need for revision surgery, such as an alternative prosthesis or arthrodesis.
8. Inadequate packaging resulting in contamination and/or deterioration
9. Osteolysis from increased polyethylene wear debris
10. Unforeseeable surgical risks or complications (i.e. – pulmonary embolism or cardiac arrest)

All of the above may result in early revisions of components, permanent damage/deformation to natural joint. They may also result in ambulation problems, leg length discrepancies, mechanical axis alignment problems, and/or other medical problems.

Below, all of the risks associated with the device will be discussed on how reductions are made. Since, all of the devices in the proposed generic-type utilize the same technology and articular surfaces, most of the risks and hence reduction of these risks, are common to all components. If a difference in the design produces a risk or additional risk, it will be noted.

❖ Biological hazards

1. Bio-incompatibility of the materials used

Bio-incompatibility may cause destruction of bone and surrounding tissues or rejection of the implant and in rare cases, there can be an allergic reaction to the material. This complication has not been well understood, and has only recently received the attention it deserves. Clinical experience indicates that about one percent of joint replacement patients may be sensitive to one of the alloying elements of Co-Cr or stainless steel alloys. Such sensitivity can produce swelling and pain in the joint. Thus, joint function can be adversely affected and the need for implant removal can develop.

To combat this bio-incompatibility, Endotec recommends the following procedures:

Firstly, all patients who expect to have a Co-Cr or stainless steel implant should have their physician check for sensitivity to the alloying elements of the materials before implanting them.

Secondly, to reduce the risk of metallic bio-incompatibility substantially, as displayed by the prototype, all the metallic components should be constructed from Ti-6Al-4V, titanium alloy. The titanium nitride (TiN) thin film ceramic coating applied to the titanium alloy is a highly biocompatible, inert material.²⁹ Titanium has been used extensively in the orthopedic community, and is the preferred material due not only to its extreme biocompatibility, but also to its improved and similar mechanical properties to bone.³⁰ Titanium is also used as an alternative in the cases of nickel sensitive patients. Materials purchased are accompanied by certifications and must meet specifications as dictated in the Quality Manual and ASTM standards to assure this criterion.

Lastly, all bearings should be constructed of Ultra-High Molecular Weight Polyethylene (UHMWPE), a highly compatible, inert material. This too, is a widely used material in the orthopedic community and is also accompanied by certifications and checked in the same manner as titanium.³¹

2. Toxicity of the materials

Only biocompatible, ANSI, ASTM standard materials are used in the implant systems.

3. Infection

Infection may cause destruction of the bone, device loosening or skin/wound healing problems. This problem is particularly acute in the ankle since it is the foot is furthest from the heart and thus the most difficult region for which to supply blood.

The main causes of infection are as follows:

Infection due to skin slough

Skin sloughs can be prevented by sound, surgical technique and post-operative care. As the main cause of skin sloughs is early motion, a short-leg cast is recommended for 6 weeks to prevent shearing of skin incision.

Infection due to systemic seeding of bacteria, no open wound

Systemic seeding of bacteria can be prevented, by avoiding local infections altogether or when they do occur treating them early to prevent bacterial seeding of implants.

Infection due to implant sterility or lack of it

All metallic components are sterilized by exposure to Gamma radiation per spec S-023, and all plastics by exposure to ethylene oxide per S-022. After sterilization, a certificate stating that bio-burden tests were performed on some of the components and that they have a sterility assurance level of 10⁻⁹ accompanies all components.

Also, to date, older products have been tested to validate the sterilization cycle to assure that the items will stay sterile for at least 9 years per ISO Validation process.

4. Degradation of the materials

Degradation of the materials may limit expected performance and cause related injuries due to prosthetic fracture. Degradation of the titanium is controlled by the application of a titanium nitride ceramic film (TiN) coating to increase the hardness and abrasive resistance of the surface. The addition of the TiN coating, when tested against UHMWPE resulted in extremely low wear.²¹ Thus, significantly reducing the affect of degradation on these materials.

Degradation of the polyethylene may occur if exposed to gamma radiation for sterilization.³²⁻³⁵ This can cause oxidation induced fatigue failure of the component. The effects of oxidation can be eliminated, by sterilizing the components with ethylene oxide without altering the polyethylene structure³⁶.

❖ Hazards related to the use of the device

1. Improper placement of components due to inadequate surgical technique

Mal-positioning of the implants can cause problems like dislocation of the implants, improper loading of components resulting in irregular wear and peri-prosthetic fractures.

To assure proper placement of the components, several instruments are designed to aid in orienting the tibial cut and aligning the components. Rasps, burrs and templates are also used to properly fashion the talar dome and tibial canal to accept the prosthesis and supply adequate fit. Although with the proposed generic type, minor misalignments will not affect stability, since the meniscal bearing will line up with the talar component, and the flat side of the bearing and tibial will allow for congruency.

The surgical technique is provided to familiarize the surgeons with the use of the implants and instruments. This document has been prepared, using 20 years of experience, by Dr. Frederick F. Buechel, an Orthopedic Surgeon, who co-developed the system. The surgical procedures are released, controlled documents to minimize the effects of errors.

Furthermore, lessons learned during the IDE clinical trial,¹¹ has led Endotec to the conclusion that although adequate guidance has been provided to the surgeons with regard to surgical technique, due to the steep learning curve associated with the surgery, additional procedures will be implemented. Endotec plans to host medical conferences complete with surgical workshops and experts on hand to help the surgeons to hone their skills.

2. Use of system by unskilled personnel

Federal Law dictates that only a qualified physician can purchase these devices. All personnel entitled to purchase these items, are trained experts in the field of orthopedic or podiatric surgery; therefore, no unskilled persons are able to obtain the implants for their use.

3. Inadequate labeling

Labeling requirements are dictated by Standard of Operating Procedures 0015, which requires the identification of part numbers and lot numbers on all boxes. Also, a certificate of conformance must be accompanied with the product from packaging to assure the appropriate labels are applied.

Also, package inserts are provided in the boxes listing all indications, contraindications, warnings and precautions for the surgeons (or other qualified hospital personnel), to provide another source of directions for assurance of informing.

❖ Hazards arising from functional failure

1. Unknown long term durability of the device

Although long-term durability is not known, clinical studies over ten years report a cumulative survivorship of 92% for 12 years.⁵ Also, simulator studies^{21, 37-39} display the durability of the implant coatings and materials and provide an adequate prediction on the life of the implants.

2. Loosening of the device components

Aseptic Loosening

All items in general, are placed with precise instrumentation assuring the fit of the device initially, reducing the risk for loosening. The design is such that, as demonstrated in Refs. 5 and 28, gross migration or loosening has been a complication only in a small percentage of cases particularly of the talar component. Additionally, reports on a cementless biological ingrowth fixation with the STAR prosthesis have shown that loosening is not a major complication.⁴⁰

Septic Loosening

Meticulous wound care intra and postoperatively using prophylactic antibiotics is an effective preventative against septic loosening. However, in the event of any loosening a detailed complication reporting system is maintained and closely monitored to assure safety and to identify trends.

3. Failure of biological fixation to occur

Clinical studies have proven that uncemented implants have better overall results than those implanted with cement.^{5, 40} Cemented prostheses have had higher aseptic loosening rates and poorer results than uncemented ones. These studies have concluded that patients without osteoporosis undergoing ankle replacement should receive cementless implants.

Refs. 5, 10 and 40 cite clinical studies that provide knowledgeable experience with similar types of prostheses that have achieved stable ingrowth.

To ensure proper biological fixation, the FDA dictates that porous coating must fall within the following ranges for acceptable ingrowth per CFR 21 888.3358:

Porosity between 30 - 70%
Average pore size between 100 and 1000 microns
Interconnecting porosity
Thickness between 500 and 1500 microns

The prototype's porous coating, BioCoat, is within this criterion.

4. Increased pain and/or deformity.

The risk of increased pain and/or deformity can be reduced by sound surgical technique, adequate fixation and minimal wear. Sound surgical technique safeguards the patient against deformity caused by surgical error and adequate fixation reduces risk of deformity caused by subsidence or sinkage. Yet, subsidence and wear reduction is really an issue of design. A good, sound design is in itself a safeguard against subsidence and unacceptable wear.

With regards to the risk of increased pain, cementless ankle replacements and the use of mobile meniscal bearings have been shown to reduce pain^{12, 18} and restore function⁸. Furthermore, the use of more flexible properties of titanium alloy⁴¹ results in reduced bone/prosthesis interface stress and therefore decreased pain. Consolidated, well-aligned components do not produce pain.

5. Dislocation and subluxation of components

Since the polyethylene is not mechanically fixed to the tibial component, there is a chance of dislocation and subluxation of the bearing from the components. Such dislocation and subluxation is resisted by normal anatomical structures (medial and lateral malleoli, and their respective collateral ligaments). These structures prohibit the bearing from dislocation and subluxation medial or laterally.²⁴ The deep sulcus of the talar component design provides medial-lateral and anterior-posterior stability of the bearing (See '3.Primary Safety Considerations: 2.The Stability of the ankle bearing'). Several publications exist which display that meniscal bearing ankle components are stable.^{8, 13, 14, 42} To date, no reports of meniscal bearing dislocation independent of tibial or talar component malpositioning due to subsidence or improper placement have been received. In addition, a ten-year study of the prototype's initial series of 49 cases, reinforce this stability statement.⁴³

6. Decreased range of motion of the joint and/or decreased patient mobility.

Decreased range of motion and patient mobility is not a problem in well-aligned, properly affixed components. Mobile bearings are designed to increase and restore mobility. An in-vivo study⁸ shows that the prototype is identical to the natural, unaffected ankle in the respect of ROM and gait.

However, improper surgical technique and implant placement can result in decreased range of motion and patient mobility. These risks can be reduced by sound surgical technique as dictated by the expert user. The surgical procedures are released, controlled documents issued with the function to minimize the effects of errors.

7. Possible need for revision surgery, such as an alternative prosthesis or arthrodesis.

The need for revision is mainly necessary as a result of wear or component loosening. As overconstraint is a major cause of loosening and increased contact stress causes wear, meniscal bearing types produce less wear debris and are not overconstrained. Thus, the need for revision surgery is minimized. It should be noted that in the event revision is needed the prototype device usually requires less than a centimeter of resection, much less than that required with the commercially available Agility device.¹⁶

In addition, sound surgical technique and vigilant pre and post-operative care, can prevent infection and mal-alignment and reduce the incidence of revision surgery.

However, this risk is still evident but it should be noted that it is by no means unique to the proposed generic type, but to all orthopedic implants.

8. Inadequate packaging resulting in contamination and/or deterioration

Endotec standard procedures SLP0014, 0015, 0016, 0021, and 0022 in Appendix B are in place to assure the integrity of packaging material, manufacture and storage after sterilization. The sterilization is rechecked at different intervals in time as mandated by the Quality Assurance department to confirm that sterility is maintained over time.

9. Osteolysis from polyethylene wear debris

Wear is an inevitable factor involving all orthopedic implants. Although, wear debris will occur, it is less likely with congruent than incongruent designs. Studies have shown that incongruent contact between polyethylene and metal results in excessive wear and is unsuitable for long-term use.^{18, 43} Congruency allows good pressure distribution and better surface deformation resistance. Buechel et al⁴³ records only one

(2%) instance of significant wear of the prototype after ten years. Furthermore this complication was due to a mal-aligned device

Additionally, wear debris can be further reduced by the improvements in TiN coating, which subsequently reduces the incidence of osteolysis. Laboratory testing shows the wear reduction when these coatings are used.^{21, 37-39}

10. Unpredictable surgical risks or complications (i.e. - pulmonary embolism or cardiac arrest)

Proper screening of patients by experienced medical personnel reduces unpredictable surgical risks.

3. Primary safety considerations

Statement of Reasons

In addition, to the risks recognized by 'The Orthopaedic Device Classification Panel', Endotec feels that there is a subset of risks that are associated with the generic device type that requires more detailed examination. These risks are best addressed by five fundamental safety considerations.

