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Pretibial Injury: Key Factors and Their Use in Developing Laboratory Test Methods

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Aims were to 1 characterize pretibial injuries and evaluate protection offered by garments/fabrics; and 2 develop a laboratory test to determine the potential protection provided by such fabrics. Most (>85%) of 75 patients treated for pretibial injury at Hutt Hospital, New Zealand sustained injury to one site and required surgery. Injuries were typically grade 3 or 4, 10-250 mm wide 30-350 mm long, and at the mid- to lower third of the tibia. The severity grade was lower when at least one fabric layer covered the site, slightly lower again with more than one layer, and when a knitted fabric/garment was worn, and a trouser type garment. Laboratory test methods and their application reflected these known variables. The force transmitted through multiple fabric layers was less then through one layer: thick pantyhouse and either denim or fabrics used in 'sweat pants' would minimize transmitted force and maximize impulse.

Keywords: pretibial; clothing; fabrics; test methods; impact

Pretibial injury in individuals older than 50 years is a significant health problem in New Zealand, and the epidemiology of such injuries has been established.[1] Although some information surrounding the injury has been identified, the principal data source, that is, discharge from a public hospital provides insufficient detail to allow full characterization of this form of injury and therefore is insufficient for developing an appropriate intervention. Information on clothing worn at the time, for example, was unavailable. What is known is that the injured are mostly females[1] (also A. Bialostocki, personal research from Wellington Regional Plastic, Maxillofacial and Burns Surgery Unit, unpublished data, 1998), mostly aged 70 to 90 years,[1] and more than half the injury events occur in the home caused by household items and furniture.[1,2] The predominance of females has been attributed in part to clothing fashion women's legs being bare or inadequately covered,[3,4] although there is no clear evidence to support this.

The use of clothing and textile products for protection is common, and protective properties of apparel and apparel fabrics have been examined for many years.[5,6] Properties of workplace protective clothing are measured using standard test methods, for example, International Organization for Standardization (ISO); European (EN); Australian/New Zealand (AS/NZS). Protective devices for the pretibial region are used in some sporting activities and are designed to prevent tibial fracture, abrasions, contusions, and lacerations,[7] although no

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published reference on protective devices for preventing or for decreasing the severity of pretibial injuries that occur during everyday activities has been identified. Devices for preventing hip fractures have been investigated[8-10] and there is literature on products such as hip pads,[11-13] a review of randomized trials,[14] and acceptability.[15,16]

Whether use of protective clothing/products reduces the incidence and/or severity of injury is difficult to determine. This is in part, at least in New Zealand, due to the paucity of detail on what was worn at the time of injury recorded during hospital admission/discharge. Even when protective clothing/equipment is mandatory, whether the injured person was wearing the item as recommended, and whether the item remained in position during the injury event is usually not documented. Additionally, test methods to develop and determine product performance generally do not adequately reflect the event leading to an injury.

Theoretically, compression of a single layer of fabric by a plate occurs as 3 stages: contact with protruding fibers on the fabric surface, reduction in size of interstitial spaces between fibers, and through-thickness compression of fibers.[17,18] That the measured thickness of a fabric is affected by the pressure applied and the surface area over which it is measured is well recognized.[17,19] The pressure–thickness relationship of a fabric can be determined instrumentally using universal test machines with compression load cells.[20,21] Several fiber, yarn, fabric structure, and finishing parameters reportedly influence the pressure–thickness responses of fabrics as single layers.[17,22-25] The compression behavior of multiple layers of fabric is influenced by yarn cross-section deformation, flattening, and bending; and consolidation and nesting of voids.[26-28]

Reports on impacting single and multiple layers of woven and knitted apparel fabrics are sparse. A pendulum, common in many laboratories, has been used to impact on several apparel fabrics such as cotton twill, wool twill, cotton fleece knit, cotton double knit, acrylic double knit, and the energy loss during the impact event calculated from changes in potential energy of the pendulum.[29] Impacting on other types of materials (eg, foam, composites) and products (eg, helmets, shin-guards) has been widely reported, usually involving the guided free fall of an impact device on the specimen.[30]

The aims of the study presented in this article were to characterize pretibial injuries and to evaluate the protection against tibial impact offered by typical garments/fabrics in part 1. In part 2, we aimed to develop a laboratory test and to determine the potential protection against impact provided by typical apparel fabrics and combinations.

Part 1

Methods

Ethical approval to carry out the study was obtained from the Health Funding Authority Southern Regional Ethics Committee (Otago) and a Secondary Ethics Committee (Wellington, 98/11/091).

A record of events surrounding a pretibial injury was made using a detailed prospective survey of consecutive injured patients presenting to the Wellington Regional Plastic, Maxillofacial and Burns Unit at Hutt Hospital (HH), Wellington, New Zealand. The sample consisted of all persons aged 50 years and older presenting with a pretibial injury to the unit until the sample size required for the power level was obtained (n = 75). All those presenting during the period January 1999 to November 2000 were invited to participate in the study. Of these, 22 were excluded for a variety of reasons, including

- delayed presentation of 2 to 4 weeks after the injury,
- having been treated conservatively in the community (n = 15), and
- dementia (n = 7).

Patients seen at HH Emergency Department who were deemed to not require surgery were not included in the study, although the number of patients in this category is unknown. They were likely to have had minor injuries similar to those seen by general practitioners and to have been treated conservatively.

