Acute angles of head-up tilt do not affect forearm and hand volume

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Physiotherapists utilise the effect of gravity in treatment of conditions associated with increased limb volume. In contrast with knowledge about the relationship between body position and lower limb volume, the effect of body position on arm volume is not well understood. To assess the efficacy of a simple intervention proposed for patients to reduce arm volume during sleep, this study investigated the effects on forearm and hand volume of two hours of head-up tilt in supine at three angles of 8, 11 and 14 degrees. Six asymptomatic subjects were measured at each tilt angle over a three-week period. Data indicated that no angle of head-up lying over a two-hour period was associated with any significant reduction in upper limb volume. [Boland RA and Adams RD (2000): Acute angles of head-up tilt do not affect forearm and hand volume. Australian Journal of Physiotherapy 46: 123-131]

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Introduction

The relationship between gravity, limb position and limb volume is of importance to many clinicians because increased upper limb volume is known to be associated with certain surgical procedures such as mastectomy (Kettle et al 1958, Swedborg 1977), when it can become a chronic and disabling problem (Morgan et al 1992, Tobin et al 1993), or after trauma such as a burn injury (Ause-Elleas et al 1994). Lower limb trauma such as an ankle sprain is also known to induce increases in lower limb fluid volume (van Dijk et al 1996). To increase venous drainage from the limb and thereby promote reduction of limb volume, either the arm (Boland and Adams 1998, Warren et al 1992) or leg (Sims 1986, Warren et al 1992) can be positioned above the level of the heart.

Limb position directly influences limb volume through the effect of gravity. During prolonged motionless standing, the action of gravity on the vertical venous column of blood can induce an increase in lower limb volume (Folkow and Neil 1973). The phenomenon of increased leg volume in standing results from pooling of blood within the venous vessels of the legs (Buckey et al 1988, Ludbrook 1980) and a similar effect on the lower limbs has also been observed during sitting (Sims 1986). The potential capacity of the venous vasculature below the level of the heart is such that it can accommodate additional blood volume of more than 500mL during relaxed standing (Folkow and Neil 1973). In the upper limb, changes in volume have been noted even within short time periods, with a mean increase of 10mL in forearm and hand volume in asymptomatic subjects observed when measurements of forearm and hand volume were repeated within a 10min period (Boland and Adams 1996).

Distribution of blood volume has also been shown to be affected by the angle to which the body or segment is tilted. Since the effect of gravity is equal to the sine of the angle of tilt (Smith et al 1987), gravity acts with increasing effect via hydrostatic pressure on the gradually more vertical column of blood as the body is tilted from supine to standing. This induces a reduction in the amount of venous return to central circulation from vasculature below the heart. Such an effect is particularly the case in the legs, which lie at the base of the hydrostatic column of blood and it results in i) a reduction of blood volume within the thorax (Smith et al 1987) and ii) an increase in leg volumes (Kapoor et al 1994).
Logically, arm volume should also be responsive to body alignment. If body posture was maintained in a sufficiently tilted position, with the heart higher than the legs, a low pressure would be maintained within the venous system and this could act against the flow of venous blood back to the central circulation. Theoretically, this would favour pooling of venous blood within vessels with a large potential capacity below the level of the heart. Available blood volume that could accumulate below this level within the arms would be reduced as blood volume accumulated within the much larger venous vessels in the legs with a higher venous capacity. Assuming no movement of the upper limbs, this might manifest as reduced arm volume and so has implications for patients with pathologically increased upper limb volume (defined as swelling). Conversely, tilting the body from standing to a horizontal alignment would be associated with increased upper limb volume as fluid shift occurred from the lower limbs to the central circulation and arms.

While the effects of body tilt and hydrostatic pressure on the lower limbs is well understood (see Rowell 1986 for a description), the extent to which these factors influence fluid volume within the arms is not so defined. An immediate reduction in whole arm volume of up to 30mL was observed during passive head-up tilting of six asymptomatic subjects from 0 to 60 degrees with the experimental arm maintained in 90 degrees of abduction (Rushmer 1976). A simultaneous increase in leg volumes also occurred during this passive tilting procedure. Other data, however, have indicated that forearm and hand volumes of asymptomatic subjects did not change after either two hours or overnight recumbency in 1) a horizontal bed or ii) a bed tilted to head-up angles of between 5 and 8 degrees (Boland and Adams 1998). This finding contrasted with an observed decrease in average forearm and hand volume of 51mL (> 3 per cent) after two hours of resting the arm on a wedge at an angle of 30 degrees of elevation, with subjects supine on a horizontal bed (Boland and Adams 1998).