These considerations are:

- 1) *The stability of the ankle joint after replacement*
- 2) *The stability of the ankle bearing*
- 3) *The load carrying capability of the ankle replacement*
- 4) *The undesirability of unnecessary constraint*
- 5) *Fixation*

1) The stability of the ankle after replacement

Refs. 5, 13, 14, 28, 42 and 44-48 are clinical studies, which, of course, involve ankle stability. It may be seen from them that stability of the ankle after replacement is not a problem with the Buechel-Pappas device, which falls within the proposed classification, or the STAR device, which has similar stability, constraint and kinematic characteristics. Komistek et al⁸ and Nelissen et al⁴⁷ are in vivo kinematic studies, which show essentially normal ankle function after replacement with the B-P device. Garde and Kofoed⁴² and Magnussen et al⁴⁸ show this to be the case with the STAR

device. The stability report by Pappas²⁴ is a theoretical analysis of the stability characteristics of the predecessor to the B-P device. It discusses the need of maintaining normal inversion-eversion stability. These studies taken as a whole are adequate in demonstrating a reasonable assurance that the proposed device classification produces a safe ankle joint, with respect to stability, that does not have any new ankle stability problems associated with the relative lack of constraint associated with meniscal bearing joints falling within the scope of the proposed new class.

It is useful to consider a comparison of the stability characteristics of a currently available device, the DePuy "Agility" ankle, that has been classified as class II and given 510(k) clearance, to the B-P device. This comparison is to show that the Agility ankle, which fits 888.3110, and is therefore considered, to be reasonably safe and effective has abnormal stability characteristics. The B-P ankle, which the ODE claims fits 888.3120, and therefore cannot be considered to be safe and effective enough to be considered class II, has, on the other hand normal stability properties that appear to be relatively free of risk.

Medial-Lateral: Such stability in the normal ankle is almost entirely provided by the ankle mortise. In the B-P device the ankle mortise is retained and thus stability is essentially unaffected.

The Agility ankle, however, resects the mortise as illustrated in Fig. 12. It replaces the mortise with tibial component sidewalls, which are much shallower than the mortise they replace. Due to this shallow engagement and the large lateral corner radii on its talar component the Agility provides much less medial-lateral resistance than the normal mortise. This is particularly true where inversion or eversion is present. Furthermore the lateral clearance of about 6mm between the talar and tibial components of the Agility provides much greater medial-lateral motion than normal meaning that the medial-lateral stability of the Agility is substantially less than normal.

The resection of the mortise used with the Agility ankle not only reduces stability but also has an additional risk of medial malleolar. Further, the fibular resection and syndesmosis fusion introduces substantial risk of fibulotibial nonunion,⁴⁹⁻⁵¹ a risk not present in the B-P ankle.

In the Agility ankle medial-lateral stability associated with the mortise is replaced by prosthetic constraints. This results in medial-lateral shearing loads being supported by the prosthesis-bone interface rather than by the natural bony structures. Thus, unnecessary shearing loads are applied to the prosthesis-bone interface. It is well known that unnecessary loads represent an unnecessary risk to the patient associated with increased possibility of loosening.

Summary: The B-P design provides superior and more normal stability than the Agility. It reduces or eliminates risks associated with mortise resection and fusion in the Agility. Further, it also reduces loosening risk by

eliminating unnecessary shearing loads. This is an important characteristic of mobile bearings.

Anterior-Posterior: Such stability is primarily provided in the normal ankle by the ankle ligaments since the tibial retaining arc is relatively shallow. As described in detail in Ref. 24, due to the inclination of the B-P flat plate and the effects of friction the difference in A-P stability between the B-P device and a normal ankle is not great. Further this difference is easily resisted by the ankle ligaments, which are well adapted to resist such shear since that is what they normally do.

The Agility ankle has substantial intrinsic A-P stability, much more so than the normal ankle. Thus the Agility is over constrained. It is well known that unnecessary constraints represent an unnecessary risk to the patient associated with increased possibility of loosening associated with unnecessary shearing loads resulting from such constraints.

Summary: The B-P design provides more normal stability than the Agility. Further, it also reduces loosening risk by eliminating unnecessary constraints.

Axial Rotation: Such stability in the normal ankle is almost entirely provided by the ankle mortise. In the B-P device the ankle mortise is retained and thus stability is essentially unaffected.

The resection of the ankle mortise with the Agility produces a loss of stability and increase of risk very similar to that associated with the loss and risk associated with medial-lateral stability.

Summary: The B-P design provides superior and more normal stability than the Agility. It reduces or eliminates risks associated with mortise resection and fusion in the Agility. Further, it also reduces loosening risk by eliminating unnecessary shearing loads. This is an important characteristic of mobile bearings.

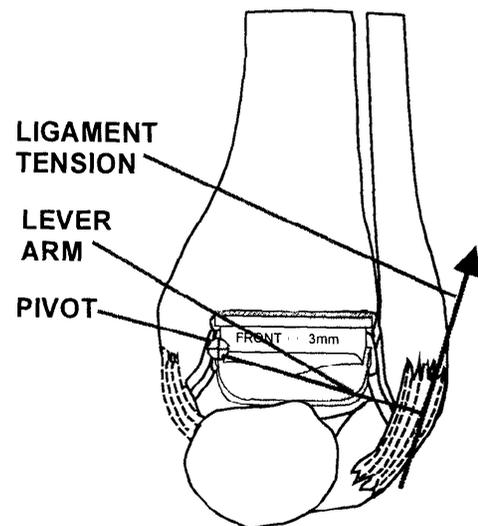
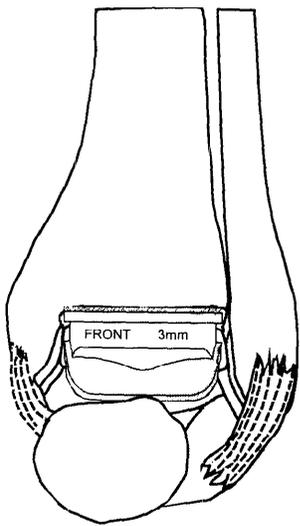
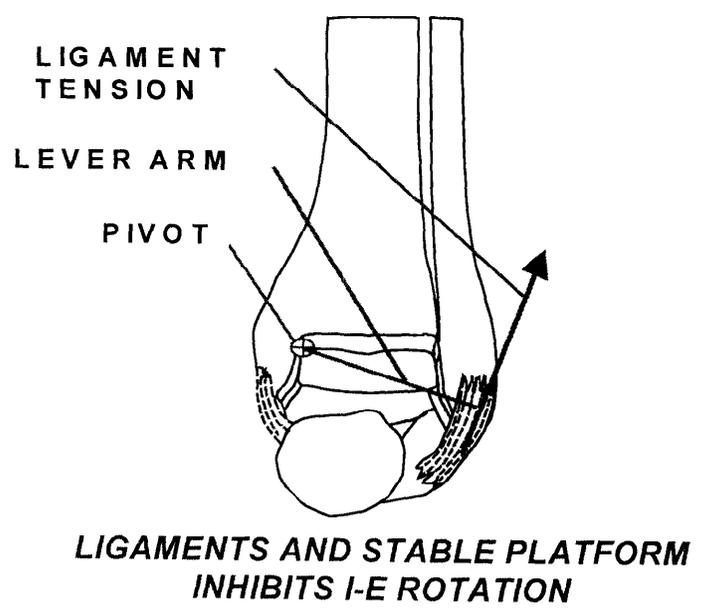
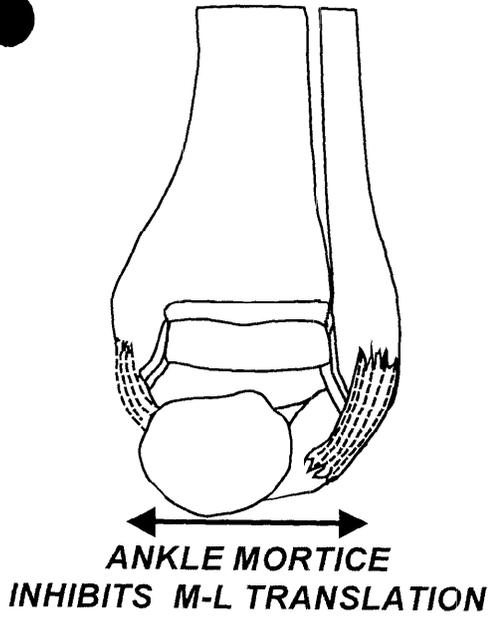


Fig. 11 B-P total ankle system – Normal Inversion-Eversion and Medial-Lateral Stability

Inversion-Eversion: Such stability in the normal ankle is primarily intrinsic. Ankle ligaments play a role where inversion-eversion torque on the ankle is present. Since the medial-lateral width of the B-P talar component is the same as the natural talus this stability mode is unaffected.

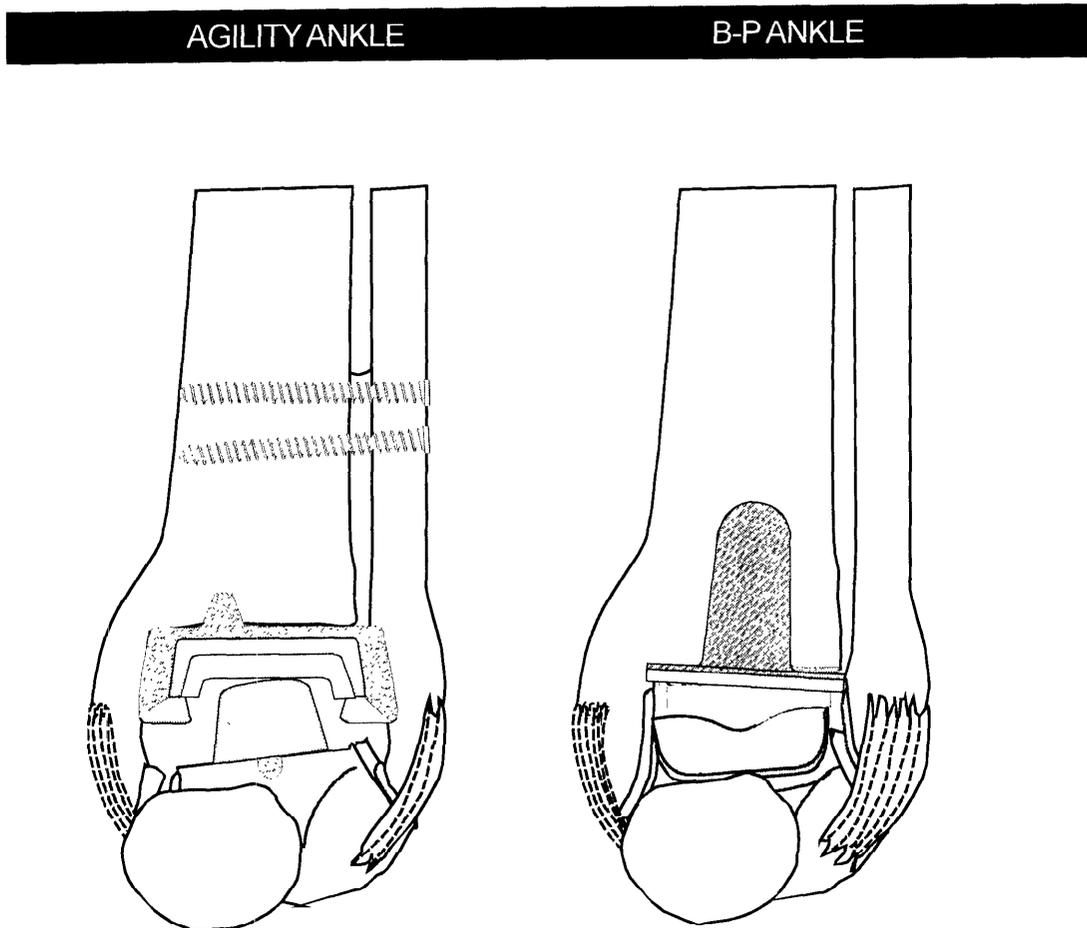


Fig. 12 Inversion/Eversion stability of the Agility and B-P total ankle systems

The talar component of the Agility ankle is, however, much narrower than the normal talus. Further, due to the large lateral corner radii used on the Agility the width of the articular surface of the talar component is considerably less than the reduced width of the component itself. These large corner radii are used in order to avoid sharp edge contact during inversion-eversion. Thus inversion-eversion stability is greatly reduced. Inversion-eversion ankle injuries are very common. Thus, a substantial reduction in such stability poses a substantial risk to the patient since it can much more easily produce overloading of the ankle ligaments and therefore ankle sprain or strain.