Demographic data of the patients, circumstances surrounding the injury event, anatomical location of the injury, the injurious agent, the injury type, and information on clothing worn both at the time of the event and typically as everyday wear, were obtained from each participant. Severity of the injury was graded using a 6-point ordinal scale (1 = hematoma, 2 = skin degloved at the dermal–epidermal junction, 3 = skin degloved at the subcutaneous level, 4 = skin degloved at the prefascial and preperiosteal level (with fascia and/or periosteum uninjured), 5 = skin degloved at prefascial level (with

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fascia injured) or a subfascial level, 6 = loss of periosteum and/or exposed tendon and/or bone). Clothing worn at the time of the injury was classified on the number of fabric layers covering the pretibial site: 0 = bare/none, 1 = one, 2 = two, 3 = three. Combinations of clothing worn at that time were recorded, as were estimates of thickness of the various fabrics that constituted the outermost covering using fabric samples from which the patient indicated an approximate thickness.

Data were analyzed using the Statistical Package for the Social Sciences.[31] Descriptive statistics were calculated and contingency tables analysed using the χ^2 analysis. In identifying any link between clothing practices and injury, two approaches were taken: analyses of data on all patients, and analyses of data on those patients whose pretibial area was reportedly covered at the time of the event.

Results

Patients, their general health, and the injury. There was a preponderance of women in the sample with a mean age of 80 years (typically aged 73-93 years), and most patients lived alone or with family at the time of the injury. These data are presented in Table 1. Three-quarters of the sample reported not having previously sustained a pretibial injury, but of those who had, one or two previous incidents were typical. Almost one-quarter of the participants were reportedly taking steroids at the time (although relevant information on medication was not recorded for approximately 10%). The three most common associated conditions were ischemic heart disease, chronic obstructive respiratory disease, and reduced general mobility mainly caused by osteoarthritis.

Most patients were treated as inpatients (n = 69, 92.0%), sustained injury to one site only (n = 72, 96.0%), and required surgery (n = 63, 84.0%). Injuries and their treatments are described in Table 2. Most injuries were graded 3 or 4 (n = 52, 70.3%), with those graded 2 considered to result from shearing rather than direct impact. Injuries were generally to the middle or lower third of the pretibial region (n = 39, 50.0% and n = 29, 37.7%, respectively), and flaps proximally or laterally based (n = 37, 50.7% and n = 29, 39.7%, respectively). The most common injury types and locations were proximally-based flaps, to the middle or lower third (n = 18, 23.7%, and n = 16, 21.1%, respectively), and laterally-based flaps to the middle of the leg (n = 15, 19.7%). Dimensions of the injury varied in width from 10 to 250 mm, in length from 30 to 350 mm, the most common being 30 × 30 to 30 × 80 mm (n = 11, 14.1%), 40 × 40 to 40 × 80 mm (n = 10, 12.8%), and 20 × 40 to 20 × 80 mm (n = 7, 9.0%). Dimensions/areas were significantly related to the grade for injury severity (2-4) (χ^2_4 = 11.41, $P \leq .05$) (injuries grouped by approximate area 1 = <300 mm^2, 2 = 310 to 600 mm^2, 3 = ≥610 mm^2). These data are presented in Table 2.

Circumstances surrounding the injury. More than 40% of injuries occurred during autumn (March, n = 12, 16.0%; April, n = 9, 12.0%; May, n = 10, 13.3%), typically mid-morning (9:30-11:30 am; n = 28, 37.3%). More than half the patients were *inside* their home or nursing home (n = 39, 52.0% and n = 5, 6.7%, respectively) at the time of injury. Stumbling/tripping (n = 21, 28.0%) or slipping (n = 20, 26.7%; not necessarily while mobilizing) together accounted for more than half the explanations as to how the injury occurred (n = 41, 54.7%); bumping into an object (n = 14, 18.6%) or falling (n = 12, 16.0%; the latter, typically from loss of consciousness) together accounted for another one third (n = 26, 34.6%). The most common objects collided against were furniture/household items (n = 33, 44.0%; stools, chairs, beds, coffee tables, lounge suites); vehicles (n = 11, 14.7%), the pavement (n = 10, 13.3%), garden items (n = 9, 12.0%), and steps/stairs (n = 8, 10.7%) were also named by respondents. Half of all contact surfaces reportedly involved were either metal or concrete (n = 22, 29.3% and n = 15, 20.0%, respectively), and edges and steps were the most common surface shapes of objects named (n = 41, 54.7% and n = 8, 10.6%, respectively). Edges of objects were commonly implicated when an item was bumped into (n = 12, 16.0%), when falling or falling flat (n = 5, 6.7% and n = 4, 5.3%, respectively), and/or when slipping or tripping (n = 10, 13.3% and n = 12, 16.0%, respectively).

Most patients reported wearing the clothing they wore normally at the time of injury (n = 67, 89.3%). Clothing on the lower part of the body (including that on the feet in that mobility/stability can be affected) consisted of trouser-type garments (ie, trousers, pyjamas, long johns; males and females, n = 40, 53.3%; females only n = 33, 49.3%), or a skirt (females only n = 24, 35.8%; Tables 3 and 4). For those whose pretibial area was covered at the time (n = 54, 72.0%), most wore trousers/trouser-type garments (n = 40, 74.1%), either trousers only

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Table 1. Patient Details and General Health