If upper limb volume could be manipulated via body position, resolution of upper limb swelling in certain pathologies might be enhanced. It would be therapeutically advantageous, as well as cost-effective, if patients could significantly reduce upper limb swelling simply by altering their sleeping position at home to a head-up tilted posture. Sleeping in a position of only 12 degrees of head-up tilt has been shown to induce increases in circulating blood volume. In patients with postural hypotension due to hormone deficiencies, this resulted in a reduction of blood pressure changes associated with standing (Ten Harkel et al 1992). While limb volumes were not specifically measured, observed diurnal changes in body weight indicated that fluid retention mediated the weight changes. It is possible that changes in arm volume may have occurred as part of this process.

The behaviour of upper limb volume is also relevant to conditions such as carpal tunnel syndrome (CTS). Carpal tunnel syndrome is a neuropathy of the wrist in which the median nerve is thought to become compressed within the bony and ligamentous carpal tunnel. The floor of the tunnel is formed by the carpal bones and the roof by the transverse carpal ligament, also known as the flexor retinaculum (Sunderland 1978). The median nerve passes through the carpal tunnel, along with the nine tendons of the flexor digitorum profundus, flexor digitorum superficialis and flexor pollicus longus. Carpal tunnel syndrome can result from swelling of these structures that accompany the median nerve within the carpal tunnel, interrupting conduction along the nerve (Phalen 1966, Sunderland 1976).

It has been argued that venous congestion in the periphery of the upper limb provokes the nocturnal symptoms of CTS (Phalen 1966), possibly due to the lack of movement during sleep (Sunderland 1976). More recently, however, it has been postulated that maintenance of the horizontal position during sleep causes CTS symptoms (Radecki 1996). The mechanism proposed is that translocation of fluid from the legs to the arms occurs during the recumbent position of sleep, causing fluid to accumulate in the arms. Resultant swelling of the contents within the carpal tunnel would embarrass the median nerve and induce the distinctive nocturnal symptoms of CTS (Radecki 1996).

The purpose of this study therefore, was to investigate the relationship between different angles of head-up tilt and change in forearm and hand volume in subjects without circulatory problems. It was proposed that redistribution of fluid volume from the legs back to the arms could be minimised by elevating the bedheads of recumbent subjects to an angle where the heart was higher than the calves. Since a previous study showed that two hours of arm elevation was sufficient to induce significant changes of forearm...
and hand volume (Boland and Adams 1998), this study measured forearm and hand volumes over the same period. Similarly, since previous data indicated that neither the horizontal position, nor angles of head-up tilt between 5 and 8 degrees were sufficient to induce changes in forearm and hand volume (Boland and Adams 1998), higher elevations of 11 and 14 degrees were investigated. These angles would be compared with 8 degrees, which could be considered the control position for this study, because angles up to that position had been shown to have no effect.

It has been reported that some subjects sleeping overnight in beds tilted to 12 degrees gradually slid to the lower end of the bed, requiring remedies such as spending the night in sleeping bags, pillows under buttocks or resting subjects’ feet against cushions at the foot of the bed (Ten Harkel et al 1992). Such remedies would potentially cause activation of lower limb postural muscles in a 2h awake study such as this, and would augment venous return from the legs via the muscle pump mechanism. Thus, to avoid these confounding effects, this study examined only bed tilt angles up to 14 degrees and subjects lay on foam carpet underlay to minimise slippage down the bed. The experimental hypothesis was that after two hours of supine head-up tilt, subjects’ forearm and hand volumes would reduce linearly in relation to angle of elevation.