Summary: The B-P design provides superior and more normal stability than the Agility. Further it reduces risk of ankle strain and sprain by providing normal rather than much less than normal inversion-eversion stability.

2) *The stability of the ankle bearing*

The position that the FDA originally took with regard to mobile bearings, based on what they probably knew at the time, appeared to be prudent. Certainly, we thought so at the time. It was our feeling that mobile bearings introduced bearing stability issues that could only be adequately addressed by a clinical trial (See 'XI. Regulatory History: IDE Clinical Investigation.')

Viewed in hindsight, from a base of knowledge available today, the position appears to have been one that probably produced more harm than good. Fixed bearing knees, including those with either inadequate mobility or excessive contact stress could be sold based on a 510k submission. Mobile bearing knees, which were capable of providing both mobility and congruity, could not. They could only be sold after a long and expensive clinical trial and PMA submission. Thus, the effect of the FDA position on mobile bearings was to discourage the use of designs that were capable of solving a fundamental dilemma of knee designers. The dilemma of finding a compromise between the conflicting requirements for mobility and congruity in fixed bearing knees. This position greatly inhibited the development and use of a superior knee concept and thus encouraged and sanctioned the use of knees with a serious fundamental flaw.

Wear is the most serious long-term complication in knee replacement. If the FDA had allowed the mobile bearing LCS to be sold under a 510k and had the FDA used a policy of insisting that knees could only be sold if they were scientifically sound, fixed bearing knees would not have been used as extensively as they are today. As a result, many thousands of patients with knees that failed due to overloading of their articulating surfaces would have been spared the disastrous results of such common replacement knee failure.

The fallacy of a position that requires a PMA approval for a mobile bearing, but allows a 510k clearance for fixed bearing designs, is particularly clear in the case of ankle prostheses. The problem of overloading is even more acute than in the knee since the ankle is very much smaller than the knee yet has loads of very similar magnitude.⁵² This is one of the most important reasons for high failure rates in ankle replacement. Due to excessive failures, ankle replacement has fallen in to general disrepute with orthopaedic surgeons who normally use fusion as the preferred treatment method.

The most serious risk associated with mobile bearings is the risk of bearing dislocation or subluxation. Although in knees such stability issues have been a problem, they have been solved. Such problems have not

been seen with current mobile bearing ankles. History indicates, that for knees, the risk associated with overloading is higher than risk associated with bearing stability and mobile bearings seem preferable to fixed bearings. This is much more true for the ankle where the risks of overloading are even higher and the risks associated with bearing stability are very much less.²⁴

The study by Keblish et al²⁸ is an unpublished paper on the results of part of a clinical study of a few hundred patients on the predecessor to the current B-P device. This study did disclose some problems with bearing subluxation. These problems were, however, secondary to talar necrosis and collapse, a fixation design problem. There was no reported case of bearing subluxation when the talar component did not subside. This problem is also discussed in Buechel et al⁵. Correction of this fixation problem in the current B-P device has minimized this subluxation.⁵ From Refs. 5, 14 and 48, one can see that it is not a major complication with either the B-P or STAR mobile bearing designs.

3) The load carrying capability of the ankle replacement

The computation of the contact stress in the intermediate ankle bearing of the B-P device is given in 'XIII. Summary of Mechanical Testing'. It may be seen that the stress of 5 MPa is well below the manufacturers recommended limit of 10MPa.⁵⁹

4) The undesirability of unnecessary constraint

The B-P device does not have unnecessary constraints as demonstrated in Ref. 21 (See also XIII. Summary of Mechanical Testing: Summary of Torsion and Shear Testing).

5) Fixation

Buechel et al⁵ and Keblish et al²⁸ demonstrate that tibial fixation in the current B-P ankle device is safe. In Ref. 28 a study of 237 cases shows a low incidence of lucent zones and a low (2%) tibial component-loosening rate for cementless devices. The same is true for the 90 cases of Ref. 5.

Details on the tibial fixation results are given in Ref. 5. These results show that the tibial component is safe for cementless use.

Fixation failure of the talar component was unacceptably high for the predecessor device primarily due to talar subsidence as described in Ref. 5. It is, however, acceptable for the current device that uses a dual fin rather than a single fin fixation to augment fixation of the talar onlay. The rationale for this change is discussed in Ref. 5. The use of dual fins minimizes the intrusion into the blood supply to the talus. An onlay greatly reduces talar bone loss on implantation allowing the preservation of much subcondral bone on the proximal talus. No talar component of the current type has been revised for loosening although one case of partial talar collapse in the 49 cases studied has been observed. Details on the talar

fixation results are also given in Ref. 5. These results show that the talar component is acceptably safe for cementless use.

Summary of the five points:

The first four points have been incorporated into the classification description. The description has been tightly drawn so as to include all elements which best current information indicates are necessary to produce a device comparable to currently commercially available ankle replacement devices in safety and efficacy. Since there are many ways adequate fixation can be achieved it is felt that the last point on fixation is best handled by special controls. Such controls can be developed after reclassification so as to allow the evaluation of other devices, which fall within the new reclassification definition.

Finally comparing the results of Refs. 5, 11, 13, 14, 16, 28 and 53 with those of 2-4, 51, 54 and 55 one may see that a replacement joint fitting this description is at least as safe as devices that are, or were, commercially available. For examples compare Table 2 of Ref. 5 with Tables I and II of Ref. 18. It may be seen that the survivorship of the meniscal bearing designs of Ref. 5 for moderate length use of 5-6 years is at least comparable to the short-term survivorship of the devices of the type used to justify the class II designation of 888.3110.

Comparing the results of Refs. 5, 11, 13, 14, 16, 28 and 53 with those discussed in Ref. 18 and 56 for arthrodesis demonstrates that the risks associated with replacement that fit the description appear acceptable, particularly when the improved functional performance of replacement is considered. Kofoed and Stürup in their long-term comparison of arthroplasty and arthrodesis draw a similar conclusion.⁵⁷

XI. Summary of Mechanical Testing

All Preclinical and In vivo testing is applicable and was performed on the Buechel-Pappas Ankle system (Deep Sulcus).

1. Summary of Torsion and Shear Testing

Four total ankle replacement devices, including the S.T.A.R. and B-P ankle, were chosen in the study of Ref. 22, characterizing these in terms of force generated during prescribed displacement. A dynamic testing system of applying biaxial loads was utilized to assess the intrinsic performance characteristics of the devices.

Anterior, posterior, medial, lateral and rotational constraints were determined for each design under a compressive load consistent with normal walking gait. A compressive load of 5x body weight and 10 degrees flexion was chosen to represent a position of gait where

maximum shear forces act in the posterior and lateral directions as well as in rotation. Anterior and medial shear forces are presented at the same gait position for completeness. A body weight of 163 lb was used in this evaluation, which corresponds to the average for a 60-year-old, 5' 8" male subject.

Rotational (Torsion) testing

Under an *in vivo* compressive load, the system was rotated both internally and externally in the transverse plane and under torque versus angular displacement recorded. Three tibial components were evaluated for each system. The study's findings were indicative of the ability of the ankle design to constrain rotation during gait.

Anterior-Posterior and Medial-Lateral Shear Testing

Under an *in vivo* compressive load, shearing displacements were applied to the system until implant subluxation. The study's findings revealed that: "these designs should allow the torques and shear forces of gait to be transferred via displacements to the soft tissues in a fashion similar to the normal ankle".

Furthermore, with particular reference to the prototype, the study noted that: "the UHMWPe-talar articulating geometries in this group (B-P ankle and STAR) are able to compensate for inversion-eversion tilting. Slight positional misalignment of the components should not significantly affect the expected *in vivo* service life of the device. In addition, this compliance to position, within the mobility displacement envelope...should allow these designs to function in patients with minor aberrant gait patterns."

In conclusion, the study noted that: "Within envelopes of normal displacement the systems studied demonstrate relatively low force and torque values which should contribute to their *in vivo* longevity."

2. Wear Testing

Wear is a major late complication with total joint replacement. As patient longevity is increasing, it is not unreasonable to assume that an active lifespan of some patients could be in excess of 35 years after implantation. Thus, the need for a harder, more abrasion resistant, counterface surface is paramount.

Refs. 21 and 37 provide wear testing using both ceramic titanium nitride coating (TiN) and Cobalt-chromium-molybdenum (Co-Cr). These references detail a comparison of Co-Cr and TiN femoral heads as well as a 48-Million cycle, hip-resurfacing test.

The testing revealed that a lower wear rate was produced by TiN over cobalt chromium vs. UHMWPe bearing couple, under similar fully congruent sliding relative motion and load patterns.

Ref 39 describes a similar comparison test for application in comparing femoral components of knee replacements. This study concludes that the TiN coating appears superior for long-term use.

The authors thus conclude that “bone destruction from wear debris can be reduced notably by using long-term simulation to identify designs and materials capable of low wear in long-term service, and by using advanced articulating surface materials that greatly reduce wear”.

3. Testing describing the Characterization of the Coating Type

The TiN coating is applied to the Ti-6Al-4V substrate by physical vapor deposition, using the cathodic arc deposition process as described in Ref. 58.

Coating hardness values are typically 3000-3200 HV.

Coating roughness is a result of the pre/post-polishing process and typically in the range of 25 – 50 nm.

The coating thickness is related to duration of coating cycle and has a typical thickness of 6-10 microns.

Adhesion of the coating is a function of surface purity and conditioning with acceptable values of 50 N upper critical loads.

Coating Type	Hardness	Roughness (Ra)	Thickness	Adhesion
TiN	3000 HV	25 nm	9 um	50.0 N

4. Contact Stress

The Buechel-Pappas Ankle Contact Stress Calculation

Contact stress can be determined via analytical or experimental methods. One experimental technique is by the Fuji-Film Method. With this approach, a pressure sensitive film is placed between the articular surfaces. Next a static, compressive load is placed on the components resulting in rupture of the pressure sensitive beads in the film. The beads contain ink and break at different stresses. Therefore, after applying a load the film can then be analyzed to determine both the contact area patch as well as the contact stress by the variation in the color of the film.

This type of test is however impractical for use with the Buechel-Pappas ankle replacement system. This is due to the compound shape of the talar

component, and the congruency of the articular surfaces. These factors will not allow the film to be controlled once placed between the components to produce the congruent contact needed in order to determine the appropriate contact stress. To expand on this statement, Fig. 13 displays a simple ball and socket congruent couple. In order for the two to be in congruent contact, the convex radii (R_1) has to be identical to that of the concave radii (R_2), as is shown. Fig. 14 shows the couple with an object with a finite thickness introduced. In this situation, the components must first be displaced the thickness of the film. Next, in order for congruent contact to exist, the outside radius of the film must be different than the inside radius. Since this cannot occur, congruent contact cannot occur.

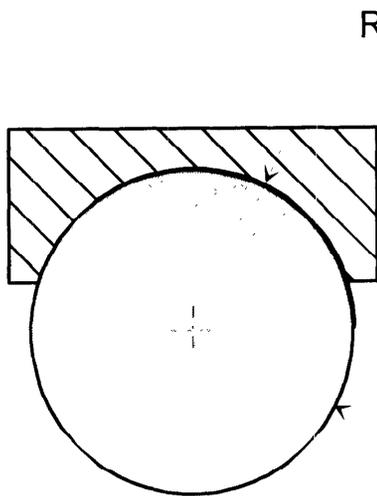


Fig. 13

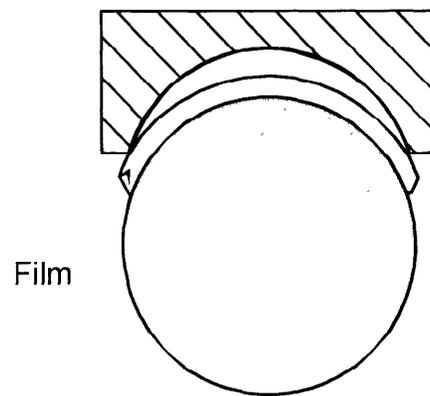


Fig. 14

Therefore, analytical methods are used here in order to calculate the contact stress. The equations for the contact stress of two curved surfaces of different radii pressing against each other (point contact) are documented in Ref. 26. For congruent, shallow cup contact, it is reasonable to assume that the contact stress is uniform over the contact area. This result is,

$$\sigma = \frac{P}{A} \quad (1)$$

where σ is the contact stress, P is the load applied, and A is the projected contact area in the plane perpendicular to the applied load.