	All Patients (n = 75)		Females Only (n = 67)	
	n	%	n	%
a. Patient details				
Gender				
Male	8	10.7	—	—
Female	67	89.3	67	100.0
Patient lives				
Alone	34	45.3	34	50.7
With family	32	42.7	25	37.3
Nursing home	7	9.3	7	10.5
Not recorded	2	2.7	1	1.5
b. General health				
Previous pretibial injuries				
No	57	76.0	51	76.1
Yes	18	24.0	16	23.9
If yes, number of previous pretibial injuries				
1	5	27.8	5	31.3
2	5	27.8	4	25.0
3	2	11.0	2	12.5
4	3	16.7	3	18.7
5 or more	3	16.7	2	12.5
If yes, side previously injured				
Right	4	22.2	3	18.8
Left	3	16.7	3	18.8
Both	11	61.1	10	62.4
Patient taking steroids?				
No	50	66.7	44	65.7
Yes	18	24.0	16	23.9
Not recorded	7	9.3	7	10.4
Past/associated medical and social history[a]				
Ischemic heart disease	32	42.7	25	37.3
CORD/asthma	24	32.0	22	32.8
Reduced mobility due to osteoarthritis	16	21.3	15	22.4
Confusion/dementia	9	12.0	9	13.4
Falls	8	10.7	6	8.9
Thin/atrophic/fragile skin	7	9.3	6	8.9
Blindness total/partial	7	9.3	6	8.9
Nonspecific poor mobility[b]	6	8.0	6	8.9
Spinal problems, polio, spinal fracture	6	8.0	5	7.5
Diabetes	5	6.7	5	7.5
CVA	3	4.0	2	3.0
Amputation of leg	1	1.3	1	1.5

NOTES: CORD = chronic obstructive respiratory disease; CVA = cerebrovascular accident.
[a] More than one condition per patient possible.
[b] Probably related to senility, general poor medical condition.

(n = 16, 21.3%) or trousers with socks (n = 13, 17.3%). Irrespective of whether or not the pretibial area was covered, socks were typically ankle length (n = 17, 89.5%). Trouser-type garments (mostly ankle length) (n = 31, 96.9%) were worn by about half, and skirts (either knee length or covering the calf) were worn by about one-third of the patients (n = 13, 54.2% and n = 10, 41.9% knee and calf length, respectively).

Of those patients whose pretibial region was covered, most wore 1 or 2 layers (n = 40, 74.0% and n = 12, 22.3%, respectively). Outer garments covering the lower limb were typically made from woven fabrics (eg, trouser-type garments n = 31, 79.5% of

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Table 2. Description of Injury[a]

	All Patients (n = 75)		Females Only (n = 67)	
	n	Valid %	n	Valid %
Anatomic site of injury				
Right	36	46.0	32	47.8
Left	42	54.0	38	56.7
Both legs	0	0.0	0	0.0
Position of injury				
Upper	6	8.0	5	7.5
Middle	39	50.0	36	53.7
Lower	29	37.7	25	37.3
Middle and lower	2	3.7	2	3.0
All three	2	3.7	2	3.0
Flap type				
Proximally based	37	50.7	33	50.8
Laterally based	29	39.7	26	40.0
Distally based	10	13.7	9	13.8
Not recorded	2	—	2	—
Classification of injury grade				
1. Hematoma only with no skin breaks	0	0.0	0	0.0
2. Skin degloved at the dermal–epidermal junction	17	23.0	15	22.7
3. Skin degloved at the subcutaneous level	27	36.5	26	39.4
4. Skin degloved at the prefascial and preperiosteal level (fascia and/or periosteum not injured)	25	33.8	20	30.3
5. Skin degloved at prefascial level (but fascia injured) or a subfascial level	3	4.1	3	4.5
6. Loss of periosteum and/or exposed tendons	3	4.1	3	4.5
Other	2	2.7	2	3.0
Not recorded	1	—	1	—
Type of surgery required				
Conservative treatment	11	14.9	8	12.1
Debridement and direct close	2	2.7	2	3.0
Debridement and split skin graft	61	82.4	56	84.9
Not recorded	1	—	1	—

[a] More than one injury per patient possible.

all trousers; skirts n = 9, 57.1% of all skirts), skirts considered "medium" or "heavy," and trousers "medium." Stockings/pantyhose/knee-highs and socks, of course, were knitted.

Walking shoes or slippers were commonly worn at the time of injury (n = 35, 47.9% and n = 19, 26.0%, respectively; Table 3). Slipping, tripping, and being bumped while wearing walking shoes (n = 13, 17.8%; n = 11, 15.1%; and n = 5, 6.8%, respectively), and falling and tripping when wearing slippers (n = 6, 8.2% and n = 5, 6.8%, respectively) accounted for the common footwear/injury records.

Is there an association between the injury and clothing practices? Five factors were considered in determining whether any links exist between the injury and clothing practices. These were

1. whether or not the pretibial area was covered;
2. if so, by how many layers of fabric;
3. the type of outer garment/fabric worn;
4. general properties of the fabric of the outer garment; and
5. the type of footwear worn.

The mean injury grade of those whose pretibial area was not covered at the time was 3.4. By comparison, the injury grades when 1 or 2 layers covered the site were 3.3 or 3.2, respectively. Thus, fabric layers seem to provide some protection although the results were generally not statistically significant for injury grades 2 to 4 (all patients; whether or not the pretibial site had been covered $\chi^2_2 = 0.42$, nonsignificant [NS]; the number of layers over the site (0, 1, 2, 3) $\chi^2_4 = 4.58$, NS; garment length $\chi^2_4 = 1.00$, NS). The number of cases in many categories was small,

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Table 3. Clothing Worn by Patients at Time of the Injury

	All Patients (n = 75)[a]		Females Only (n = 67)	
	n	Valid %	n	Valid %
Clothing worn on the lower body[b]				
None	1	1.3	1	1.5
Trousers	36	48.0	31	46.3
Skirt	24	32.0	24	35.8
Stockings, pantyhose, knee-highs	22	29.3	22	32.8
Socks	19	25.3	13	19.4
Dressing gown	5	6.8	5	7.5
Night gown	4	5.3	4	6.0
Pyjama bottoms	3	4.0	1	1.5
Shorts	2	2.7	1	1.5
Long johns	1	1.3	1	1.5
Footwear worn				
None	6	8.2	5	7.6
Walking shoes	35	47.9	33	50.0
Slippers	19	26.0	17	25.8
Sneakers	6	8.2	5	7.6
Rubber boots	2	2.8	2	3.0
Tramping/leather boots	2	2.8	1	1.5
Sandals	2	2.7	2	3.0
Jandals	1	1.4	1	1.5
Not recorded	2	—	1	—