**Method**

**Experimental design** Ethical approval for the study had been granted by the Human Ethics Committee of The University of Sydney and written informed consent was obtained before subjects participated in the study. Three angles of head-up bed tilt were tested using a group of healthy volunteers, and effects on forearm and hand volumes were evaluated. The study employed a repeated measures design in which subjects acted as their own control, with the independent variable being angle of bed tilt of either 8, 11 or 14 degrees, and the dependent variable being forearm and hand volume. Since previous data indicated that no effect on forearm and hand volume was associated with head-up tilt angles of up to 8 degrees (Boland and Adams 1998), this became the control angle for this study. Testing order for angle of bed tilt and for the arm designated as experimental were randomly chosen for each subject. Subjects removed jewellery from the experimental limb for the duration of each 2h period. All measurements were conducted from mid afternoon to early evening, with the earliest measurement taken at 3.14pm and the latest taken at 8.06pm (Table 1). Each subject was tested over three successive weeks on the same weekday, and at the same time, to control for any diurnal variation in volume. Subjects were not asked to alter or control their activity levels or diets prior to testing, since previous data had indicated that forearm and hand volume did not vary from week to week when data was collected at the same time of day from subjects who did not control these factors (Boland and Adams 1996).

**Subjects** A sample of convenience consisting of three female and three male volunteers aged between 18 and 30 years was recruited from the university student body via advertisements placed around the university campus. Inclusion criteria were that volunteers were healthy and exclusion criteria were the presence of any of the following conditions: a peripheral neuropathy, cardiovascular instability, past history of limb or digit amputation, and conditions which could cause fluid accumulation within the arm. Volunteers were excluded if they were taking any medication or substance that affected the heart, vascular system or fluid volume (eg steroids, calcium channel or beta blockers). Subjects were paid to participate in the study.

**Experimental method** Forearm and hand volumes were measured via the water displacement method, using a previously described technique that has been shown to be reliable and accurate (Boland and Adams.
The method required subjects to immerse their experimental forearm and hand in a purpose-built volumeter filled (Figure 1) with water warmed to 32 ±1 degrees Celsius, ie within the skin comfort range (Harrison 1985). Overflow water from the volumeter was collected in a measuring cylinder with a manometer mounted on the side (Figure 1). The accuracy of measuring bottles of known volumes using this volumeter and measuring cylinder has been shown to be better than 0.50mL across the range of volumes likely to be measured during forearm and hand volumetry. Within-sessions and between-sessions intraclass correlation coefficient (ICC) values of 0.99 were observed in a volumetric study of the forearms and hands of 23 asymptomatic normal adults and the error of the system was found to be < 1 per cent (Boland and Adams 1996).

Since the aim of the current study was to determine the effect of three angles of head-up tilt on lower arm volume when rested by subjects’ sides for two hours, a method of isolating fluid volume within the lower arm was needed. This was achieved by using an aneroid sphygmomanometer cuff that was inflated around subjects’ upper arms prior to each measurement of arm volume. For convenience, this was applied while the subject was standing, but inflated in sitting for pre-recumbency measurements. For post-recumbency measurements, the cuff was applied and inflated while the subject was still lying, prior to moving from the tilted position held for the experimental period. This method trapped the blood within the forearm and hand segment upon cuff inflation.

After the cuff had been applied around the upper arm in standing and fixed in place with tape, the subject sat in a chair alongside the measurement equipment and the cuff was inflated to a supra-systolic pressure between 220 and 230 mmHg, which was within the range of 200 mmHg (Jozsa et al 1980) and 300 mmHg (Hutchinson and McClinton 1993) used by other researchers to occlude vascular flow in the upper limb. The subject was then asked to hold the elbow, wrist and fingers straight and immerse their arm in the volumeter until the tip of the middle digit touched a screw-adjustable stopper resting on the floor of the volumeter (Figure 1). Each subject’s forearm and hand length had previously been measured with a flexible tape measure to the nearest 0.5cm, from the level of the elbow crease to the tip of the middle finger. Changing the height of the stopper ensured that depth of limb immersion could be standardised to the level of the elbow crease for all subjects. The outside height of the volumeter was 54cm and subjects were allocated individual stoppers adjusted according to the formula: Forearm and hand length to elbow crease plus stopper height = 54.0cm. Each subject was allocated a single stopper for the three weeks of their participation by adjusting different stoppers for different subjects.