CONTACT AREA

The minimum projected contact area for the ankle device between the bearing/talus couple as shown in Fig. 15.

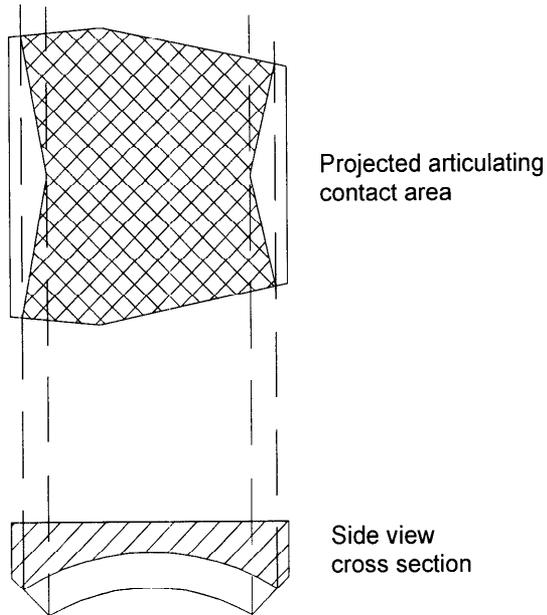


Fig. 15

In order to calculate the minimum contact area, it is divided into a series of rectangles and triangles. As can be seen from Fig. 16, if the bearing is divided in half, the resultant figure is broken into 4 triangles and 2 rectangles.

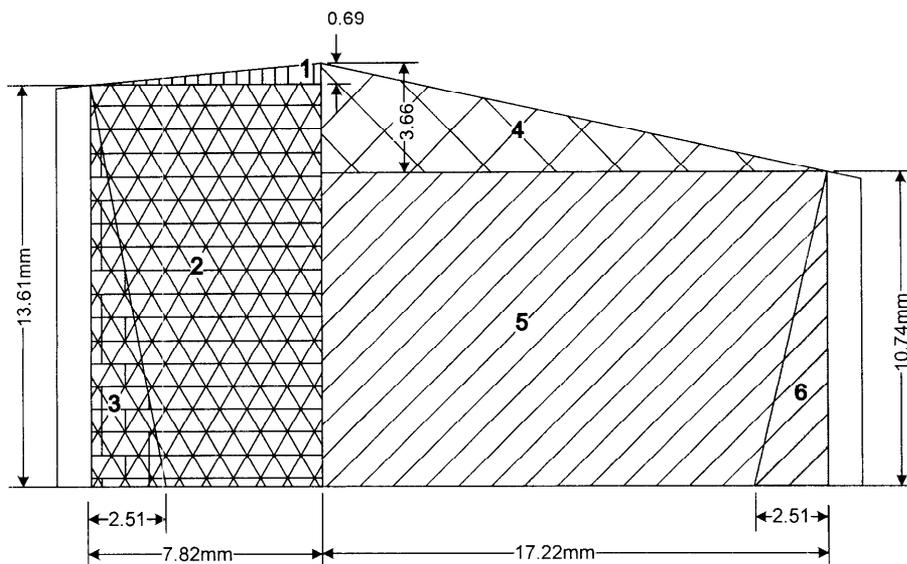


Fig. 16

From the above, the projected area for a standard, size 3, bearing becomes:

For area 1:

$$A_1 = \frac{1}{2}(b)(h) = \frac{1}{2}(0.69)(7.82) = 2.70mm^2 \quad (2)$$

For area 2:

$$A_2 = (7.82)(13.61) = 106.43mm^2 \quad (3)$$

For area 3:

$$A_3 = \frac{1}{2}(13.61)(2.51) = 17.08mm^2 \quad (4)$$

For area 4:

$$A_4 = \frac{1}{2}(17.22)(3.66) = 31.51mm^2 \quad (5)$$

For area 5:

$$A_5 = (17.22)(10.74) = 184.95mm^2 \quad (6)$$

For area 6:

$$A_6 = \frac{1}{2}(2.51)(10.74) = 13.48mm^2 \quad (7)$$

Therefore, the total projected area is:

$$A_{TOT} = 2(A_1 + A_2 - A_3 + A_4 + A_5 - A_6) \quad (8)$$

$$A_{TOT} = 2(2.70 + 106.43 - 17.08 + 31.51 + 184.95 - 13.48) = 590.06 \text{mm}^2 \quad (9)$$

ANKLE FORCES

The tibiotalar compressive forces have been estimated to exceed four times body weight during normal walking, and the posterior shearing forces approximately 80% of body weight⁵² (See Fig.17).

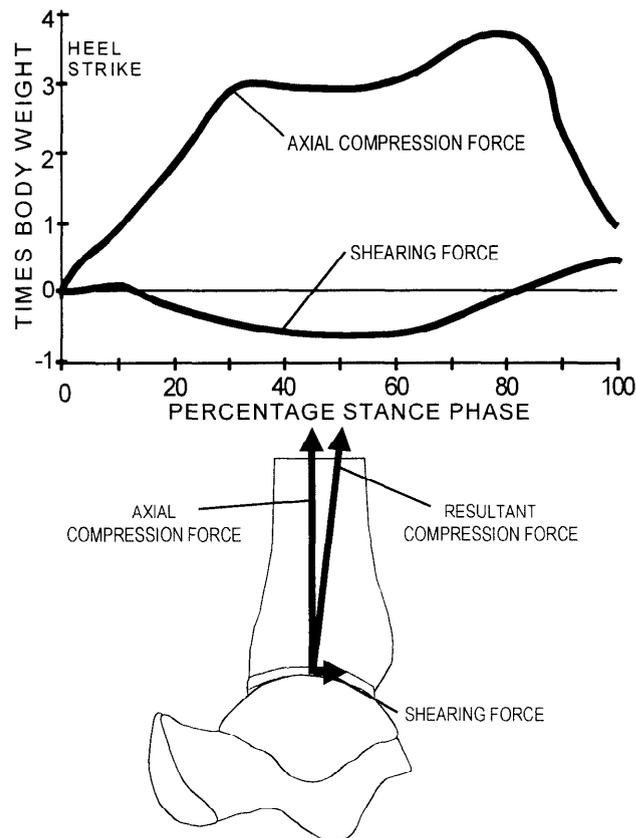


Fig. 17 Ankle Loads During Walking

For the standard, size 3, component used for the projected contact area, the body weight is assumed to be 150 lbs (68.1 kgs). Therefore, the resultant compressive forces is given from:

$$\begin{aligned}
 F_{compressive} &= \sqrt{(4 \cdot BW)^2 + (0.8 \cdot BW)^2} \\
 &= \sqrt{(4 \cdot 681.)^2 + (0.8 \cdot 68.1)^2} = 278g
 \end{aligned}$$

(10)

The compressive load is therefore 278kg or 2.42 kN. Using equation (1) yields a contact stress:

$$\sigma = \frac{2.42(10^3)N}{5.9(10^{-4})m^2} = 4.6MPa$$

(11)

The knee is used here as a comparison since the situation in the ankle is similar. However, the ankle is smaller in size, and hence projects a smaller articular surface. The manufacturer of the UHMWPe recommends that the contact stress in applications having a compressive fluctuating load is 10MPa⁵⁹. Fig. 18 displays the computed contact stress for area, point, line and quasi-line contact of several knee designs and the prototype, B-P ankle.

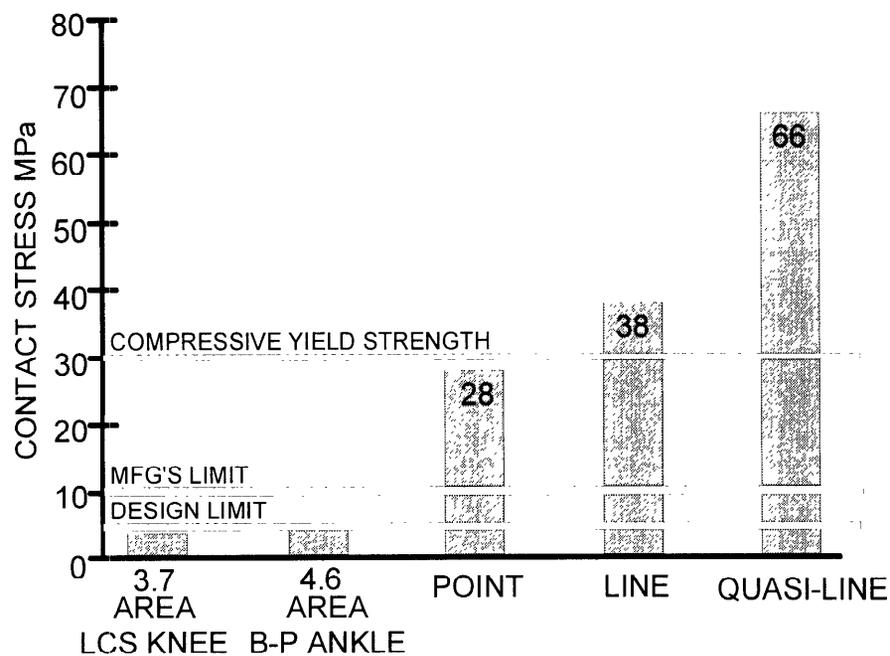


Fig. 18 Surface Contact Stresses for the B-P Ankle and various knee components

The data for the knee designs was taken from the study of Ref. 26, which demonstrated the adequacy of classical analytical methods for such stress estimates.

5. A Summary of Kinematic Testing

The Buechel-Pappas Total Ankle Replacement system was examined using an *in vivo*, weight-bearing methodology, to determine relative motions between implant components under dynamic conditions⁸.

The study involved the analysis of ten ankles, all clinically successful without ligamentous instability or pain. The post-operative time interval was 5 years. Under weight bearing each patient's affected and unaffected ankle was examined in both plantar and dorsiflexion for maximum range of motion analysis and digitized with video fluoroscopy.

The following biomechanical observations were observed:

"Contact positions of medial and lateral condylar contact are similar to non-implanted ankles."

"The present fluoroscopic evaluation has confirmed and elucidated the complex three-dimensional rotation and articular sliding of the ankle joint in motion."

"(The) total ankle design must make some accommodation for the normal rotation of the ankle joint. The axis of rotation of the mobile bearing ankle used in this study is midline, but it is unknown where that rotational axis maybe in the normal ankle."

"Kinematic patterns of motion were similar for normal and the tested implanted ankles in this study, which is a mobile rotationally unconstrained implant."

"The mildly posterior location of the tibial and talar contact of the TAA (Total Ankle Arthroplasty) could reflect ligamentous deficiency from degenerative disease, pre-operative trauma, or posterior surgical placement of the talar component."

"Horizontal rotation of the ankle joint was clearly identified with tibial external rotation when moving from dorsiflexion to plantar flexion."

6. Conclusion

Mechanical testing is extremely useful in providing information, which may offer a reasonable prediction of whether a device will be safe and effective. However, extensive clinical studies can only confirm the validity of mechanical testing. This is clearly evident with the B-P ankle. In the light of the long-term clinical history of this device and the relatively large number of reported clinical studies, *in vitro* testing data is of secondary significance. Even so, analytical methods (See 4. Contact Stress) and Kinematic tests (See 5. A summary of Kinematic testing) are adequate to predict and map the *in vivo* performance of this device.

XII. Summary of clinical findings

1. Cemented Total Ankle Arthroplasty

On Friday, July 2, 1982, in the Federal Register, Vol. 47, No. 128, the FDA published the proposed Rules for 888,3110; Docket No. 78N-3060; Ankle joint metal/polymer semi-constrained prosthesis. The Orthopedic Device Classification Panel's recommendations found that there was sufficient scientific evidence to support a Class II designation. (See section XI. Regulatory History: *Regulatory History of the ankle joint metal/polymer non-constrained prosthesis*). The Panel based its recommendation on four oral presentations based upon four semi-constrained ankles presented to the Panel. These presentations described and presented the relatively short-term clinical results of the following devices:

1. The Oregon ankle prosthesis presented by Dr. Harry Groth.
2. The Irvine ankle prosthesis presented by Dr. Theodore Waugh.
3. The Beck-Steffee ankle prosthesis presented by Dr. Arthur Steffee.
4. The TPR ankle prosthesis presented by Dr. Paul Thompson.