[a] More than one garment per patient possible.
[b] Valid percentage of sample wearing each type of garment.

hence the lack of statistical significance was not surprising. The mean injury grades were 3.2 and 3.5 for those patients who wore trousers and those who wore a skirt respectively (the latter 3.6 when all patients were considered). Fabrics over the site were generally of "medium" thickness, but the thickness grade was not related to the injury grade (2-4; $\chi^2_4 = 4.24$, NS), nor, technically, was there a statistically significant relationship between the injury grade and the fabric structure ($\chi^2_2 = 5.78$, $P = .0555$ just below the accepted threshold for significance). Nevertheless, a higher proportion of patients who wore garments of knitted fabric had injuries graded as 2, whereas a higher proportion of patients who wore garments of woven fabrics had injuries graded as 3. This suggests fabric structure may be associated with the severity of the injury, at least at the lower end of the scale. The type of footwear worn was not related to the injury grade ($\chi^2_{10} = 11.67$, NS). When those barefooted, wearing walking shoes, and wearing slippers were examined, no relationship was identified with either key aspects of the medical history or the area injured (ie, small, medium, large; $\chi^2_{22} = 32.08$, NS; $\chi^2_4 = 1.39$, NS, respectively).

Part 2

Method

Impacting Devices

Two impacting devices were used. These are presented in Figure 1a and b. Each was connected to a personal computer via charge amplifiers and a PowerLab 16 SP (ADInstruments, Consultancy House, Dunedin, New Zealand). Data (voltage, time) were collected (not filtered) at 40 000 points per second (the maximum sample rate available) using Chart 4.2 for Windows (ADInstruments).

Pendulum. Fabric specimens (100 mm × 100 mm, n = 5) were arranged so the striker (flat, mass = 0.215 kg) impacted the technical face of the fabric under conditions of free fall initiated at varying angles to the vertical axis (15°, 45°, 90°; 0.04 J, 0.22 J, 0.59 J). The impact force transmitted through the specimen was measured using a quartz force sensor (ICP Model 208C01, range = 0.05 to 22 kN, hemispherical end cap; Industrial Technologies, Albany, Auckland, New Zealand) mounted behind

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Table 4. Garment Coverings[a] of Patients' Lower Limbs

	Garment Characteristic					
	n	%	n	%	n	%
All patients (n = 75)						
	Length					
	Knee		Calf		Ankle	
Stockings, pantyhose, knee-highs	18	100.0				
Socks	1	8.5	1	8.5	17	89.5
Skirt	13	54.2	10	41.7	1	4.1
Shorts	2	100.0	—	—	—	—
Trousers[b]	1	3.1	—	—	31	96.9
Night gown	—	—	2	50.0	2	50.0
Dressing gown	—	—	1	20.0	4	80.0
	Thickness					
	Thin		Medium		Thick	
Stockings, pantyhose, knee-highs	11	50.0	11	50.0	—	—
Skirt	—	—	11	47.8	12	52.2
Shorts	—	—	2	100.0	—	—
Trousers[b]	3	7.7	27	69.2	9	23.1
	Structure					
	Woven		Knitted			
Stockings, pantyhose, knee-highs	—	—	22	100.0		
Socks	—	—	19	100.0		
Skirt	9	42.9	12	57.1		
Shorts	2	100.0	—	—		
Trousers[b]	31	79.5	8	20.5		
Female patients only (n = 68)						
	Length					
	Knee		Calf		Ankle	
Stockings, pantyhose, knee-highs	18	100.0	—	—	—	—
Socks	1	7.7	—	—	12	92.3
Skirt	13	54.2	10	41.7	1	4.1
Shorts	1	100.0	—	—	—	—
Trousers[b]	1	3.6	—	—	27	96.4
Night gown	—	—	2	50.0	2	50.0
Dressing gown	—	—	1	33.3	2	66.7
	Thickness					
	Thin		Medium		Thick	
Stockings, pantyhose, knee-highs	11	50.0	11	50.0	—	—
Skirt	—	—	11	47.8	12	52.2
Shorts	—	—	1	100.0	—	—
Trousers[b]	2	6.3	22	68.7	8	25.0
	Structure					
	Woven		Knitted			
Stockings, pantyhose, knee-highs	—	—	22	100.0		
Socks	—	—	13	100.0		
Skirt	9	42.9	12	57.1		
Shorts	1	100.0	—	—		
Trousers[b]	24	75.0	8	25.0		

[a] More than one garment per patient possible.
[b] Includes pyjama bottoms and long johns.