Water that spilled from the drainhole in the volumeter was channelled into the measuring cylinder. Once all water flow had ceased, the subject’s hand was withdrawn from the tank, pressure was released and the cuff removed. Subjects then moved from the chair to lie supine for a period of two hours on a plinth tilted to the designated bed angle of 8, 11 or 14 degrees. These angles are equivalent to elevating the head of a typical queen size bed by approximately 28cm to achieve an angle of 8 degrees, 39cm for 11 degrees and 50cm for 14 degrees. To prevent subjects from slipping down the bed during the experimental period, a length of rubber carpet underlay was taped to each plinth.

For the entire 2h period, subjects rested the experimental arm alongside their trunk. Subjects watched a video and were instructed to lie as still as possible and not to move the experimental arm at all during the data collection period. Two pillows were...
placed under subjects’ heads to allow clear viewing of the video monitor but care was taken to ensure that the pillows rested under the head and neck rather than the upper thoracic area. At the conclusion of the 2h period, the cuff was re-applied to the experimental arm with care taken to avoid moving the limb. The cuff was then inflated to between 220 and 230 mmHg and the subject moved from the plinth to the chair. Forearm and hand volume was then re-measured in the same manner as for the pre-intervention measurement.

**Measurement protocol** Before each measurement, the volumeter was filled with water warmed to the appropriate temperature. A small amount of the warmed water was also poured into the measuring cylinder so that a level of water could be seen in the perspex tube mounted on the side of the cylinder (Figure 1), which allowed the cylinder to act as an open ended manometer. The lower of two sliding clamps on the tube of the measuring cylinder was aligned against this baseline level of water (Level 1) and the subject then immersed the experimental arm in the volumeter. When water had finished dripping and the arm had been withdrawn, the upper clamp on the measuring cylinder was moved so that it aligned against the new level of the meniscus in the tube (Level 2). The distance between Levels 1 and 2 (Figure 1) was then measured using vernier callipers capable of measuring to 0.05mm. The volume (V) of water within the measuring cylinder was determined by multiplying the difference between Levels 1 and 2 (D) by the cross sectional areas of the measuring cylinder (M) and perspex tube (T) respectively. The sums of these volumes represented the volume of the forearm and hand (V = DxM + DxT).

The conversion factor for millimetres to millilitres was known to be: 1mm of vertical displacement (as measured by the callipers) = 8.78mL of volume (Boland and Adams 1996).

**Analyses** A planned contrast analysis within a fully repeated measures ANOVA was used to analyse the data (Winer 1971). Based on previous data, two hours of arm elevation gives an effect size of 51mL with a standard deviation (SD) of 27mL (Boland and Adams 1996). In this study, for an effect size of 34mL (1.25 SD units), the power is 85 per cent for a 2-tailed test at α = 0.05 (91 per cent for 1-tailed) for n = 6 (Welkowitz et al 1972).

**Results**

The left arm was tested in five subjects, which corresponded to the dominant arm being tested in only two of the six subjects. Figure 2 shows the results for each angle of head-up tilt. No pre-post difference due to angle of elevation was observed for any of the three angles tested with $F_{(1,5)} = 2.280$, $p = 0.191$ for 8 degrees tilt; $F_{(1,5)} = 1.031$, $p = 0.357$ for 11 degrees; and $F_{(1,5)} = 0.067$, $p = 0.806$ for 14 degrees. Additionally, no difference was observed when change in forearm and hand volume due to 8 degrees of elevation was compared with 14 degrees of elevation (Linear $F_{(1,5)} = 1.143$, $p = 0.33$) and no difference was observed when change in volume due to 11 degrees was compared with 8 and 14 degrees of elevation (Quadratic $F_{(1,5)} = 2.459$, $p = 0.178$).

Comparisons between the weekly pre-intervention measurements for each subject were also made to ensure that forearm and hand volumes did not change from week to week. Mean(SD) values were 1347(156)mL for Week 1, 1335(133)mL for Week 2 and 1338(123)mL for Week 3. No difference was observed when Week 1 measurements were compared with Week 3 (Linear $F_{(1,5)} = 0.251$, $p = 0.638$) and no
difference was observed when Week 2 measurements were compared with Weeks 1 and 3 (Quadratic $F_{(1,5)} = 0.261, p = 0.631$). Figure 3 illustrates individual subject responses for each intervention. No subject underwent a consistent response of increased or decreased arm volume across all three angles of tilt, nor was a consistent response evident across all subjects for any angle of tilt. It can also be seen that, contrary to the experimental hypothesis, the largest absolute changes in volume occurred as a result of tilting at 8 degrees when Subjects 2 and 6 underwent negative changes in arm volumes of more than 30mL.