The FDA agreed with the panel's recommendations and sought additional data and information on the safety and effectiveness of these devices. The FDA cited the following studies on two additional devices.

For the Mayo ankle prosthesis:

60. Stauffer RN; Total joint arthroplasty. The ankle. *Mayo Clin Proc* 1979 Sep;54(9): 570-5

The Mayo clinic developed a prosthetic ankle joint replacement. The Mayo total ankle replacement is a metal-on-polyethylene, congruent, constrained prosthesis. Analysis of 94 patients (102 ankle prostheses) revealed good clinical results in patients with rheumatoid arthritis and in older persons with posttraumatic degenerative disease. Younger, more active patients in the latter category had more disappointing results. Further design development is under way to improve range-of-motion characteristics, decrease constraint forces, and improve bone fixation of the prosthetic components.

For the Scholz ankle prosthesis:

61. Scholz KC: Total ankle arthroplasty using biological fixation components compared to ankle arthrodesis. *Orthopedics* 1987 Jan;10(1):125-31.

When conservative measures fail to alleviate pain and disability of ankle joint disease, tibiotalar arthrodesis is the present accepted surgical treatment. Unfortunately, ankle arthrodesis also carries a significant rate of complications and the success rate does not parallel the results of hip and knee joint arthroplasties. A large percentage of ankle arthrodeses remain painful, and function is not normal. There is no satisfactory "salvage procedure" to a painful ankle fusion. Patients with primary ankle arthritis tend to develop bilateral ankle involvement as well as involvement of the subtalar and midtarsal joints; bilateral ankle fusion results in a severe handicap to gait and function. Total ankle arthroplasty using cement fixation remains controversial. Continued use of polymethylmethacrylate and additional design changes do not appear to be the answer to possible ankle joint replacement.

He concluded that the initial success using the PCA concept of biological cementless fixation of the Scholz total ankle prosthetic components appears to offer a new dimension in the success of total ankle arthroplasty.

The FDA also cited an additional reference on the Irvine ankle:

62. Waugh TR; Evanski PM; McMaster WC; Irvine ankle arthroplasty. Prosthetic design and surgical technique. *Clin Orthop* 1976 Jan-Feb;(114): 180-4.

The Irvine total ankle arthroplasty is presented for highly selected cases. The design stems from investigations on the anatomical and biomechanical characteristics of the human ankle joint. The prostheses are inserted through an anterior approach. Full weight-bearing is well tolerated within a few days. The immediate results on 20 ankles are most encouraging.

It may be seen that the decisions of the panel and the FDA to designate semi-constrained ankles as class II were founded on relatively short-term encouraging results of early ankle designs based on presentations and publications of the developers of these ankles. Longer-term studies, however, clearly demonstrate that the ankle types are failures.

Consider the longer-term experience with the Mayo ankle prosthesis based on reports by several authors including:

63. Stauffer RN; Segal NM: Total ankle arthroplasty: four years' experience. *Clin Orthop* 1981 Oct;(160): 217-21

A review of 102 Mayo total ankle arthroplasties performed during a four-year period revealed that complications occurred in 41%. 22% with impingement of various types 6.9% with loosening and 2.9% with deep sepsis. The best results were obtained in patients with rheumatoid arthritis and those with posttraumatic osteoarthritis who were older than 60 years of age.

They concluded that total ankle arthroplasty currently should not be considered in patients with posttraumatic osteoarthritis who are younger than 60 years old. Also, arthrodesis remains the only acceptable method of treatment in these individuals. Therefore, total ankle arthroplasty seems indicated in patients who have significant ankle joint disability secondary to rheumatoid arthritis and in elderly patients with disabling posttraumatic degeneration whose physical demands are limited.

64. Lachiewicz PF; Inglis AE; Ranawat CS: Total ankle replacement in rheumatoid arthritis. *J Bone Joint Surg Am* 1984 Mar; 66(3): 340-3

Fifteen single-axis arthroplasties were implanted in patients suffering from rheumatoid arthritis. Fourteen were of the Mayo type and one was of the Buchholz type. After an average follow-up of thirty-nine months seven ankles were rated excellent and eight, good. The relief of pain was gratifying in all of the patients, only four patients having residual slight pain with starting activity. The average gain in the range of motion was 9 degrees. No patient had loosening that required reoperation, although radiolucent lines were seen in eleven ankles. Thirteen of the fifteen ankles had moderate to severe arthritic changes in the talonavicular, subtalar, or other intertarsal joints. They concluded that the early results were encouraging.

4. Kitaoka H.B. et al: Survivorship Analysis of the Mayo Total Ankle Arthroplasty. *The Journal of Bone and Joint Surgery* 76-A: 974-979, July 1994.

From 1974 until the end of 1988, 204 primary Mayo total ankle arthroplasties were performed at the Mayo Clinic. By means of actuarial analysis, the study determined that the cumulative rates of survival with failure (defined as removal of the implant) as the end point. The average duration of follow-up was nine years (range, two to seventeen years). By applying the Cox proportional-hazards general linear model, two independent variables were identified and associated with a significantly higher risk of failure. These variables were, a previous operative procedure on the ipsilateral foot or ankle and an age of 57 years or less. The overall cumulative rate of survival at five, ten, and fifteen years was 79, 65, and 61 per cent, respectively. The probability of an implant being in situ at ten

years was 42 per cent for patients who were 57 years old or less and who had had previous operative treatment of the ipsilateral ankle or foot and 73 per cent for those who were more than 57 years old and who had had no such previous operative treatment.

The study concluded that it is not recommended to use the Mayo total ankle arthroplasty, particularly in younger patients who have had a previous operative procedure on the ipsilateral ankle or foot.

65. Kitaoka HB; Patzer GL: Clinical results of the Mayo total ankle arthroplasty. *J Bone Joint Surg Am* 1996 Nov; 78(11): 1658-64

Two hundred and four primary Mayo total ankle arthroplasties were performed in 179 patients at the Mayo Clinic from 1974 through 1988. The clinical result was evaluated after 160 arthroplasties in 143 patients who had been followed for two years or more (mean, nine years; range, two to seventeen years). The result was good for thirty-one ankles (19 per cent), fair for fifty-five (34 per cent), and poor for seventeen (11 per cent); fifty-seven arthroplasties (36 per cent) were considered to be a failure (defined as removal of the implant). Adequate preoperative and follow-up radiographs were available for 101 ankles (eighty-nine patients). There was radiographic evidence of loosening of eight tibial components (8 per cent) and fifty-eight talar components (57 per cent), but we found no association between the clinical and radiographic results. Complications occurred after nineteen (12 per cent) of the 160 arthroplasties, and ninety-four additional reoperations were necessary after sixty six (41 per cent).

The study concluded that ankle arthroplasty is not recommended with a constrained Mayo implant for rheumatoid arthritis or osteoarthritis of the ankle.

66. Unger AS; Inglis AE; Mow CS; Figgie HE: Total ankle arthroplasty in rheumatoid arthritis: a long-term follow-up study. *Foot Ankle* 1988 Feb;8(4): 173-9

Twenty-one patients with rheumatoid arthritis were implanted with Mayo total ankle arthroplasties and had a minimum of 2 yr follow-up were reported. Of the original 21 patients, 17 were available for review. Twenty-three ankle replacements with an average follow-up of 5.6 yr were studied. On follow-up 2 ankles were rated excellent, 13 were rated good, 4 were rated fair, and 4 were rated poor. Thus, 83% were satisfactory on follow-up. Radiographic analysis revealed migration and settling of the talar component in 14 of 15 cases. Bone cement radiolucencies were found in 14 of 15 cases. Bone cement radiolucencies were found in 14 of 15 tibial components with tilting in 12 of these components. The postoperative position of the implant did not correlate with the development of radiolucencies or migration of the implant.

Thus, clearly the Mayo ankle prosthesis must be considered a failure.

Next consider the Irvine device:

67. Evanski PH; Waugh TR: Management of arthritis of the ankle: An alternative of arthrodesis. *Clin Orthop* 1977 Jan-Feb;(122): 110-5

Twenty-eight Irvine ankle arthroplasties were implanted and evaluated on a 100-point ankle analysis scale preoperatively and postoperatively. The average preoperative score was 35 and the average postoperative score was 74. Significant improvement occurred in function, pain relief and range of motion. The average follow-up period for these patients was 9 months. Complications included wound-healing problems in 3 patients. Mal-alignment of the prosthesis occurred in 2 other patients; one required revision. Ankle replacement failed in 2 patients. One patient required a fusion; the other an amputation following occlusion of the posterior tibial artery after surgery.

They concluded that at the present time, ankle replacement appears to be an acceptable alternative to ankle arthrodesis. Yet warned that the number in each group is small and that it does not appear that the procedure has merit for the treatment of ankle arthritis from such diverse causes as trauma, rheumatoid arthritis, aseptic necrosis of the talus and talectomy.

The Beck-Steffee device was similarly unsuccessful as demonstrated in:

2. Wynn A.H. et al: Long-term Follow-up of Conaxial (Beck-Steffee) Total Ankle Arthroplasty. *Foot and Ankle* 13: 303-306, Jul/Aug 1992.

Between 1975 and 1977, 30 patients with traumatic arthritis or rheumatoid arthritis underwent 36 Beck-Steffee Conaxial ankle replacements. Thirty-two were primary replacements and four were revisions of previous ankle arthroplasties. Twelve patients had traumatic osteoarthritis and 18 patients had rheumatoid arthritis. The average age at operation of patients with rheumatoid arthritis was 61 years (range 28-67 years) and with osteoarthritis was 52.9 years (range 32-72 years). The average follow-up was 10.8 years, with a range of 10 to 13 years. Early postoperative complications included wound dehiscence in 39% of patients (14 patients), deep wound infection in 6%, fractures of the medial or lateral malleolus in 22%, and painful talofibular impingement in 14%. At 2-year follow-up, 27% of the ankle replacements were loose. Sixty percent were loose at 5 years and 90% were loose at the 10-year follow-up. Ten patients had implant removal and attempted fusion. Six, or 60%, fused in an average of 5 months. Of those patients who achieved ankle fusion, four had internal fixation and iliac crest autografting, one had a Charnley compression apparatus with allograft bone, and one had internal fixation with allograft bone.

The study concluded that the constrained Conaxial ankle replacement should no longer be implanted because of a 90% loosening rate at 10 years and an overall complication rate of 60%.

The TPR ankle prosthesis is also not successful as demonstrated by:

68. Jensen NC; Kroner K: Total ankle joint replacement: a clinical follow-up. *Orthopedics* 1992 Feb; 15(2): 236-9

The TPR total ankle joint replacement system (Smith & Nephew Richards) was implanted in 30 ankles in 25 patients. Twenty-three ankles in 18 patients were followed; 21 had rheumatoid arthritis and two had osteoarthritis. The average age at surgery was 62 years (range: 37 to 77), and the average follow up was 59 months (range: 37 to 89). The improvement was especially obvious with respect to pain and function. The average walking distance improved from 260 m preoperatively to 975 m postoperatively.

The study concluded that even though there was some improvement with respect to pain and function, the results of the study are disappointing in comparison to studies of ankle arthrodesis.

In addition several other semi-constrained ankle prostheses have been unsuccessful. These include the ICLH ankle device the clinical experience of which is reported by:

69. Herberts P; Goldie IF; Korner L; Larsson U; Lindborg G; Zachrisson BE: Endoprosthetic arthroplasty of the ankle joint: A clinical and radiological follow-up. *Acta Orthop Scand* 1982 Aug; 53(4): 687-96

Eighteen ICLH ankle arthroplasties were implanted in 16 patients. They were followed up after 15 to 52 months postoperatively (mean 36 months) by a review of the records, and clinical and radiological examinations. Five arthroplasties were performed for osteoarthrosis and 13 for rheumatoid arthritis. The overall clinical result was rated excellent in 2, good in 8, fair in 6, and poor in 2 joints. In osteoarthritic joints the results were somewhat poorer, no patient obtaining a rating of excellent but 2 of good, 2 of fair, and one of poor. Radiolucent zones greater than 2 millimeters were seen around the tibial component in 7 cases. Loosening defined as radiographic signs of movement between the prosthetic components and bone was present in 4 cases.