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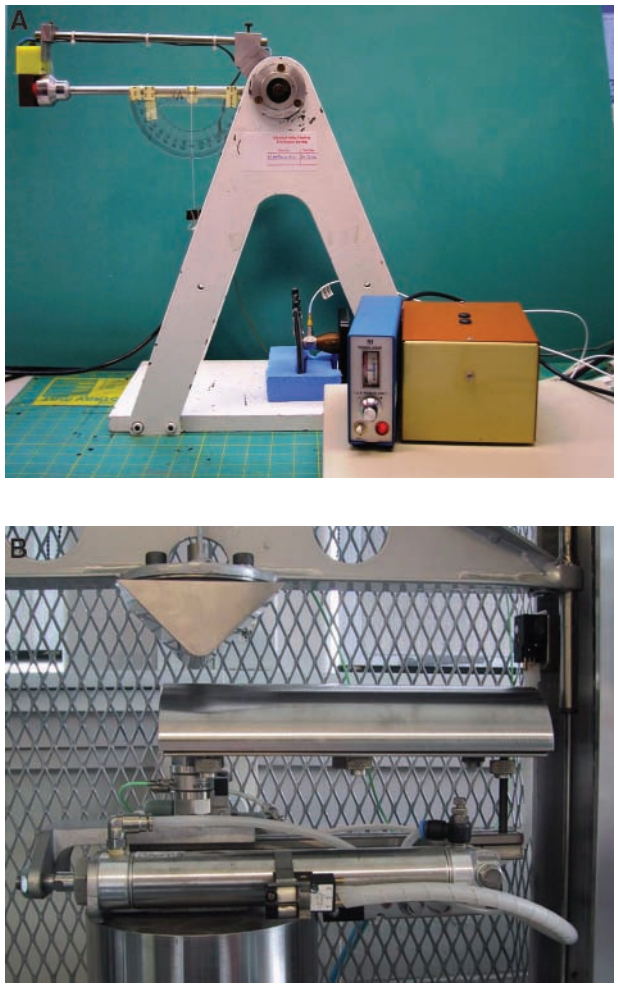

Figure 1. Impact instruments: (a) pendulum and (b) "impact and scrape."

the specimen. Data were transferred to a computer (volts–time) using a charge amplifier (PCB Model 484B; Industrial Technologies).

"Impact and scrape." This guided free-fall instrument was developed with reference to the typical injury event of bumping into and scraping along a "sharp" edge. Fabric specimens (200 mm × 200 mm, n = 5) were mounted, technical face up, on the "impact and scrape" anvil, a half-cylinder manufactured to represent dimensions/shapes of the non-injured shins of patients. A magnetic switch released the drop assembly (3 kg) from the crosshead. A kerbstone striker manufactured to dimensions in AS/NZS 2512.3.2:1997[32] was used to impact on the specimens, the edge perpendicular to fabric wales or warp and the long axis of the "impact and scrape" anvil, thus simulating the most likely real-life event (ie, edge of table, step). The anvil and striker were manufactured from steel, and although this experimental setup does not represent responses of the human body to an impact, it does allow differences in attenuation of impact by the fabric specimens without degradation in physical or mechanical properties of the anvil and striker. The impact energy (1.50 J) was calculated with reference to gait velocity of elderly persons (~1.0 m/s).[33] Initiation of the scrape by the striker and the length over which the striker scraped along the anvil were controlled by 2 magnetic slide switches, the scrape action driven by compressed air. The test length was 80 mm, the typical maximum length identified in part 1. The impact force transmitted through the specimen was measured using a quartz force sensor (Kistler type 9331B, range + 20 kN; Kistler Instruments, Rowville, Victoria, Australia) mounted under the anvil and connected to a charge amplifier (Kistler type 5037; Kistler Instruments).

Fabrics and Specimen Preparation

Fabrics represented those in clothing typically worn by the patients (Table 5), with specimens cut according to EN 12751:1999,[34] not pretreated but conditioned according to ISO 139:2005[35] and tested under these conditions (except for testing "impact and scrape"). Selected properties of each fabric were measured: mass per unit area (n = 5) as specified in EN 12127:1998[36] using a Mettler Toledo AT400 balance (accurate to 0.001 g; Mettler-Toledo GmbH, Lower Hutt, New Zealand; capacity 405 g) and a steel rule; thickness (n = 5) according to ISO 5084:1996[19] using a SDL Atlas MO34A digital thickness gauge (foot area = 20 cm^2, applied pressure = 1000 Pa; SDL Atlas Textile Testing Solutions, Stockport, UK; readable to 0.01 mm); and yarn density (warp/weft or wales/courses, n = 5) according to BS 5441: 1988[37] and ISO 7211/2:1984: ISO 7211/2:1984 (method B).[38]

Single-layer and 3-layer specimens of the same fabric were impacted using the pendulum instrument to ascertain if multiple layers of one fabric would attenuate impact forces differently from a single layer of that fabric. Single-layer and 2-layer specimens were impacted using the "impact and scrape" instrument, in this case the 2-layer specimens formed by overlocking fabrics typical of pantyhose, tights, stockings, knee highs (fabrics A and B; extended by ~30%) under fabrics typical of outerwear (fabrics C and D), thus representing combinations worn by patients. After conditioning, each

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Table 5. Properties of Selected Apparel Products/Fabrics

Fabric Property	Fabric Code				Reference
	A (Pantyhose, Thin)	B (Pantyhose, Thick)	C (Denim)	D (Sweat Pants)	
Fiber content[a]	100% polyamide, 15 denier	84% polyamide, 15% elastane, 1% cotton, 70 denier	95% cotton, 5% Spandex	100% cotton	100% cotton
Fabric structure	Single jersey, knit	Single jersey, knit	2 × 1 Z twill, woven	Single jersey, brushed inner, knit	Double-end plain, woven
Thickness (mm)					
Mean	0.49	0.76	0.87	1.90	0.88
SD	0.03	0.07	0.02	0.04	0.01
Mass per unit area (g/m^2)					
Mean	52.60	183.90	289.50	309.70	311.20
SD	2.25	8.04	1.72	0.96	2.07
Wales (warp) per 10 mm					
Mean	58.00	52.6	22.2	14.7	29.4
SD	5.52	3.13	0.45	0.27	0.55
Courses (weft) per 10 mm					
Mean	35.40	40.40	22.80	11.90	11.70
SD	2.95	5.73	0.84	2.00	0.27

NOTE: SD = standard deviation.
[a] As reported by the manufacturer.

specimen was placed in a sealed polymeric bag, transferred to the impact laboratory, and removed from the bag immediately before testing.