**Discussion**

The aim of this study was to determine the effects of recumbency in head-up tilted positions on forearm and hand volumes, using bed angles that could be reasonably replicated in patients' homes. The results suggest that forearm and hand volume are not affected by two hours of lying in a head-up tilted position at 8, 11 or 14 degrees. For the lowest elevation or control position, these data are consistent with a previous finding that forearm and hand volume do not change after recumbency at head-up tilt angles of up to 8 degrees over the same 2h period, or after overnight sleep (Boland and Adams 1998). At the higher elevations, however, they are in contrast with data from a small study that detected changes in whole arm volume after tilting from supine through an angle of 60 degrees (Rushmer 1976). The difference between studies could be due to three factors, the first being the angle of tilt, the second being the position of the arm during testing and the third being a difference in the size of the segment measured in each study. It is unlikely that the time course over which changes in volume were measured was responsible for the difference between studies.

A minimum angle of 8 degrees of head-up tilt was chosen for this study, since previous data investigating the responsiveness of forearm and hand volume to head-up tilt had only tested up to this angle (Boland and Adams 1998). The maximum angle of 14 degrees was chosen because there is evidence to show that sleeping in head-up tilted beds at this angle is associated with cardiovascular changes that can be beneficial for certain patient groups. The difficulty with this angle of tilt is that subjects were observed to slide down their beds during the night (Ten Harkel et al 1992). Thus angles above 14 degrees were not evaluated, since subjects were unlikely to be able to maintain their positions on the bed without using a remedy like a footboard. Such a remedy would be likely have the effect of stimulating or encouraging activity in postural muscles, such as those in the calf group, resulting in increased venous return to central circulation from the lower limbs via the muscle pump mechanism (Folkow and Neil 1973, Rowell 1986). Consequently, it would be impossible not to ascribe at least some of any observed changes in forearm and hand volume to this muscle pump effect.

The need to ensure that postural muscle activity was eliminated during subjects' 2h period of recumbency meant that only relatively acute angles were tested. It is possible that lying at angles greater than 14 degrees would be associated with reductions in forearm and hand volume.
hand volumes, as blood could then accumulate in the legs and circulating blood volume might concomitantly reduce. The possibility that beneficial effects for patients with upper limb swelling could be gained from higher sleeping angles cannot be ignored, therefore, although the practical difficulty of maintaining position on the bed in such an experimental situation would need to be overcome. In this study, rubber carpet underlay was used to prevent slippage. Whether this would also be effective at higher angles is unknown, as is whether subjects/patients could tolerate sleeping or even lying for two hours at higher angles of head-up tilt.

The previous observation that tilting through 60 degrees was associated with a reduction in arm volume could have been due to the position of the experimental arm in that study. Subjects’ arms were strapped to an arm-board and held in 90 degrees of abduction during the tilting manoeuvre (Rushmer 1976). This facilitated venous drainage from the limb for two reasons. Firstly, the position of the arm above the level of the heart is an alignment associated with positive hydrostatic pressure along the whole arm (compared with the reference point in the right atrium) (Folkow and Neil 1973). Secondly, the horizontal alignment of the arm would have maintained an even hydrostatic pressure along the entire length of the arm, so venous flow from the hand towards the axilla was not impeded. These factors contrast with the effects associated with the alignment of the experimental arm in this study.

In this study, subjects’ arms were rested on the bed by their sides, since the intention was to assess the effect of body angle on arm volume and strapping the arm in abduction was not a feasible overnight home intervention. Arm alignment was parallel to the angle of body-tilt being tested, so subjects’ hands were maintained in position below their shoulders at angles of 8, 11 or 14 degrees. The hydrostatic pressure gradient was, therefore, against the flow of venous blood up the experimental arm to the right atrium, since blood had to flow up to approximately the level of the axilla before a favourable pressure gradient would facilitate venous return to the heart. The lack of movement in the arm over the 2h period might even have favoured an accumulation of venous blood in the forearm and hand over the experimental period, particularly since there are fewer valves in the venous system of the upper limb compared with lower limb (Folkow and Neil 1973). Under this hypothesis, incremental increases in forearm and hand volumes would have been observed when changes in volume were compared across the three angles from lowest to highest, but were not (Figure 2). Reasons for this absence of effect are speculative but could range from differences between the compliances (and therefore potential capacities) of the venous vessels or muscle compartments of the upper versus lower limbs, to the differences between the (sine of the) angles of elevation being insufficient to generate measurable increments in forearm and hand volumes.