They concluded that the high occurrence of obvious loosening and large radiolucent zones indicates that mechanical problems will be encountered frequently in the future and that ankle arthroplasty has a definite place in the treatment of severe arthritis in rheumatoid patients.

70. Helm R; Stevens J: Long-term results of total ankle replacement. *J Arthroplasty* 1986; 1(4): 271-7

Nineteen ICLH total ankle replacements were implanted in 18 patients with rheumatoid or other inflammatory arthritis. After a mean follow-up period of

54.4 months (minimum, 24 months), three arthroplasties had failed, all because of loosening.

The study concluded that although all of the remaining patients were improved in terms of pain and function, there was radiographic evidence of loosening in a further eight patients.

71. Bolton-Maggs BG; Sudlow RA; Freeman MA: Total ankle arthroplasty: A long-term review of the London Hospital experience. *J Bone Joint Surg Br* 1985 Nov; 67(5): 785-90

Sixty-two ICLH total ankle arthroplasties were performed between 1972 and 1981. Forty-one of these have been reviewed clinically after an average follow-up of five and a half years; only 13 can be described as satisfactory. The complications encountered in all 62 arthroplasties are detailed, the most significant being superficial wound healing problems, talar collapse, and loosening of the components; 13 prosthetic joints have already been removed and arthrodesis attempted. The management of the complications is discussed.

The study concluded that In view of the high complication rate and the generally poor long-term clinical results, it is recommended that arthrodesis be the treatment of choice for the painful stiff arthritic ankle, regardless of the underlying pathological process.

And the Smith ankle and other semi-constrained devices reported by:

72. Dini AA; Bassett FH: Evaluation of the early result of Smith total ankle replacement. *Clin Orthop* 1980 Jan-Feb;(146): 228-30

The Smith total ankle replacement was performed in 21 joints. During a 3-year period, the function was good in 50% of the patients with traumatic degenerative arthritis and 40% with rheumatoid arthritis.

The study concluded that improper technique; infection and component loosening were the most common causes of failure in 11 patients, with fair to poor prognosis.

73. Takakura Y; Tanaka Y; Sugimoto K; Tamai S; Masuhara K: Anklearthroplasty:Acomparative study of cemented metal and uncemented ceramic prostheses. *Clin Orthop* 1990 Mar;(252): 209-16

From 1975 to 1980, Thirty Takakura cemented total ankle arthroplasties were implanted using a metal/polyethylene prosthesis in twenty-eight patients with painful arthritis. However, because loosening and sinking of the prosthesis were significant, a ceramic total prosthesis was designed in 1980 to be used without cement. Between 1980 and 1987, 39 ankles in 35 patients with osteoarthritis, rheumatoid arthritis, and hemophilic arthritis

were replaced using the ceramic prosthesis. Out of 39 ankles, nine were replaced with cement and 30 without cement. The follow-up period for the cemented metal and ceramic cases ranged from 13.4 to 6.2 years, with an average of 8.1 years, and for uncemented ceramic cases from 1.2 to 6.4 years, with an average of 4.1 years. Based on a rating scale for ankle evaluation, 27% of the cemented cases and 67% of the uncemented cases are satisfactory. Five metal ankles and one ceramic ankle were reoperated upon, with one revision and five arthrodeses performed.

The study concluded that ceramic total ankle arthroplasty, performed without cement, has to date provided mostly excellent stable results.

74. Kofoed H; Sorensen TS Ankle arthroplasty for rheumatoid arthritis and osteoarthritis: prospective long-term study of cemented replacements. *J Bone Joint Surg Br* 1998 Mar;80(2):328-32

Fifty-two cemented ankle arthroplasties were implanted for painful osteoarthritis (OA) (25) or rheumatoid arthritis (RA) (27) using an ankle prosthesis with a near-anatomical design. The patients were assessed radiologically and clinically for up to 14 years using an ankle scoring system. The preoperative median scores were 29 for the OA group and 25 for the RA group and at ten years were 93.5 and 83, respectively. Six ankles in the OA group and five in the RA group required revision or arthrodesis. Survivorship analysis of the two groups showed no significant differences with 72.7% survival for the OA group and 75.5% for the RA group at 14 years.

27. Kofoed H Cylindrical cemented ankle arthroplasty: a prospective series with long-term follow-up. *Foot Ankle Int* 1995 Aug; 16(8):474-9

From 1981 to 1985, twenty-eight ankle arthroplasties were implanted using a congruent and cylindrical ankle design. The talus component was an anatomically shaped cap to cover the talus dome and the facets. The tibial component was congruent toward the talus and had two parallel bars on the back for fixation into the distal tibia. The diagnosis was osteoarthritis in 15 cases and rheumatoid arthritis in 11 cases (two bilateral cases).

The clinical results speak for themselves. There occurred seven failures, giving a cumulative estimated survival rate of 70% for the prosthesis at 12 years.

These studies are summarized by:

18. Neufeld S.K. and Lee T. H.: Total Ankle Arthroplasty: Indications, Results, and Biomechanical Rationale. *American Journal of Orthopedics* 593-602, Aug 2000.

Many physicians today, are reluctant to opt for a total ankle replacement and advocate ankle arthrodesis. They conclude that an ankle replacement has generally poor long-term results and a high rate of complications.

This caution is warranted states Neufeld, when applied to early ankle replacement designs, "Published studies of early series with greater follow-up show that ankle arthroplasties did not provide lasting pain relief or improve function, and ultimately failed".

These studies are summarized in the following table:

Short Term Follow-up: Cemented Total Ankle Arthroplasty

Authors	Device*	Number of Cases	Diagnosis	Average Follow-up	Survival Rate (%)
Stauffer & Segal ⁶⁰	Mayo	102	SA (56), RA (43), OA (3)	1.9 yr	93
Lachiewicz et al ⁶⁴	Mayo	15	RA (15)	3 yr	100
Herberts et al ⁶⁹	ICLH	21	RA (14), OA (7)	3 yr	86
Newton ⁷	Newton	50	RA (10), OA (34), SA (6)	3 yr	(60), (38), (0)
Dini & Bassett ⁷²	Smith	5	RA (5) SA (16)	2.5 yr 2.1 yr	80 75
Evanski & Waugh ⁶⁷	Irvine	16	RA (5), OA (23)	9 mths	93
Stauffer & Segal ⁶⁰	Mayo	28	SA (56), RA (43), OA (3)	1.9 yr	93

Early optimism soon gave way to failure as shown below:

Longer Term Follow-up: Cemented Total Ankle Arthroplasty

Authors	Device*	Number of Cases	Diagnosis	Average Follow-up	Survival Rate (%)
Jensen and Kroner ⁶⁸	TPR	148	RA (21), OA (2), RA (125)	4.9 yr	48
Kitaoka et al ⁴	Mayo	79	SA (65), OA (14)	5 yr, 10 yr, 15 yr	79, 65, 61
Kitaoka & Patzer ⁶⁵	Mayo	168	RA (96), SA (64), OA (8)	9 yr	64
Wynn & Wilde ²	Beck-Steffee	30	RA (18), SA (12)	2 yr, 5 yr, 10 yr	73, 40, 10
Helm and Stevens ⁷⁰	ICLH	19	RA (19)	4.5 yr	83
Bolton-Maggs et al ⁷¹	ICLH	62	RA (34), OA (13), SA (15)	5.5 yr	47
Unger et al ⁶⁶	Mayo	23	RA (23)	5.6 yr	65
Takakura et al ⁷³	Takakura Cemented	33	OA (20), RA (11), SA (2)	8.8 yr (metal), 6.7 yr (ceramic)	15
Kofoed & Sorensen ⁷⁴	2 piece (early) 3-piece (later)	52	OA (25), RA (27)	14 yr	75.5 (RA) 72.7 (OA)
Kofoed ²⁷	Cylindrical 2-piece Cemented	28	RA (13) OA (15)	12 yr	70

* Mayo = Mayo Clinic ankle (Rochester, MN); ICLH = Imperial College London Hospital (London, England); Newton (Howmedica, Rutherford, NJ); Smith (Dow Corning Wright, Arlington, TN); Irvine (Howmedica, Rutherford, NJ).

Although early ankle replacement designs were failures, this fact did not discourage designers.

Ankle arthrodesis is not a perfect solution. It can be fraught with complications like non-union and mal-union and even in perfect alignment it has been proven to put increased stress on the knee, subtalar and midfoot regions.

Furthermore, Neufeld states "the diminished overall motion and increased stresses on the remaining joints may lead to a poor result in an ankle arthrodesis. After a pantalar arthrodesis, dorsiflexion is diminished by approximately 63% and plantarflexion by about 82%... an ankle fusion is helpful only initially and that eventual failure due to the subtalar or talocalcaneal joints becoming overstressed is inevitable. Therefore, a reliable ankle replacement system would be a welcome addition to orthopedic practice"¹⁸. The early ankle designs did not provide this.

After early successes, the longer-term results bred failure. "Lachiewicz and colleagues reported in 15 patients, with one of the most widely used prostheses, the

Mayo ankle, with an average follow-up of 3.3 years and excellent results. When Unger and coworkers reported in the same 15 patients with a longer follow-up of 6.2 years, deterioration in their clinical scores and radiographs was apparent”¹⁸.

“Several reasons for the long-term failure of the early prostheses have been suggested. First, many original designs required excessive bone resections and relied on cement fixation onto soft cancellous bone. Constrained prostheses placed excessive stress on the cement-cancellous bone interface. Subsequently the main reason for their failure was aseptic loosening. Unconstrained prostheses...failure occurred due to malleolar and soft-tissue impingement... Therefore, the failure of early designs may have been caused by the lack of respect for the anatomy, kinematics, alignment and stability of the ankle joint”¹⁸.

Also, the early, constrained devices that failed suffered from high contact stresses, “Therefore, an implant should minimize tensile or shear loads and transmit forces by compression...the Buechel-Pappas prosthesis attempt(s) to achieve this goal by using broad, congruent surfaces and both tibial and talar components and allowing axial rotation and mediolateral and anteroposterior sliding”¹⁸.

Furthermore, “They (early constrained designs) have failed to incorporate the biomechanical characteristics of the ankle joint...The design of the implant should permit effective transfer of joint loads, be inherently stable, allow ease of surgical implantation/removal with minimum bone loss, and have resistance to wear, creep, fatigue failure and compressive shear loading...The newer second-generation (e.g. B-P ankle, Agility and STAR), uncemented, semi-constrained, porous-coated designs seem promising”¹⁸.

Therefore, despite encouraging early results, long-term studies proved that constrained ankle devices were not viable and were subsequently abandoned by the orthopaedic community in favor of arthrodesis. Yet, under the present classification system they can still be manufactured and sold today. It may be true that, given the preliminary evidence of these early studies, that the Orthopedic Device Classification Panel in July 1982 were correct in classifying these devices as Class II, yet based on the long-term studies this is clearly no longer the case today.

2. The Agility Total Ankle System

Endotec has chosen the following articles as examples of the high rate of complications associated with a semi-constrained device that is cleared by the FDA and legally marketed throughout the United States.

55. Saltzman CL Et al, Challenges With Initial use of a Total Ankle, Presented to the *American Academy of Orthopedic Surgeons, 67th Annual Meeting*, Wed., March 15 to Sun., March 19, 2000.

There were 26 patients in the study. The average age was 63 (range: 38-85 years). There were three postoperative deep infections. One deep infection was treated with debridement and placement of an antibiotic-impregnated cement spacer. Two required implant removal and attempted ankle arthrodesis. One arthrodesis failed and was subsequently treated with below the knee amputation. Five of the seven rheumatoid patients in this study had delayed fusion of their syndesmosis at six months. The average orientation of the tibial component on the anterior/ posterior radiograph was 86 degrees (range: 76-96) and on the lateral radiograph it was 88 degrees (range 73-98). 22 patients reported increased function, 20 decreased pain and 18 decreased pain with medication use.