Experimental Design and Analysis

Specimens were impacted, in randomized blocks, with a reference fabric (single layer, n = 5, Table 5) impacted prior to and following each block. Environmental conditions in the impact laboratory were monitored using a Tiny Tag (Gemini Data Loggers; Tiny Tag Energy Engineering, Remuera, Auckland, New Zealand). Voltage data were converted to force (N) using calibration values provided with the force sensors. Each impact event, defined as the maximum recorded force ±200 data points, was extracted using a custom-written Fortran 77 computer program (GNU G95 Fortran compiler). For each event, the baseline force was taken as the mean of 50 data points before the start of the impulse, and the maximum transmitted force calculated by subtracting this baseline from the maximum recorded force. For a given impact energy, a lower transmitted force suggests that fabric has absorbed more energy, thus provides more protection. Calculation of the impulse of the impact event was also considered important, that is, to consider the time over which the force would be applied to the pretibial area. A force acting over a longer period allows the fabric to deform, and hence maximizes both the energy absorbed during deformation and the protection offered. For calculation, t_{start} was defined as the time at which the recorded force was equal to the baseline force plus 2 standard deviations, t_{end} as the time at which the maximum transmitted force was recorded, and $F = 0$ the baseline force.

Summary statistics were calculated for both maximum transmitted force and impulse (mean, standard deviation), and significance of differences attributable to the test variables identified by univariate analysis of variance where appropriate, with Tukey's multiple comparison tests used to identify significant differences among means.[39] When nonhomogeneity of variance precluded further analysis, relationships between mass per unit area and maximum force and impulse, and between thickness and

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mass per unit area and impulse were explored. Coefficients of determination (R^2) were calculated for relevant pairs of variables.

Results

Environmental conditions during impact testing were as follows: temperature, 20.5°C to 25.4°C; relative humidity, 37.7% to 52.7%. The results are summarized in Tables 6 and 7.

Pendulum. For a single layer, the maximum transmitted force ranged between 0.19 kN (sweat pants, 0.04 J) and 11.81 kN (thin pantyhose, 0.59 J) and the impulse between 0.09 N.s (thin pantyhose, 0.04 J) and 0.42 N.s (sweat pants, 0.59 J). Increasing the impact energy resulted in greater maximum transmitted forces and impulses. The maximum force transmitted through one layer of fabric seemed related to its mass per unit area (0.04 J, $R^2 = 0.92$; 0.22 J, $R^2 = 0.99$; 0.59 J, $R^2 = 0.91$). Again with single layers, for other paired variables (transmitted force vs thickness, impulse vs thickness, impulse vs mass per unit area) coefficients of determination ranged from $R^2 = 0.25$ to $R^2 = 0.85$, positive but nonsignificant.

The maximum transmitted force was generally lower and the impulse higher when impacting 3 layers than 1 layer of fabric, as expected, although the increasing protection offered by more fabric layers was not simply additive. The percentage reduction in transmitted force for the knitted fabrics decreased with increasing impact energy (eg, for fabric B: 0.04 J, by 75.49%; 0.22 J, by 59.98%; 0.59 J, by 40.10%). Interestingly, the percentage reduction was similar irrespective of impact energy with the woven fabric (0.04 J, by 59.75%; 0.22 J, by 64.34%; 0.59 J, by 59.66%). Three layers resulted in smaller percentage reductions for impulse than was the case with changes to maximum transmitted force, the difference generally larger at higher than at lower impact energies (eg, denim: 0.04 J, by 14.68%; 0.22 J, by 18.09%; 0.59 J, by 26.05%).

Visual examinations of fabric specimens following the impact test revealed yarn flattening as the main damage mechanism, with no evidence of penetration.

"Impact and scrape." The mean maximum transmitted force for single-layer specimens ranged from 12.65 kN to 15.54 kN and for 2-layer specimens from 10.80 kN to 12.04 kN. The type of fabric/combination

Table 6. Fabric Responses to Impact: Pendulum

	Fabric Code							
	A (Pantyhose, Thin)		B (Pantyhose, Thick)		C (Denim)		D (Sweat Pants)	
No. of layers	1	3	1	3	1	3	1	3
Maximum transmitted force (kN)								
0.04 J impact energy								
Mean	0.72	0.21	0.35	0.09	0.31	0.13	0.19	0.04
SD	0.04	0.01	0.01	0.01	0.02	0.01	0.01	0.01
0.22 J impact energy								
Mean	5.43	3.36	4.13	1.65	2.83	1.01	2.33	0.64
SD	0.11	0.06	0.09	0.11	0.10	0.05	0.04	0.06
0.59 J impact energy								
Mean	11.81	10.03	10.65	6.39	9.67	3.90	8.45	2.74
SD	0.21	0.18	0.50	0.20	0.21	0.10	0.13	0.34
Impulse to maximum transmitted force (N.s)								
0.04 J impact energy								
Mean	0.09	0.11	0.10	0.10	0.09	0.11	0.10	0.09
SD	0.01	0.00	0.00	0.01	0.01	0.02	0.01	0.01
0.22 J impact energy								
Mean	0.24	0.27	0.23	0.30	0.25	0.30	0.27	0.30
SD	0.02	0.03	0.02	0.01	0.02	0.02	0.01	0.02
0.59 J impact energy								
Mean	0.34	0.44	0.39	0.49	0.39	0.53	0.42	0.50
SD	0.07	0.08	0.09	0.05	0.06	0.02	0.06	0.04

NOTE: SD = standard deviation.