It is also possible that the difference in data between studies was due to the difference in size of the arm segment measured in each study. Whereas Rushmer (1976) measured whole arm volume, the current study measured only the volume of the forearm and hand segment. It is likely that volume of this distal segment reduced as the abducted arm was tilted through 60 degrees in Rushmer’s study. However, as stated, fluid volume could have accumulated in the forearm and hand in this study if drainage from the upper to lower arm occurred. It is even possible that some decrease of upper arm volume did occur during the 2h period, as venous volume flowed distally into the lower part of the arm. If some upper arm volume was reclaimed by the central circulation and a concomitant efflux of upper arm volume into the lower arm did occur, an overall decrease in whole arm volume might have actually occurred in this study. However, since upper arm volume was not measured, the relationship between upper and lower arm volumes during prolonged head-up tilt remains to be clarified. Future research might be directed towards investigating the relationship between upper limb volume and lower limb volume during head-up tilt.

While Rushmer (1976) detected an immediate change in arm volume in response to tilting, it is unlikely that a comparable effect would have been observed in the current study if volume had been measured immediately upon subjects assuming the experimental position. A difference in the direction of volume change, however, might have been detected. The immediate effect of supine to head-up tilting is to increase the hydrostatic pressure gradient such that venous drainage into dependent segments such as the legs occurs (Watenpaugh et al 1997). While the horizontal arm position of 90 degrees abduction is associated with reduced whole arm volume, the arm-by-the-side position of this study is dependent and an immediate tendency towards increased forearm and hand volume might be anticipated. This is likely since volume shift as measured in the calf and neck has
been shown to be immediate (Watenpaugh et al 1997) and 10 minutes has been shown to be a sufficient period for an increase of 10mL in forearm and hand volume to occur during relaxed sitting (Boland and Adams 1996). Over the 2h experimental period in this study, however, it was hypothesised that reduction in forearm and hand volume would be observed, as a large increase in lower limb volume gradually occurred. It was thought that this would reduce central venous volume and induce homeostatic changes that would draw venous volume from other sources, such as the upper limb, resulting in reduced volume in the forearm and hand. While this effect was not observed up to 14 degrees, the effect at an angle of 60 degrees is unknown and an increase in volume might still occur. Future research could attempt to resolve this question, though it is unlikely that patients would be able to sleep at such a high angle at home.

The findings suggest that head-up tilt is not an appropriate intervention to reduce upper limb volume for patients with swelling of the forearm and hand segment. Other interventions such as combination therapy for subjects with post-mastectomy lymphoedema (Morgan et al 1992) or elevation of the arm at an angle of 30 degrees for two hours (Boland and Adams 1998) are known to be effective interventions to reduce arm volume. While this study did not evaluate the effect of horizontal recumbency on forearm and hand volume in subjects with conditions such as CTS, the data here indicate that any increased volume of the arm that might be peculiar to this pathology/patient group is unlikely to be dissipated by having patients with CTS lie for two hours on a bed tilted to a head-up of 14 degrees.

Conclusions

Current data indicate that head-up tilt to angles in the range up to 14 degrees has no effect on the volume of the forearm and hand segment in a group of asymptomatic subjects. While the merit of bed elevation as a simple, cost effective intervention is theoretically appealing, there appears to be no effect of reduced arm volume associated with lying at angles within a range that is readily achievable in patients’ homes. This is despite a perturbation to homeostatic mechanisms that employed an angle of 14 degrees, equivalent to elevating the head of a typical queen sized bed through a height of 50 centimetres. There is, therefore, no indication for the use of head-up body tilt as a home intervention for patients with swelling of the distal segment of the upper limb. The simplest and most cost effective means of reducing volume in this segment of the arm remains elevation of the arm, as has been shown previously (Boland and Adams 1998).

Manufacturers information (a) The Lumiscope Company, Inc., Edison NJ, 08837, USA. (b) Mitutoyo Corporation, Tokyo, Kanto, Japan.

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