51. Rippstein P.: Agility Ankle Prosthesis: Result of 27 Cases. AOFAS 2000 Meeting Annual summer Meeting, 2000.

A total of 27 ankles were implanted in 25 patients. 19 PTA and 8 RA. Mean age 56.9 years. Mean follow-up 14.7 months. Eight revisions. Four seriously migrated. Two removed and ankle fused, one had tibial replacement, another was asymptomatic and left implanted. One early deep infection successfully treated. One case of complicated and painful tibial is nerve neuropathy. Three revisions due to bony proliferation on the resected talus area, which was painfully impinging on the tibial component during dorsal extension. One Dwyer osteotomy performed as a result of medial ankle pain due to a varus malposition in the previously fused subtalar joint.

The author admitted that the high complication rate could be improved with further surgical experience, yet expressed serious concerns about the difficulty of performing any future potential fusion.

50. Pyevich, M. T. et al: Total ankle arthroplasty: A unique design. 5. *Bone Joint Surg.* 80: 1410-1420, 1998.

There were 100 ankles were implanted in 95 patients. 12 patients died leaving 86 ankles. The average age was 63 years. Average follow-up 4.8 years. Five revisions. Twenty-one (24%) components had migrated. Twenty-eight ankles suffered delayed union of syndesmosis fusion and nine non-union associated with the development of lysis around the tibial component. Non-union of the syndesmosis was also associated with the migration of the tibial component. One removal resulting in ankle fusion. 55% of ankles were not painful. 28% mildly painful. 93% were satisfactory to the patients.

The author concluded that early clinical results with the Agility were encouraging, although radiographic findings remained a cause for concern. Long-term studies will clarify as to whether delayed union or non-union of the syndesmosis is associated with an increased rate of clinically important problems.

77. Spirt AA et al: Complications and Failure after Total Ankle Replacement. *J Bone Joint Surg Am.* 86-A(6):1161-1171, June 2004.

306 ankles were implanted in 303 patients. 85 patients (28%) underwent 127 reoperations for debridement of heterotopic bone (58), correction of axial malalignment (40) component replacment (31). Survivorship with failure as an endpoint was 80%. With reoperation as the endpoint was 54%.

The authors concluded that there was a relatively high rate of reoperation due to complications. Younger age was found to be a negative effect on reoperation and failure.

The four studies are summarized as follows:

Study	Saltzman (55)	Rippstein (51)	Pyevich (50)	Spirit (77)
Device	Agility TAR	Agility TAR	Agility TAR	Agility TAR
Number of cases	26	27	86	306
Age (mean)	63	57	63	53
Follow-up	Mean 39 mths (24-52 mths)	Mean 15 mths (5-22 mths)	Average 5 years (3-12 years)	Average 2.5 Years (2-6 years)
Delayed union of syndemosis	10 (38%)	-	28 (29%)	14(5%)
Revision fusion of syndemosis	2 (8%)	-	8 (9%)	14(5%)
Debridement	-	-	-	69(23%)
Achilles tendon lengthening	2 (8%)	-	-	-
Component exchange	-	4 (15%)	4 (5%)	31(10%)
Below Knee Amputation	-	-	-	8(3%)
Malleolar fracture	6 (23%)	-	-	-
Infection	3 (12%)	1 (4%)	2 (2%)	11(4%)
Survivorship (%)	73	-	-	54
Patients reported decreased pain (%)	91	-	-	-

Of these studies that of Spirit et al is the most important since it is done by an independent group and has the largest number of cases. From this study the Agility seems clearly unacceptable for general use in ankle replacement.

3. The S.T.A.R. Total Ankle System

Clinical experience with what the FDA considers “non-constrained” devices are however favorable. Consider the studies of the S.T.A.R. device. These studies present the clinical result of the S.T.A.R. prosthesis over a ten-year time span. Four studies are as follows:

76. Valderrabano V, Hintermann B. & Dick W., : Scandinavian Total Ankle Replacement. *Clinical Orthop* 424:47-56, 2004

65 patients representing 68 S.T.A.R. arthroplasties were reviewed for 2-6 years. No infection occurred, no patients died during the follow-up. Early experience with the S.T.A.R. is encouraging, although more complications have been encountered than previously reported.

44. Schernberg F.: Current results of Ankle Arthroplasty – European Multi-center Study of Cementless Ankle Arthroplasty. *Chapter 9, Current Status of Ankle Arthroplasty, Berlin, Springer 1998, Kofoed H., ed.*

131 STAR ankles were implanted in a multi-center study covering six European sites. There were eight failures after 1-year and 5 failures after 2 years. No failures were seen after the 2-year follow-up mark. The good results depended upon good patient selection and good technical management of the procedure.

6. Kofoed H. :Scandinavian Total Ankle Replacement (STAR) . *Clinical Orthop* 424:73-79, 2004.

19 patients with rheumatoid arthritis were implanted with the STAR device. One patient only gained limited benefit from the procedure and some patients had revision surgery for progressive RA.

“(The STAR)...offers the patient satisfactory function, with low post-operative morbidity and low risk of complication. It provides excellent pain relief and, overall, at 3 years assessment, is “better” than open arthrodesis.”

46. Kofoed H. :Ankle Arthroplasty: Indications, Alignment, Stability and Gain in Mobility: Chapter 4, *Current Status of Ankle Arthroplasty, Berlin, Springer 1998, Kofoed H., ed.*

76 STAR devices were implanted. 44 had osteoarthritis, 22 had rheumatoid arthritis, 4 talar necrosis, 4 psoriatic arthritis, and a conversion of a previous fusion. Five failed of the OA, RA diagnoses and all four of the AVN sufferers. Yet, despite the failures the current results are competitive with the best results of arthrodesis, without contracting secondary sub-talar problems.

The author concluded that for good and lasting results, alignment and stability are mandatory. The early designs were too constrained to give stability resulting in a transfer all stresses to the bone-cement interface, leading to excessive loosening. Also, the spheroid design led to reliance on ligaments without certainty of maintaining the ankle axis. Conversely, the 3-part design offers both alignment and stability without overconstraint. They preserve both the axis of the ankle cylindrical motion and remain as anatomical as possible.

The four studies are summarized as follows:

Study	Valderrabano (78)	Schernburg (44)	Kofoed (6)	Kofoed (46)
Device	S.T.A.R . Mobile Bearing TAR	S.T.A.R . Mobile Bearing TAR	S.T.A.R . Mobile Bearing TAR	S.T.A.R . Mobile Bearing TAR
Number of cases	68	131	58	76
Age (mean)	56	-	59	56
Diagnosis	PTA, RA, OA	OA, RA	OA, RA	RA, OA PA, AVN, Fusion takedown
Follow-up	Mean 3.7 Year (2.4-6.2 years)	6 yrs	9 yrs	10 yrs
Delayed Wound Healing	-	-	-	-
Talar Subsidence	1 (4%)	-	-	-
Bearing subluxation	1 (4%)	-	-	-
Severe bearing wear	3 (13%)	-	-	-
Malleolar fracture	0 (0%)	-	-	-
Infection	0 (0%)	-	-	-
Reflex sympathetic Dystrophy	1 (6%)	-	1(2%)	-
Tibial component loosening	2 (9%)	-	6(10%)	-
Survivorship (Percentage)	-	87.3 (Kofoed, 1986)	82.7 (Kofoed, 1986)	86.7 (Kofoed, 1986)
Average Overall (Percentage)	85 (AOFAS)	85 (Kofoed, 1986)	83 (Kofoed, 1986)	-

4. The predecessor: B-P Total Ankle System (Shallow Sulcus)

The predecessor for the B-P ankle first implanted in 1978 was more successful than the typical semi-constrained devices. Unfortunately it suffered from a problem, which although unrelated to constraint, caused the device to be abandoned and redesigned. Endotec has summarized six mobile bearing clinical studies associated with this early mobile bearing design. These studies represent the prototype's predecessor over a twenty-year time span. Studies 5, and 20 as well as those of 10, 43 and 81 by Dr. Buechel elements of the population group of Ref. 5 studied over different periods of time. Further the study of Ref. 28 uses Dr. Buechel's patients as part of the study group. The study of Doets is independent of the other studies of this group of studies. The four studies are as follows:

5. Buechel .F.F, Buechel F.F. Jr., and Pappas M.J., :Twenty Year Evaluation of Cementless Mobile-Bearing Total Ankle Replacements. *Clinical Orthop.* 424:19-26, 2004.

There were 38 patients implanted with 40 ankles over an eighteen-year time span. Mean age was 55 years. Using a strict ankle scoring system, twenty-eight (70%) patients reported good/excellent results. One patient developed a fracture of the loading plate. Two patients had tibial components revised as a result of excessive wear. No tibial components were noted as clinically loose, all revised tibial components were stable at time of revision. Bearing subluxation problems occurred in 10% of cases. Talar subsidence occurred in 15% of cases. Both were rectified by a revised design (see 5. The prototype: B-P TAR, deep sulcus). Cumulative survivorship using an endpoint of revision of any component was 74.2% at eighteen years.

The author concluded that the mobile bearing greatly improved the ability of surgeons to replace ankles while minimizing wear and loosening problems. Design improvements, such as the deepening the sulcus while maintaining bispherical congruity of the bearing surface, have enhanced the longevity of the device.

20. Buechel F. F. and Pappas M.J et al.: New Jersey Low-Contact Stress Ankle Replacement: Biochemical Rationale and Review of 23 Cementless Cases: *American Orthopedic Foot and Ankle Society*, 1988, 279-290.

There were 21 patients implanted with 23 ankles. The mean age was 56 years. The follow-up period ranged from 24 months to 64 months with a mean of 35.3 months. The pre-operative ROM arc was 15 to 24 degrees. Post-operatively mean arc was 25 to 34 degrees. Postoperatively, 87% of ankles had no pain or, at most, mild pain and all had an improvement on their preoperative condition.

The author concluded unconstrained congruent bearing elements of the trochlear design appear to work well in patients throughout the 5-year period.

28. Keblish P.A.: Cementless Meniscal Bearing (Shallow Sulcus) TAR: *Multicenter Clinical Trial of 237. Unpublished.*

There were 237 patients implanted in 72 months. The mean age was 57 years. Survivorship was 90.7% and good to excellent results of 81.5% and 77% of patients had no/slight pain. 25 ankles were removed and 14 required arthrodesis.

The author concluded, "in order for total ankle replacement to gain general acceptance as a viable surgical option, several criterion must be met:

- ❖ Prosthetic design must permit optimal contact stress at the articulating surfaces and optimal fixation (preferably biological);
- ❖ Stability must be enhanced without compromising mobility;
- ❖ Strict criteria for surgical indications must be established;
- ❖ Arthrodesis must be a reasonable option as a salvage procedure (e.g. minimal bone resection)."

Cementless, meniscal bearing ankle systems fit this criterion.

Furthermore, "The complication rate is high...increased sensitivity in patient selection and surgical technique should decrease the complications and failure rate".

79. Doets H.C.: 6 (2-13) Year Results with the LCS/Buechel-Pappas Mobile Bearing Prosthesis. ERASS, 2002.

There were 58 prostheses implanted in 50 patients. 42 were women (8 bilateral) and 8 were men, 54 were diagnosed with rheumatoid arthritis, 3 with juvenile chronic arthritis and 1 with psoriatic arthritis. Mean age was 55 (22-77). Six patients (seven ankles) died of causes unrelated to the device. Ten had to be converted to Arthrodesis, six for a varus or a valgus deformity and 3 for aseptic loosening of the tibial component and one for an early deep infection. Mean post-operative score improved from 37 to 74/100.

The author concluded that for polyarthritis the LCS/Buechel-Pappas TAP give good clinical results if correct alignment is achieved in surgery.

14. Doets H.C.: The Low Contact Stress/Buechel-Pappas Total Ankle Prosthesis: *Chapter 6 Current Status of Ankle Arthroplasty, Berlin, Springer 1998, Kofoed H., ed.*

There were 30 prostheses implanted in 28 patients, 20 shallow-sulcus, the remaining number with the Buechel-Pappas prosthesis. The average age was 56 years. 25 of the number were diagnosed with rheumatoid arthritis the rest with juvenile chronic arthritis, psoriatic arthritis and osteoarthritis. Three patients (four ankles) died of causes unrelated to the device. Four failed and were successfully converted to arthrodesis. Average post-operative score was 84/100.