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Table 7. Fabric Responses to Impact: "Impact and Scrape" (Impact Energy = 1.5 J)

	Fabric: 1 Layer			
	A (Pantyhose Thin)	B (Pantyhose, Thick)	C (Denim)	D (Sweat pants)
Maximum transmitted force (kN)				
Mean	15.54	12.65	13.09	13.34
SD	0.11	0.33	0.26	0.11
Impulse to maximum transmitted force (N.s)				
Mean	3.11	2.32	2.41	2.66
SD	0.08	0.18	0.15	0.06

	Fabrics: 2 Layers			
	A + C (Pantyhose Thin + Denim)	A + D (Pantyhose Thin + Sweat Pants)	B + C (Pantyhose Thick + Denim)	B + D (Pantyhose Thick + Sweat Pants)
Maximum transmitted force (kN)				
Mean	11.85	12.04	10.80	11.26
SD	0.26	0.20	0.24	0.32
Impulse to maximum transmitted force (N.s)				
Mean	2.40	2.43	2.25	2.45
SD	0.09	0.11	0.07	0.13

Significance of Differences Among Fabrics (1 and 2 Layers) (Tukey Groups)

Maximum Transmitted Force (kN)

	Groups				
Fabrics	1	2	3	4	5
B + C	10.80				
B + D	11.26				
A + C		11.85			
A + D		12.04			
B			12.65		
C			13.09	13.09	
D				13.34	
A					15.54

Impulse to maximum transmitted force (N.s)

	Groups		
Fabrics	1	2	3
B + C	2.25		
B	2.32		
A + C	2.40		
C	2.41		
A + D	2.43	2.43	
B + D	2.45	2.45	
D		2.66	
A			3.11

NOTE: SD = standard deviation.

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affected the maximum transmitted force ($F_{7,32}$ = 186.54, $P \leq .001$), with 5 groups identified. Again, as expected, the force transmitted through 2 layers was less than that through 1 layer for all fabric combinations. Impacting thick pantyhose with denim and with sweat pants resulted in similar and the least force transmitted, and impacting thin pantyhose the greatest force transmitted. As a single layer, thick pantyhose transmitted the least force after impacting, and when part of a 2-layer arrangement (with denim, with sweat pants) transmitted ~11% to 15% less.

The mean impulse for fabrics as single layers ranged from 2.32 N.s to 3.11 N.s, and as 2 layers from 2.25 N.s to 2.45 N.s. The type of fabric affected the calculated impulse ($F_{7,32}$ = 27.14, $P \leq .001$), with 3 groups identified. The highest mean impulse was observed for thin pantyhose (3.11 N·s), with remaining fabrics in 2 overlapping groups: results for fabrics/fabric combinations that included the thick pantyhose and the denim (fabrics B + C, B, A + C, C) were similar and the lowest.

Visual examinations of specimens post impact revealed several forms of failure—yarn flattening, yarn severance, smearing (Figure 2). All single-layer specimens were penetrated, with yarn flattening, and fiber and yarn fracture evident. In 2-layer specimens, the layer first impacted was penetrated, with lesser damage evident on the lower specimen; and the lower specimen exhibited less damage than specimens impacted as single layers. This visual evidence is consistent with differences in the injury severity grades with increasing number of clothing layers observed in part 1.

Discussion

The study presented in this article was done in 2 parts. In the first part, the epidemiology of pretibial injury in our local community was studied. In the second part, attempts to model such injuries and the effect of everyday clothing in the context of injuries were studied. The results suggest that 4 aspects of the study warrant discussion, namely, the general health of patients, the details of the injury, clothing used and their properties, and the laboratory measurement of fabric properties.

A total of 25% of all patients had previously experienced a pretibial injury, and of those who had, 70% had experienced 2 or more such injuries. Thus, these pretibial injuries cannot be considered as one-off events, and they cannot be planned for either. Such injuries were experienced by patients otherwise generally not in good health. Interestingly, only 10% had previously experienced a fall, and only 10% reportedly had thin, atrophic, fragile skin, both issues commonly connected to the form of pretibial injury under study.

The left and right legs were equally prone to injury, and both legs had been injured in 60% of patients who sustained repeated injury. Most injuries involved the middle and lower part of the tibia, with either proximally-based or laterally-based flaps, and common dimensions were in the 20-40 × 30-80 mm range. A proximally-based flap seems likely to have resulted from tripping or slipping on a step, for example, presenting upwards and forwards towards the tibia, with the point of impact at the middle and lower leg. A laterally-based flap seems likely to have resulted from scraping the leg along a coffee table or similar object, perhaps when the leg was lifted up and striding forward, resulting in impact to the middle third, the force being directed laterally. Any values that these observations may possess have not been determined in this study.

In relation to clothing and its properties, the issues were whether the pretibial region was covered, clothing style at the gross level, and clothing fabrics. The pretibial region of most patients reportedly *was* covered at the time of injury. If one assumed that garments remained in place during the injury event, most patients could have had 1 or 2 layers over the shin region. The fact that those wearing trousers of some sort had a mean injury grade of 3.2 and those wearing a skirt a mean injury grade of 3.5 suggests trousers/trouser-type garments may offer slightly better protection, possibly because they do remain over the shin. Another layer such as knee-highs or socks worn under trousers may have confounded this set of results, as undergarments could not be taken into account. Implications of possible confounding are considered modest because most socks were ankle length and knee-highs are made typically from thin knitted fabric. No relationship between the type of footwear worn and pretibial injury was observed. The higher incidence of injury observed among women has been attributed to fashion, women typically wearing skirts and thus having uncovered or inadequately covered legs.[3,4] However, more female patients wore trousers than skirts and more than 70% of patients reportedly had their legs covered at the time of the injury. Most trousers and skirts were of woven fabrics, medium to heavy thickness, and most fabrics over the pretibial region were as a single layer. A slightly lower injury severity grade was observed with an increasing number of fabric layers (0, 1, 2), and wearing a knit (grade 2) rather