The author concluded "Compared with two-component designs, the mobile bearing LCS/Buechel-Pappas TAP provides much better results, with low incidence of mechanical loosening." Furthermore, "With the STAR, also a three-component resurfacing design...similar good results have been reported. This demonstrates that in the ankle joint there is only place for a TAP, which uses a mobile bearing, and that the use of the two-component design is no longer indicated".

78. San Giovanni T. et al: Long-term follow-up with second generation, cementless Total Ankle Replacement. *Annual meeting of the American Orthopedic Foot and Ankle Society (AOFAS), Summer 1999.*

There were 21 prostheses implanted in 16 patients. Mean follow-up 5.5 years. 18/21 had excellent results with no to mild pain. 3/21 had radiographic changes in component position. Two patients suffered talar subsidence and one a tibial component loosening. No polyethylene subluxation was noted. Three prostheses were considered failures. One prosthesis was removed secondary to deep infection (prosthesis revised). One had a polyethylene exchange for painful talar subsidence. A third prosthesis displayed tibial component loosening and will require revision or arthrodesis. The authors concluded: "The present study with intermediate-term follow-up demonstrates encouraging results with the use of a cementless, minimally constrained total ankle replacement...The overall patient satisfaction was high."

As can be seen from the table below, putting aside the problems of talar subsidence and bearing subluxation (See section IX. Historical Background: 2. Evolution of the prototype, B-P Total Ankle Replacement System), there are few device related complications. The dominant complications are medical and surgical which can be dealt with by improvement in instrumentation and operative and surgical techniques.

The four studies are summarized as follows:

Study	Buechel (5)	Buechel (20)	Keblish (28)	Doets (79)	Doets (14)	San Giovanni (78)
Device	NJ LCS TAR (Shallow Sulcus)					
Number of cases	38	21	237	58	28	21
Age (mean)	55	56	57	55	56	-
Diagnosis	PTA, OA, RA	PTA, OA, RA, AVN	PTA, OA, RA	RA, JCA, PA	RA, JCA, PA, OA	RA
Follow-up	Mean 10 Yrs (2-28 Yrs)	Mean 35 mths (24 - 64 mths)	Mean 45 mths (18 - 72 mths)	Avg. 6 Yrs (2 - 13 Yrs)	Avg. 6 Yrs (3 - 9 Yrs)	Mean 5.5 yrs (3.3-9.0 yrs)
Delayed Wound Healing	9 (24%)	4 (19%)	2 (1%)	0 (0%)	3 (11%)	-
Talar Subsidence	6 (16%)	0 (0%)	3 (2%)	0 (0%)	0 (0%)	2 (10%)
Bearing subluxation	4 (10%)	1 (5%)	11(5%)	0 (0%)	3 (11%)	0 (0%)
Severe bearing wear	4 (11%)	0 (0%)	17 (7%)	2 (3%)	0 (0%)	1 (5%)
Malleolar fracture	3 (8%)	1 (5%)	6 (11%)	-	5 (18%)	-
Infection	2 (5%)	1 (5%)	9 (4%)	1 (2%)	1 (4%)	2 (10%)
Reflex sympathetic Dystrophy	2 (5%)	2 (10%)	1 (1%)	0 (0%)	0 (0%)	-
Varus/ Valgus Deformity	-	-	-	6 (10%)	-	-
Tibial component loosening	0 (0%)	0 (0%)	6 (3%)	3 (5%)	1 (4%)	1 (5%)
Survivorship (Percentage)	74.2 (Kaplan-Meier)	100 (Kaplan-Meier)	90.7 (Kaplan-Meier)	-	75 (Kaplan-Meier)	-
Average Overall (Percentage)	70 (NJOHAEF)	83.7 (NJOHAEF)	81.5 (NJOHAEF)	74 (NJOHAEF)	84 (NJOHAEF)	87 (AOFAS)

5. B-P Total Ankle System (Deep Sulcus)*

The original design was modified to improve talar fixation. This modification reduced talar subsidence and the risk of bearing subluxation and subsequently limited severe bearing wear. The results of this modification are given in:

5. Buechel F.F, Buechel F.F. Jr., and Pappas M.J., :Twenty Year Evaluation of Cementless Mobile-Bearing Total Ankle Replacements. *Clinical Orthop.* 424:19-26, 2004.

There were 74 patients (75 implants) implanted over a twelve-year time span. Using a strict ankle scoring system, the system had good/excellent results in 88% of the cases. Cumulative survivorship using an endpoint of revision of any component was 92%.

The authors concluded that mobile-bearings improve the success of total ankle replacement by minimizing wear and loosening problems.

“Considering the current status of ankle fusion and progressive hindfoot arthritis known to follow, cementless, mobile-bearing ankle replacement, with the ability to exchange worn bearings if needed, offers a reasonable alternative in properly selected patients”.

16. Rippstein P.F., :Clinical experiences with three different designs of ankle prostheses. *Foot Ankle Clin N Am.* 7:817-931, 2002.

There were 25 patients (25 implants) implanted over a ten-year time span. Using a strict ankle scoring system, the system had good/excellent results in 94% of the cases. Cumulative survivorship using an endpoint of revision of any component was 88%.

The authors concluded that the B-P prosthesis design was technically easier to implant and was the preferred for most ankle replacements.

92. Su E.P., Kahn B., and Figgie M.P., :Total Ankle Replacement in Patients with Rheumatoid Arthritis. *Clinical Orthop.* 424:32-38, 2004.

There were 19 patients (18 implants) implanted over a ten-year time span. Using a strict ankle scoring system, the system had good/excellent results in 79% of the cases. Cumulative survivorship using an endpoint of revision of any component was 95%.

The authors concluded that the early to intermediate results in patients with end-stage RA show that they are doing well.

11. Endotec Inc.: 2003 IDE Annual Progress Report: Result of 51 cases. *IDE #G970158 FDA Submittal, December 2003.*

* Also see reference 79. Doets H.C.: 6 (2-13) Year Results with the LCS/Buechel-Pappas Mobile Bearing Prosthesis. ERASS ,2002.

There were 51 Patients implanted with a mean follow-up of 36 months. Using a strict ankle scoring system average post-operative total score amounted to 85/100. 3 prostheses were removed due to infection. No device failures were reported to date.

The study is summarized as follows:

Study	Buechel (5)	Rippstein (16)	Su (92)	Endotec (11)
Device	Buechel-Pappas TAR	Buechel-Pappas TAR	Buechel-Pappas TAR	Buechel-Pappas TAR
Number of cases	74	25	19	58
Age (mean)	49	56	50	49
Diagnosis	PTA, OA, RA	PTA, OA, RA	RA	PTA, OA, RA, AVN, Polio
Follow-up	Mean 5 Years	Mean 2 Years	Mean 4.4 Years	Mean 12 mths (3 - 33 mths)
Delayed Wound Healing	11 (14.7%)	0 (0%)	0 (0%)	2 (2%)
Talar Subsidence	3 (4.0%)	1 (4%)	0 (0%)	0 (0%)
Bearing subluxation	0 (0%)	0 (0%)	1 (5%)	0 (0%)
Severe bearing wear	3 (4.0%)	0 (0%)	0 (0%)	0 (0%)
Malleolar fracture	6 (6.0%)	0 (0%)	0 (0%)	6 (6%)
Infection	2 (2.7%)	1 (4%)	1 (5%)	5 (7%)
Reflex sympathetic Dystrophy	3 (4.0%)	0 (0%)	0 (0%)	0 (0%)
Tibial component loosening	0 (0%)	0 (0%)	2 (11.5%)	0 (0%)
Survivorship (%)	92 (Kaplan-Meier)	88	95	-
Average Overall (%)	88 (NJOHAEF)	94 (VAS Scale)	79 (AOFAS)	84 (NJOHAEF)

From Ref. 5 it may be seen that talar subsidence is greatly reduced compared to the original design and that bearing subluxation was completely eliminated. The single case of severe bearing wear in Ref. 5 was the result of a tibial component malpositioning. In this case, only half of the bearing engaged the tibial component articulating surface plate. This mal-positioning produced significantly increased contact stresses and accelerated the bearing wear due to the metal edge of the plate wiping over the bearing during ankle motion.

6. Additional references

Lewis⁸⁰, and Saltzman^{81-82, 84} review the state of the art of the current ankle devices and find that they, with cautious use, have a place in ankle treatment. Saltzman et al in Ref. 84 describes the effect of the Agility device on ankle ligaments. Jung et al⁸⁵ propose the use of plating to reduce syndesmosis nonunion common with the Agility device. Grisberg et al⁸⁶ describe and discuss revision of painful ankle fusion with an Agility ankle replacement and conclude it may be preferable to amputation of the foot. McGarvey et al⁸⁷ compare malleolar fractures in the S.T.A.R. and Agility devices, a significant complication in ankle replacement, and suggest means for its reduction and treatment.

Kobayashi et al⁸⁸ describe the nature of wear particles in knee and ankle replacements and find them similar. Of interest they find similar wear in the congruent S.T.A.R. and incongruent Agility devices. Nicholson et al⁸⁹ find that the contact stress of the incongruent Agility device is within the yield strength of UHMWPE and that this stress is excessive at least for some patients.

Wood et al⁹⁰ compare a cemented incongruent ankle device with an uncemented congruent mobile bearing device and finds that the latter is far superior.

Buechel et al⁹³ review the design rationale and clinical performance of the Mark I (shallow sulcus) and Mark II (deep sulcus) B-P ankle devices over an 18 year period and show that the survival rate for the Mark II is similar to typical knees and hips and that both the Mark I and II have much greater survival than the Agility. Edwin et al⁹⁴ report on the generally successful application of the Mark II B-P device for the replacement of the ankle in Rheumatoids.

Bonnin et al⁹¹, Hintermann et al⁹⁴ and Leardini et al⁹⁵ describe newer mobile bearing ankle devices for which indicate generally good performance.

Thus these additional references reinforce conclusions that can reasonably be made on the basis of the references and data cited in the earlier sections.

XIII. Medical device reports and adverse events

To date 16 complaints have been received.

Three (3) complaints were received as a result of improper packaging. The findings of the Endotec complaint review committee determined that the cause of the improper packaging was a result of human error. In this case, the procedures and inspection steps in place to safeguard against such eventualities were not followed, resulting in the error. The personnel involved received a verbal warning.

Eight (8) complaints were received as a result of Malleolar/Talar Oestolysis. In all cases the Talar component was found to be oversized and the corrective action was additional guidance regarding size selection and alignment being added to the surgical procedure.

Three (3) complaints were received regarding porous coating failure. In all cases severe component loosening or malalignment was found to be the cause.

Two (2) complaints were received regarding component fracture. One was the result of tibial mal-alignment the other's cause was unknown after an extensive investigation.

XIV. Summary of Devices currently available

There are no devices currently available in the U.S.A. in the 888.3120 category since they are Class III. Clinical trials are now in progress on several devices fitting 888.3120. Only the Class II Agility ankle that falls within 888.3110 is now available in the U.S.A, to the best of our knowledge.

XV. Conclusion

The data presented herein demonstrates within a sufficient degree of scientific certainty such that one can reasonably conclude that:

1. The scientific validity of the clinical and laboratory data presented on the performance and characteristics of devices fitting the generic description proposed in this petition is at least equal to the scientific validity of the data used to obtain a Class II designation for devices fitting 21 CFR 888.3110.

2. Devices fitting the identification and description of the proposed sub-type of 888.3120 do not have any greater, and probably far lower, risks associated with them, than commercially available devices.
3. The B-P device fits this proposed identification and description.

Thus, to minimize the well-known damage resulting from use of devices fitting 888.3110 the petition for this new sub-classification should be granted and the B-P Ankle device reclassified into Class II so that surgeons will have a viable option for ankle replacement.

XVI. Bibliography

Endotec performed a MEDLINE search using the key words of 'ankle arthroplasty' and 'ankle arthroplasty complication'. The bibliography presented represents a relevant selection of the material from over two hundred references. In addition, Endotec added some references from our own private research of the subject.

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