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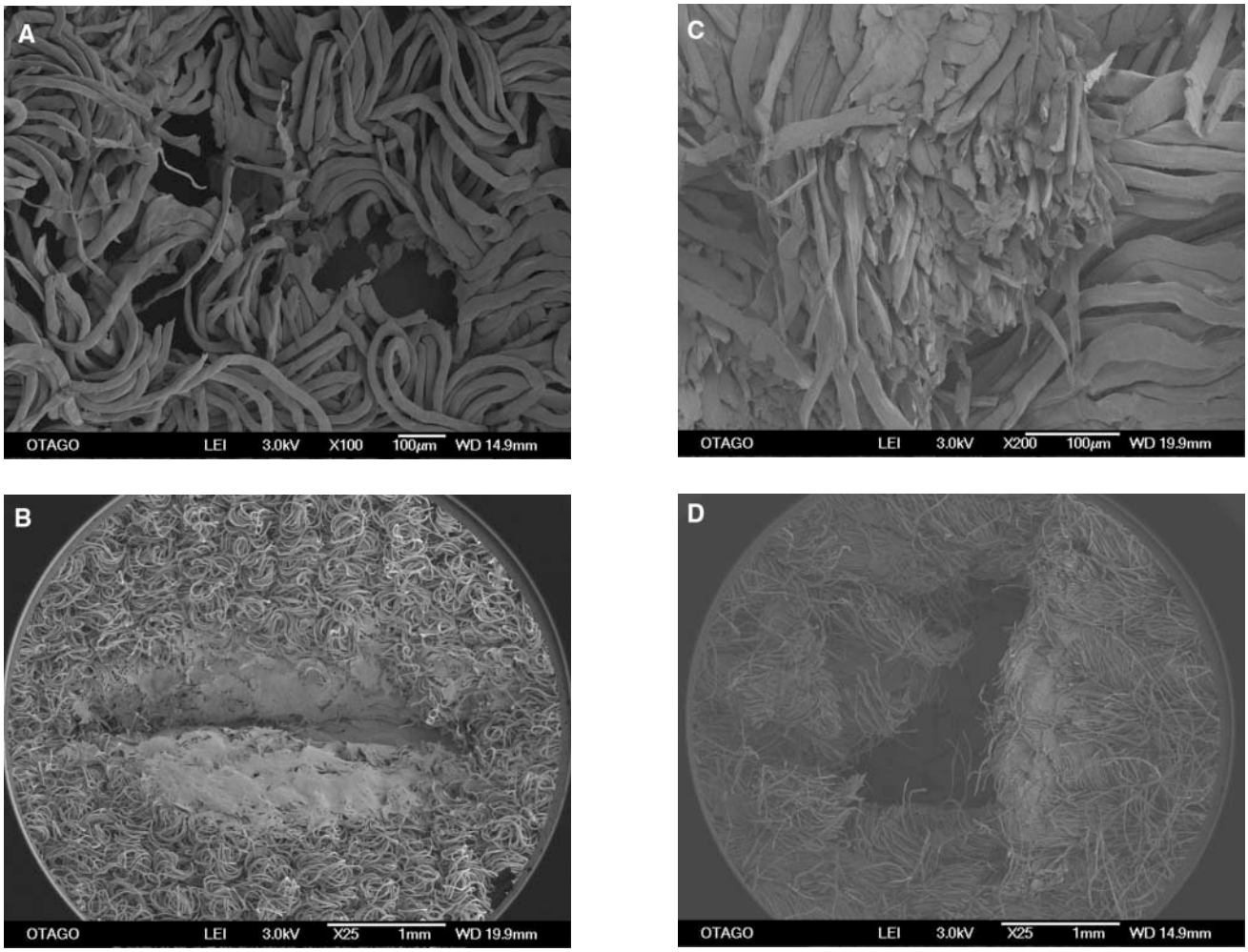

Figure 2. Appearance of fabrics (single layer) following 'impact and scrape': (a) pantyhouse (thin) fabric; (b) pantyhouse (thick), (c) denim fabric; (d) 'sweat pants', fabric.

than a woven (grade 3), although no link was observed between the injury severity grade and the coarse estimate of fabric thickness. Thus, neither the "bare leg" explanation nor the "just cover the leg" instruction is supported.

Turning towards the modeling aspect of the study, the pendulum test instruments do not operate in a way reflecting a real-life pretibial impact. These instances are available widely. Development of the "impact and scrape" instrument has permitted a laboratory assessment of fabrics typical of garments worn by the patients. To minimize the force transmitted to the pretibial area, 2-layered clothing solutions are recommended: This is consistent with the slightly lower injury severity grade observed with an increasing number of fabric layers from part 1. Wearing thick pantyhose or knee-highs under another layer (jeans, sweat pants) should reduce the transmitted force (~6% to 10%) compared with wearing thin pantyhose or knee-highs in any such injury event. Wearing thick pantyhose under (thick, knit) sweat pants rather than under (thinner, woven) jeans provided no obvious advantage (ie, the impulse for both combinations were comparable). If just one layer was to be worn over the shin, based on fabrics examined in this study, the best option to minimize the force transmitted would be either thick pantyhose or trousers manufactured from a denim-type fabric, the latter not strictly consistent with the suggestion from part 1 of knits being linked with lower injury severity grades than wovens. Although the highest impulse was observed with the thin pantyhose, the force transmitted through this fabric was much higher (>14%) than that through other fabrics,

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indicating the impulse for this fabric was influenced more by the high maximum force than were the other fabrics. When considering impulse, there appears to be no advantage in wearing thick pantyhose under (thick) sweat pants compared with under (thinner) jeans.

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